Investigating the Optimisation of Food Waste Management

Nicholas Edward Davison

Submitted in accordance with the requirements for the degree of

Doctor of Philosophy as part of the Integrated PhD with MSc in Bioenergy

The University of Leeds

School of Chemical and Process Engineering

December 2022

The candidate confirms that the work submitted is his own, except where work that has formed part of a jointly authored publication has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

- Davison, N., Young, W., Ross, A., Cockerill, T. and Rajput, S., 2022. Investigating the Impacts of Behavioural-Change Interventions and COVID-19 on the Food-Waste-Generation Behaviours of Catered Students in the UK and India. Sustainability, 14(9), p.5486.

This publication has contributed towards some of the sections of Chapter 4. The candidate designed the experiments, conducted the experimental work, conducted the data analysis and drafted the manuscripts for the publication.

- Prof William Young, Dr. Andrew Ross, Prof and Timothy Cockerill supervised the project.
- Prof William Young, Dr. Andrew Ross, Prof Timothy Cockerill, and Dr. Shailendra Singh Rajput reviewed and provided feedback.

This copy has been supplied on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement. The right of Nicholas Edward Davison to be identified as Author of this work has been asserted by him in accordance with the Copyright, Designs and Patents Act 1988.

© 2021 The University of Leeds and Nicholas Edward Davison

Acknowledgements

Firstly, I would like to express my sincere gratitude to my incredible supervisors, Prof Timothy Cockerill, Dr. Andrew Ross and Prof William Young, for their continued support, belief and advice. I could not have done it without you.

I would also like to express my gratitude to Dr. Gaurav Nahar (Defiant Renewables) and Dr. Anurag Garg (Indian Institute of Technology Bombay), as well as Dr. Shailendra Singh Rajput for hosting me at their respective organisations during my placements – both were amazing experiences.

I would also like to thank Dr. Shailendra Singh Rajput, Suyog Shaha and Divya Gupta for helping to facilitate my research in India, Yuzhou Tang and Dr. Xueliang Yuan for helping facilitate my research in China, as well as the sustainability, residential, and catering services at the University of Leeds, and AWM for helping facilitate my research in the UK. Without your help, it would have been impossible to conduct the research while Covid-19 restrictions were ongoing.

I would also like to thank Yiwen Guo for his excellent work translating all of the survey, focus group, and interview questions from English to Chinese.

I would like to acknowledge EPSRC, for providing the funding to support this research degree and UKIERI for funding my research in India. I must also thank the administrative staff at the University of Leeds, in particular Emily Bryan-Kinns and James McKay.

I would like to express my gratitude to Bergmann Direct for your cooperation, for providing me with data, allowing me to visit your site, to collect samples and for sharing your expertise with me.

Thank you to all my friends and colleagues that I have had the pleasure of meeting and working with throughout my time studying for my PhD. I would specifically like to thank Aaron Brown, Jaime Borbolla Gaxiola, and Yuzhou Tang for your help and guidance especially with research methodologies and data gathering, as well as Douglas Bray, and Poppy Cooney for your support and guidance with my research.

I would also like to thank my study skills tutor Jennifer Elberg for helping enormously to improve the quality of the thesis document and providing me with the skills to improve my research going forwards.

Finally, a special thank you to my family, especially my wife Fangting, my wife's family, my mum Barbara, my dad Mike, my sister Sam and her family, as well as my brother Tom. Your continued support has got me to the place I am today.

Abstract

Vast quantities of food waste are generated at universities around the world, at cafeterias and residences, resulting in significant environmental and economic costs. There is little consensus however as to the best food waste treatment practices, or the extent of behavioural change opportunities regarding greenhouse gas and cost savings, or how university and country specific factors influence food waste management optimisation. This thesis aimed to address this through studying food waste management optimisation in UK, Indian and Chinese universities.

When studying behavioural change opportunities, this research found introducing table cards, posters and signs led to a per capita food waste reduction of 13% in a UK University canteen, meanwhile the same interventions alongside Covid-19 impacts led to a per capita food waste reduction of 50% in an Indian University canteen. Additionally, food waste recycling interventions led to food waste recycling increases of around 70%. Food waste recycling was not researched at the Indian and Chinese Universities however, as these universities only had catered students.

Scenarios were formed for food waste reduction, food waste recycling as well as various onsite food waste treatment approaches, with their greenhouse gas and economic impacts being assessed when compared to the current business as usual approach being applied at the studied Universities. Food waste reduction brought about significant greenhouse gas mitigation in all universities. Moreover, desiccation with combustion and heat generation was the most cost effective option in the UK, with desiccation and animal feed production the best option for greenhouse gas mitigation. Conversely, due to more carbon intensive grid energy, the net energy generating scenarios, in particular anaerobic digestion had the greatest levels of greenhouse gas mitigation in the Indian and Chinese Universities. Overall, all universities that had their food waste collected and treated offsite by an external company, could adopt scenarios that would have both greenhouse gas and economic savings.

This analysis, alongside surveys and interviews conducted on university food waste management stakeholders, were used to form a framework for creating a multi-criteria food waste management decision-making tool with essential data inputs as well as desired data outputs and formats identified. Further research and the creation of the tool could lead to enormous greenhouse gas and cost savings in universities across the UK, India and China.

Table of Contents

Acknowledgements.....iii

Abstract.....iv

Table of Contents.....v

List of Tables.....xvi

List of Figures.....xviii

List of Acronyms and abbreviations.....xix

1. INTRODUCTION.....1

1.1. Background.....2

1.2. Aims.....3

1.3. Objectives.....4

1.4. Scope.....5

1.5. Thesis structure.....5

2. LITERATURE REVIEW.....7

2.1. Background.....7

2.1.1. Food waste by sector.....7

2.1.2. Food waste treatment and disposal.....8

2.2. Food waste in the UK.....10

2.2.1. UK Current situation.....10

2.2.2. UK Current trends.....11

2.2.3 Legislation and policies.....12

2.2.3.1. New food waste policy.....12

2.2.3.2 Health and safety.....12

2.2.3.5 Incentives.....13

2.2.3.6 Taxes.....13

2.2.3.7 Policy gaps.....13

2.2.4 UK summary.....13

2.3. Food waste in India.....14

2.3.1 India current trends.....14

2.3.2 India policies and legislation.....15

2.3.3 India food waste summary 16
2.4. Food waste in China 17
2.4.1 China current trends 17
2.4.2 Chinese policies and legislation 17
2.4.3. Chinese food waste summary 19
2.5. Impacts of Covid-19 on food waste 19
2.5.1. Emergence of Covid-19 in the UK, India, and China 19
2.5.2. Impacts on food waste generation and composition 20
2.5.3. Impacts on food waste treatment 21
2.5.4. Covid-19 summary 21
2.6. Waste management options 21
2.6.1 Surplus food redistribution 21
2.6.2 Animal feed production 23
2.6.3. Anaerobic digestion 24
2.6.4. Composting 24
2.6.5. Incineration 25
2.6.6. Desiccation 25
2.6.7. Hydrothermal carbonisation 26
2.6.8. Food waste management options summary 26
2.6.9. Effect of composition on treatment technologies 27
2.6.9.1. Elemental properties of food waste 27
2.6.9.2. Physical properties of food waste 27
2.6.9.3. Other properties of food waste 28
2.6.9.4. Implication of differing food waste compositions in the UK, India and China 28
2.7. Behavioural change interventions 28
2.7.1. Nudge theory 29
2.7.2. Block leaders 30
2.7.3. Public commitment making 30
2.7.4. Feedback on performance 31
2.7.5. Behavioural change summary 31
2.8. Life cycle analysis 31
2.9. Decision-making tools 32

2.10. Previous studies 32
2.10.1. Previous LCAs comparing food waste treatment technologies 33
2.10.2. LCAs on general waste treatment options 35
2.10.3. Summary on food waste and general waste treatment LCAs 36
2.10.4. LCAs on food waste reduction 37
2.10.5. Economic assessment of food waste management options 38
2.10.5.1. Economic assessment of food waste treatment options 38
2.10.5.2. Economic assessment of food waste reduction 39
2.10.6. Previous surveys, interviews and focus groups 39
2.10.7. Previous interventions 40
2.11. University feasibility studies 42
2.11.1. Food waste treatment studies 42
2.11.1.1. UK University studies 42
2.11.1.2. Indian university studies 43
2.11.1.3. Chinese university studies 44
2.11.2. Food waste reduction studies 44
2.11.3. University feasibility study summary 45
2.12. Typical university characteristics in the UK, India and China 45
2.12.1. UK university characteristics 46
2.12.2. Indian university characteristics 46
2.12.3. Chinese university characteristics 47
2.12.4. Representativeness of the studied universities 47
2.12.5. Contrasting characteristics of UK, Indian and Chinese universities 48
2.12.6. Contrasting food waste generation in UK, Indian and Chinese universities 50
2.13. Waste management decision-making tools 50
2.14. Literature review summary 52
3. ASSESSMENT OF INSTITUTIONAL FOOD WASTE GENERATION AND MANAGEMENT PRACTICES 54
3.1. Introduction 54
3.2. Methodology 55
3.2.1. General infrastructure 55
3.1.2. Catered food waste management infrastructure 55
3.1.3. Self-catered food waste management infrastructure 56

3.1.4. Interviews and focus groups (infrastructural insights) 56
3.1.5. Infrastructural impacts of Covid-19 56
3.1.6. Food waste composition 57
3.2. Current food waste management infrastructure 57
3.2.1. General infrastructure 57
3.2.2. Catered food waste management infrastructure 59
3.2.3. Self-catered food waste management infrastructure 62
3.2.4. Infrastructural insights from Interviews and focus groups 63
3.2.4.1. Key stakeholders and interviewees 65
3.2.4.2. Infrastructural reasons for food waste 65
3.2.4.3. Infrastructural reasons for not recycling food waste in the UK 67
3.2.4.4. Infrastructural factors in food waste treatment 69
3.2.4.5. Infrastructural opportunities to reduce food waste 69
3.2.4.6. Infrastructural opportunities to increase food waste recycling 72
3.2.4.7. Infrastructural opportunities to improve food waste treatment 73
3.2.5. Current food waste management infrastructure conclusion 73
3.3. Infrastructural implications of Covid-19 on food waste management 74
3.3.1. UK Covid-19 impacts 75
3.3.1.1. Impacts on campus-wide food waste generation 75
3.3.1.2. Covid-19 related changes to campus-wide catering services 76
3.3.1.3. Impacts on catering at the UK University residence 77
3.3.1.4. Covid-19 impacts on self-catered students at the UK University residence 78
3.3.2. India Covid-19 impacts 78
3.3.2.1. Covid-19 related changes to campus-wide catering services 78
3.3.2.2. Impacts on food waste generation 79
3.3.3. Covid-19 impacts on China 79
3.3.4. Covid-19 impacts conclusion 82
3.4. Food waste characterization 83
3.4.1. Physical food waste properties 83
3.4.2. Elemental food waste properties 83
3.4.3. Biochemical properties 84
3.4.4. Energy content 84

3.4.5. Food waste characterization conclusion 85
3.5. General conclusion.....85
4. BEHAVIOURAL CHANGE.....88
4.1. Introduction 88
4.2. Methodology.....89
4.2.1. Setting 89
4.2.2. Survey.....89
4.2.3. Semi-structured interviews and focus groups 91
4.2.4. Food waste reduction interventions.....92
4.2.4.1. Awareness campaign 92
4.2.4.2. Covid-19 implications in Indian University canteen 93
4.2.5. Food waste Segregation interventions 93
4.2.6 Research methodology framework.....95
4.3. UK……. 96
4.3.1. Survey.....96
4.3.1.2. Self-catered UK 96
4.3.1.3. Catered.....99
4.3.1.4. Self-catered vs catered students in the UK.....101
4.3.2. Interviews and focus groups 102
4.3.2.1. Introduction/rationale 102
4.3.2.2. Reasons for food waste 102
4.3.2.3. Reasons for not recycling food waste.....103
4.3.2.4. Motivations to tackle food waste issues 103
4.3.2.5. Key opportunities to mitigate food waste issues 104
4.3.2.6. Effect of behavioural change interventions on food waste generation and recycling 104
4.3.3. Food waste segregation.....105
4.3.4. Food waste reduction 107
4.4. India.....108
4.4.1. Survey.....108
4.2.1.1. Catered.....108
4.4.2. Interviews and focus groups 109
4.4.2.1. Reasons for food waste 109

4.4.2.2. Motivations to tackle food waste issues 110
4.4.2.3. Key opportunities to mitigate food waste issues 110
4.4.2.4. Effect of behavioural change interventions on food waste generation and recycling 111
4.4.3. Food waste reduction 111
4.5. China 112
4.5.1. Covid-19 limitations 112
4.5.2. Survey 112
4.5.2.1. Catered 112
4.5.3. Interviews and focus groups 114
4.5.3.2. Motivations to tackle food waste issues 114
4.5.3.3. Key opportunities to mitigate food waste issues 115
4.5.3.4. Effect of behavioural change interventions on food waste generation 116
4.5.4. Food waste reduction 117
4.6. UK, Indian and Chinese comparison 117
4.6.1. Introduction 117
4.6.2. Survey 117
4.6.3. Interviews and focus groups 120
4.6.4. Food waste reduction interventions 121
4.7. Discussion 122
4.7.1. Exploring survey findings 122
4.7.1.1. Catered and self-catered student comparison 122
4.7.1.2. UK, Indian and Chinese student comparison 123
4.7.2. Exploring interview and focus group findings 125
4.7.2.1. Reasons for food waste 125
4.7.2.2. Barriers to food waste recycling 126
4.7.2.3. Impacts of interventions 126
4.7.3. Exploring food waste reduction findings 126
4.7.3.1. Impacts of awareness campaign 126
4.7.3.2. Impacts of Covid-19 infrastructural changes 127
4.7.3.3. Combined impacts of awareness campaign and Covid-19 infrastructural changes 128
4.7.3.4. Additional food waste reduction opportunities 130

4.7.4. Exploring food waste recycling findings 130
4.7.4.1. Impact of interventions 130
4.7.4.2. Additional food waste recycling opportunities.....131
4.8. Conclusion.....131
5. LIFECYCLE ASSESSMENT AND LIFECYCLE COST.....134
5.1. Introduction 134
5.1.1. Specific objectives.....134
5.2. Methodology.....135
5.2.1. Goal and scope.....135
5.2.2. Scenario Analysis.....136
5.2.2.1. Business as Usual (BAU).....137
5.2.2.2. Scenario 1: Food waste reduction 138
5.2.2.3. Scenario 2: Food waste segregation 138
5.2.2.4. Scenario 3: Anaerobic digestion 139
5.2.2.5. Scenario 4: Composting 139
5.2.3. Scenario 5: Desiccation 140
5.2.3.1. Scenario 5a: Desiccation with offsite anaerobic digestion 140
5.2.3.2. Scenario 5b: Desiccation with onsite incineration (both 5b i. and 5b ii.) 140
5.2.3.3. Scenario 5c: Desiccation with use as animal feed 141
5.2.4. Scenario 6: Hydrothermal Carbonisation.....141
5.2.4.1. Scenario 6a: Hydrothermal carbonisation with soil amendment.....141
5.2.4.2. Scenario 6b: Hydrothermal carbonisation with combustion.....141
5.2.5. Scenario 7: Offsite landfilling 142
5.2.6. Scenario exploration 143
5.2.7. Sensitivity analysis 143
5.2.8. Life cycle inventory and assumptions 144
5.2.9. GHG assessment 144
5.2.10. Economic assessment 144
5.2.11. Combined economic value of cost reduction and CO_2 mitigation.....145
5.2.12. Assessment mechanisms 145
5.3. UK.....148
5.3.1. GHG assessment 148

5.3.2. Economics 149
5.2.3. Cost per tonne of CO_2 mitigated 151
5.4. Indian Institutions 153
5.4.1. Indian institute A 153
5.4.1.1. GHG assessment 153
5.4.1.2. Economics 155
5.4.1.3. Cost per tonne of CO_2 mitigated 156
5.4.2. Indian institute B 158
5.4.2.1. GHG assessment 158
5.4.2.2. Economics 159
5.4.2.3. Cost per tonne of CO_2 mitigated 160
5.5. China 163
5.5.1. GHG assessment 163
5.5.2. Economics 164
5.5.3. Cost per tonne of CO_2 mitigated 166
5.6. Country comparison 168
5.6.1. GHG assessment 168
5.6.2. Economics 171
5.6.3. Combined GHG and economic savings 175
5.7. Scenario exploration 178
5.7.1. UK 178
5.7.2. India 180
5.7.2.1. Indian institute A 180
5.7.2.2. Indian institute B 183
5.8. Sensitivity analysis 187
5.8.1 GHG assessment 187
5.8.1 Economic assessment 187
5.9. Impact of discount rate 190
5.10. Discussion 190
5.10.1. Key findings from food waste reduction and recycling costs and GHGs 190
5.10.2. Key factors affecting contrasting cost and GHGs of scenarios in different countries 191
5.10.3. Key site-specific factors affecting contrasting GHGs and costs of scenarios 193

5.10.4. Key implications from scenario explorations....193
5.10.5. Further considerations implicating the viability of the food waste management scenarios....194
5.10.5.1. Practical considerations for the food waste management scenarios....194
5.10.5.2. Other factors related to food waste management strategies....197
5.10.5.3. The value of CO_2 mitigation....199
5.11. Conclusion....200
6. DECISION-MAKING TOOL METHODOLOGY PILOT STUDY....202
6.1. Introduction....202
6.2. Materials and methods....204
6.2.1. Surveys....204
6.2.2. Semi-structured interviews....204
6.2.3. Decision-making tool methodology framework....205
6.3. Results....205
6.3.1. Socio-demographics....205
6.3.2. Desired data outputs....206
6.3.2.1. Theoretical data....206
6.3.2.2. Practical information....210
6.3.3 Desired data formats....214
6.3.4. Available data inputs....217
6.3.4.1. Food waste generation and composition....217
6.3.4.2. Food waste treatment....217
6.3.4.3. Canteens and catering....218
6.3.4.4. Self-catering....219
6.3.5. Decision-making tool framework....220
6.3.5.1. Desired data outputs....220
6.3.5.2. Available inputs....221
6.3.5.3. Specific questions, outputs, structure and format of decision-making tool....223
6.3.5.4. Framework....224
6.4. Discussion....225
6.4.1. Practical considerations....225
6.4.3. Scale of opportunities....226

6.4.3.1. Scale of GHG mitigation opportunities 227
6.4.3.2. Scale of economic opportunities 227
6.4.3.3. Scale of combined GHG and cost savings 228
6.5. Conclusions 228
7. CONCLUSIONS 230
7.1. Contribution to the optimisation of food waste management 230
7.1.1. Achieving GHG and cost savings through food waste management optimisation 230
7.1.2. Understanding food waste treatment opportunities 231
7.1.3. Understanding behavioural change opportunities in food waste management 233
7.2. Contributions to practice 234
7.2.1. Achieving food waste management optimisation in universities 234
7.2.2. Informing policies for optimising food waste management 235
7.3. Contributions to literature 236
7.3.1. Optimal food waste management approaches 236
7.3.2. Impact of current trends on food waste management 237
7.4. Future work 237
7.4.1. Decision-making tool creation 237
7.4.2. Food waste reduction research expansion 238
7.4.3. Exploring policy for facilitating food waste management optimisation 238
7.4.4. Food waste drying research 239
7.4.5. Expanding the scope of the research 239
Appendix A behavioural change chapter 260
Appendix A1: Food waste attitudes survey 260
Appendix A2: Semi-structured interview 267
Appendix A3: Semi-structured interview 268
Appendix A4: Food waste reduction materials 268
Appendix A5: Food waste recycling materials 271
Appendix A6: Behavioural change previous studies 274
Appendix B 284
Appendix B1: LCA assumptions 284
Appendix table B2. LCC assumptions 286
Appendix table B3. LCC exploration of soil amendment values 288

Appendix table B4: LCC scenario exploration of HTC 289
Appendix C.....1
Appendix C1: Food waste decision-making tool survey 1
Appendix C2: Decision-making tool interview questions 7
Appendix C3: Decision-making tool input questions proposed.....9

List of Tables

Table 2.1. Food waste quantities per type in the UK, India and China **8**
Table 2.2. Comparison of LCA figures on FW treatment GHG emissions **33**
Table 2.3. Comparison of LCA figures on GHGs from food wastage **34**
Table 2.4. Review of FW characteristics at UK, Indian and Chinese Universities. **49**
Table 2.5. Total food waste quantities from universities in the UK, India and China **50**
Table 3.1. Key general information on the studied universities and the FW management situations at these sites **58**
Table 3.2. Catering information on the studied universities and the related FW management situations **61**
Table 3.3. Self-catered information on the studied universities and the related FW management **62**
Table 3.4. Key characteristics of participants **63**
Table 3.5. Key themes identified **63**
Table 3.6. Key general information on infrastructural impact from Covid-19 ..... **81**
Table 3.7. key differences in FW characteristics **84**
Table 4.1. Socio-demographics of students surveyed. **90**
Table 4.2. Key categorization of participants **91**
Table 4.3. Key themes identified **91**
Table 4.4. Self-catered UK students- Causes of FW and quantities generated **97**
Table 4.5. Self-catered UK students- Extent to which students were bothered by FW and why **98**
Table 4.6. Catered UK students- Causes of FW and quantities generated **99**
Table 4.7. Catered UK students- Extent to which students were bothered by FW and why **101**
Table 4.8. UK self-catered vs catered students- Quantities of FW thrown away and why are students **102**
Table 4.9. Catered Indian students – Causes of FW and quantities generated **108**
Table 4.10. Catered Indian students – Extent to which students were bothered about FW and why **109**
Table 4.11. Catered Chinese students – Causes of FW and quantities generated **113**
Table 4.12. Catered Chinese students – Extent to which students were bothered about FW and why **114**
Table 4.13. Comparing UK, Indian and Chinese catered students- the causes of FW and self-perceived generation **118**
Table 4.14. Comparing UK, Indian and Chinese catered students- Why students were bothered about FW **119**
Table 5.1. Options and brief explanation **137**
Table 5.2. Inputs figures used for scenarios **147**
Table 5.3. UK University GHG mitigation figures from FW management strategies **149**
Table 5.4. UK University economic figures from FW management strategies **150**
Table 5.5. Indian institute A GHG mitigation figures from FW management strategies **154**
Table 5.6. Indian institute A economic figures from FW management strategies **156**
Table 5.7. Indian institute B GHG mitigation figures from FW management strategies **159**
Table 5.8. Indian institute B economic figures from FW management strategies **160**
Table 5.9. Chinese University GHG mitigation figures from FW management strategies **164**
Table 5.10. Chinese University economic figures from FW management strategies **165**
Table 5.11. GHG sensitivity analysis **165**
Table 5.12. UK University economics sensitivity analysis **165**

Table 5.13. Indian University economics sensitivity analysis **165**
Table 5.14. Chinese University economics sensitivity analysis..... **165**
Table 5.15. Impact of discount rate on payback time **165**
Table 6.1. Socio-demographics of FW managers surveyed. **205**
Table 6.2. Key characteristics of participants **206**
Table 6.3. Environmental output preferences of FW managers **207**
Table 6.4. Economic output preferences of FW managers **209**
Table 6.5. Combined GHG and economic output preferences of FW managers **210**
Table 6.6. Perceived usefulness of steps and information to proceed by FW managers **212**
Table 6.7. Perceived usefulness of on key considerations by FW managers **214**
Table 6.8. Desired data output formats by FW managers **216**
Table 6.9. Available food waste generation and composition data inputs **217**
Table 6.10. Available food waste treatment data inputs **218**
Table 6.11. Available canteen and catering data inputs **219**
Table 6.12. Available self-catering data inputs **220**
Table 6.13. Estimation of potential GHG and cost savings from the decision-making tool **228**

List of Figures

Figure 1.1. ..... **4**
Figure 2.1. ..... **9**
Figure 2.2. ..... **26**
Figure 3.1. ..... **75**
Figure 3.2. ..... **78**
Figure 4.1. ..... **95**
Figure 4.2. ..... **106**
Figure 5.1. ..... **149**
Figure 5.2 ..... **152**
Figure 5.3 ..... **152**
Figure 5.4. ..... **155**
Figure 5.5. ..... **156**
Figure 5.6. ..... **157**
Figure 5.7. ..... **159**
Figure 5.8 ..... **160**
Figure 5.9. ..... **164**
Figure 5.10. ..... **166**
Figure 5.11. ..... **167**
Figure 5.12. ..... **170**
Figure 5.13. ..... **172**
Figure 5.14. ..... **174**
Figure 5.15. ..... **176**
Figure 5.16. ..... **177**
Figure 5.17. ..... **179**
Figure 5.18. ..... **182**
Figure 5.19. ..... **184**
Figure 5.20. ..... **186**
Figure 5.21. ..... **192**
Figure 5.22. ..... **192**
Figure 5.23. ..... **192**
Figure 6.1. ..... **225**

List of Acronyms and abbreviations

ABP	Animal by-products
AD	Anaerobic digestion
BAU	Business as usual
C/N ratio	Carbon to Nitrogen ratio
CO_2eq	CO_2 equivalent
FW	Food waste
GBP	Great British pound
GHG	Greenhouse gas
HC	Hydrochar
HHV	Higher heating value
HTC	Hydrothermal carbonisation
LCA	Lifecycle analysis
LCC	Lifecycle cost
LCI	Lifecycle inventory
LHV	Lower heating value
MSW	Municipal solid waste
MT	Million tonnes
PW	Process water
tFW	Tonne food waste
TPD	Tonne per day
TS	Total solids
RMB	Renminbi**/**Chinese Yuan
RPS	Indian rupee
USD	United States dollar
VS	Volatile solid

CHAPTER 1: INTRODUCTION

1.1. Background

Vast quantities of food waste are produced at universities around the world, at cafeterias and halls of residences, resulting in significant environmental impacts and incurring great economic costs (Reynolds et al., 2019). Moreover, universities are different from other sectors because they are businesses comprising of a mixture of canteens, residences, and various other buildings and facilities, generating food waste onsite that they have a requirement to treat themselves, or pay for the waste to be collected and treated elsewhere. For these reasons, they require their own systems for food waste management, with costs and environmental impacts associated with different management strategies varying significantly. There is little consensus as to the best food waste management practices regarding environmental, economic and social impacts, as well as technical feasibility, or how institutional and regional factors impact food waste management optimisation (Vision 2020, 2013).

Waste legislation, infrastructure and availability of technology vary between countries and can influence what management options are feasible and favourable (Davison et al., 2017; Andreadou, 2017). Additionally, institutions create differing amounts and types of waste which can affect the performance of different food waste management approaches (Abramse and Steg, 2013; Li et al., 2013). When assessing food waste management approaches there are often major knowledge gaps concerning certain treatment technologies, as many technologies are not well understood. These knowledge gaps need to be filled to conduct a valid assessment (Davison et al., 2017). Additionally, food waste related behaviour is little understood, with behaviour differing greatly in different types of accommodation and eateries. There has been a lack of successful large-scale food waste reduction and segregation intervention studies, with significant knowledge gaps regarding what affects people`s food waste behaviour and what can effectively change food waste related behaviour (Abramse and Steg, 2013; Reynolds et al., 2019).

In order to ascertain the environmental impact of different food waste management strategies at different institutions, life cycle analyses can be carried out (Kim et al., 2013). While life cycle analyses have been done on waste management in eateries and households (NYU, 2016), including those in research institutions, there have been no studies which have looked at both behavioural change and food waste treatment options. Further to this, these studies have not looked in-depth at how food waste composition may affect the performance of different waste

treatment types. Also, they have not looked at the use of the novel pre-treatment technologies of food waste drying using a desiccator (Dhar, 2016) and hydrothermal carbonization, heating food waste in pressurized water (Li et al., 2013), or the utilization of the different products these novel technologies produce (Berge et al., 2011). There are also no existing studies comparing how conditions in both developing countries (India and China) and a developed country (UK) can influence food waste management optimization, regarding greenhouse gas (GHG) emissions and economics. Additionally, no one has found a way to identify the optimal food waste management strategy without requiring a detailed assessment.

1.2. Aims

The overall aim of the research project is to find the most effective way in which to reduce costs and GHGs from food waste management operations in educational institutions in countries of differing economic categorisation the UK, India and China. The UK was selected as it is a high-income country with a very well established higher education sector and a developed food waste management infrastructure. India was selected as a lower-middle income country with a very large population, high food waste generation levels, and considerably less well established food waste management infrastructure. Moreover, China was selected as a higher-middle income country, with the largest total population, largest student population, greatest total food waste generation, and highest carbon footprint of all countries, alongside a rapidly developing food waste management infrastructure (Zhou et al., 2021).

In order to reduce costs and GHGs in FW management it is necessary to uncover the key environmental and economic knowledge gaps regarding food waste treatment technologies such as hydrothermal carbonisation, desiccation, anaerobic digestion and composting, as well as behavioural change interventions concerning food waste reduction and increasing segregation. A further part of this aim is to form a methodological framework for creating a pilot food waste management decision-making tool based on the identification of optimal waste management strategies for the studied educational institutions. This tool would allow the user to input simple, easily found, or pre-known data to the system that will then evaluate the different available food waste options and show the most environmentally and economically viable options based on the preferences of food waste managers.

1.3. Objectives

The overall aims will be achieved through the following objectives, which are illustrated in Figure 1.1.

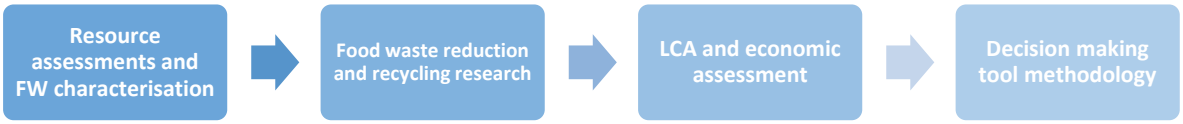


Figure 1.1.

1. Assessments of current food waste management infrastructures
    a. Conducting a resource assessment at a UK University, two Indian Universities and a Chinese University to quantify current FW generation levels.
    b. Gaining an understanding of current food waste management differences between institutions.
        i. FW treatment technology
        ii. Catering system and infrastructure
        iii. Self-catering system and FW recycling approach
    c. Gaining data on the composition of the different food waste at the UK University, Indian institute A, the Chinese University and compiling data for food waste treatment technologies from research being carried out at the institutions.

2. Gaining experimental behavioural change data at a UK University, Indian institute and Chinese University:
    a. Assessing the percentage of total FW that could be reduced through behavioural change interventions.
    b. Assessing the percentage increase in food waste segregation that could be achieved through behavioural change interventions.
    c. Gaining insights into students' food waste generation behaviours, how they differ between the different institutions and how they are affected by the interventions.

3. Evaluating the GHG and cost impacts of the different waste treatment and behavioural change related management options at the UK University, Indian institute A, Indian institute B as well as the Chinese University when compared to their business as usual approach.

4. Conducting a pilot study to form a methodology for the creation of a food waste management decision-making tool based on specific key inputs and outputs from the Lifecycle Analysis (LCA) and Lifecycle Costing (LCC), as well as food waste manager insights.

1.4. Scope

This research was limited to site specific analyses of a total of four universities (one in the UK, two in India, and one in China), with an assumption made that the methodological approach would be relevant for all universities in the studied countries. Two Universities were assessed in India because it was not possible to conduct the behavioural change research in Indian Institute A, so behavioural change aspects were assessed in Indian Institute B instead. It was identified that Indian Institute B was sufficiently different to Indian Institute A, particularly in terms of its FW treatment approach, and thus the decision was made to include it fully as a case study site. Moreover, it was argued that the methods could be applied to other universities in the studied countries, with a framework being created to illustrate how a decision-making tool could be formed to assess food waste management options in all UK, Indian and Chinese universities.

1.5. Thesis structure

The thesis comprises of eight chapters, Chapter 1 presents the rationale behind the PhD study while Chapter 2 comprises of a review of literature, providing a detailing of the costs and benefits associated with the different food waste management options, as well as a review of previous studies assessing food waste management options relevant to this study.

Chapter 3 then provides a preliminary assessment to gain all essential background information on current food waste management strategies, food waste quantities and characterisations for the studied Universities through gaining official data, conducting interviews and focus groups on food waste managers, and gaining data from the literature, thus focussing on objectives 1a-c. Specifically, it involves gaining food waste generation figures (objective 1a), as well as figures on food waste compositions such as carbon and nitrogen content, moisture content and calorific value (objective 1c). It also involves gaining information on food waste treatment information such as current treatment technology used and costs involved, information on the catering service, information on self-catering and food waste recycling, and any other information relevant to food waste management at the studied sites (objective 1b).

Chapter 4 delves deeper into catering and self-catering in the studied Universities, with food waste reduction and food waste recycling interventions being conducted to assess related

opportunities from behavioural change on food waste management, thus addressing objectives 2a-c. Specifically, it involves gaining food waste generation figures before and after the introduction to food waste reduction interventions to assess achievable food waste reduction levels (objective 2a). It also requires getting figures to ascertain changes before and after food waste recycling interventions were introduced to assess achievable food waste recycling levels (objective 2b). Moreover, surveys, interviews and focus groups are used to better understand food waste attitudes and behaviours at the different institutions before and after the interventions (objective 2c).

Chapter 5 uses data from Chapters 4 and 5 to conduct food waste and economic analyses on food waste management options (related to both behavioural change and food waste treatment) at the studied universities, thus focussing on objective 3. Specifically, this section includes the evaluation of the environmental performance (Annual and lifecycle GHG reductions), economic performance (lifecycle savings and simple payback time), and combined environmental and economic performance (cost per tonne of CO_2eq mitigated) of the different waste treatment and behavioural change related management options at the UK University, Indian institute A, Indian institute B, and the Chinese University.

Chapter 6 then combines an understanding of the necessary data inputs acquired in Chapter 4, as well as the data outputs generated in Chapter 6 to form a framework for the creation of a decision-making tool, thus focussing on objective 4. Specifically, surveys and interviews were conducted with food waste managers to understand which of the data inputs used in the study would be available for input without a specific researcher working (such as me) sourcing the data. The surveys and interviews were also used to determine the outputs that the food waste managers would consider which of the data outputs generated useful, and in what format they would like these outputs to be presented. All of this information is then considered and utilised in order to form the methodological framework for the creation of a food waste management decision-making tool for optimising food waste management at UK, Indian and Chinese universities.

Chapter 7 then considers all of the findings of the study to form associated conclusions and recommendations for future research.

CHAPTER 2: REVIEW OF LITERATURE

A literature review has been conducted on food waste (FW) and management related issues in the UK, India and China. It gives a background to the extent of the FW issue, why it is a problem, before going into specific FW policies, FW treatment technologies and behavioural change possibilities. After this, it assesses previous studies on FW management aspects, such as lifecycle analyses (LCAs) and behavioural change research, whilst also looking at what has been done in regard to decision-making tool creation and application.

It has been structured this way so that it explains why FW is an issue worth studying, what is currently happening in the area, what the different options are for improving FW management, and their relative strengths and issues. It then discusses what the different methods are for assessing FW management performances and what previous studies have found when assessing the environmental credentials of the different FW management options.

The literature review aims to justify the rationale for conducting the PhD project, highlighting the novelty of the project and the increasing understanding of FW related issues relevant to the PhD, in turn progressing a number of the project objectives.

2.1. Background

There has been ever increasing interest in waste management, especially the management of FW. Around a third of all food is wasted (FAO, 2011). FW is of particular interest due to its generation and disposal having a particularly large impact on climate change economics and greater societal issues such as food security (WRAP, 2017).

2.1.1. Food waste by sector

Food is wasted and lost throughout the food system, from on-farm production, transport and storage, processing, retail, and consumption. Each sector of the system generates waste for different reasons and treats the waste in different ways resulting in differing opportunities and challenges. Food is wasted during primary production due to food not meeting the market requirements, such as fruits and vegetables with visual defects, or animals with diseases (Joensuu et al., 2020). Other reasons for waste can include crop decimation through pests, diseases, climate impacts, or livestock deaths (Bandow and Herago, 2017). Wasted crops are often fed to animals or ploughed back into the ground (Joensuu et al., 2020), while livestock waste utilisation is highly dependent on the cause of the wastage for reasons of health and safety (Bandow and Herago, 2017). Food is also lost during the storage and transportation processes due to inadequate storage and cooling conditions. This wastage is more common in lower income countries (Gustavsson et al., 2011). Processing waste is generated in factories and abattoirs, and consists of by-products not fit for human consumption. These wastes tend to be well segregated and each by-product has a distinct composition suited to the production of high-value products such as the refining of specific chemicals, or animal feed generation

(Van Dyk et al., 2013). Food is also lost at the retail stage when it is not possible to sell foods before their sell-by-date. Ideally, this food is redistributed to charities, or recycled (Alexander and Smaje, 2008). Post-consumer FW tends to be highly homogenised and consists of both losses in households as well as the catering sector. Catering FW is often recycled, whereas household FW typically ends up in general waste (Lelicińska-Serafin et al., 2023).

Table 2.1 shows a breakdown of the FW from the different stages in India, the UK and China. Post-consumer waste consists of the majority of food losses in India and the UK, as well as a large proportion in China. Moreover, post-consumer FW has a higher landfilling rate than pre-consumer waste in both the UK and India.

Due to the diversity of pre-consumer food waste streams and causes of food losses, it is difficult to identify overarching methods in which to reduce losses and optimise FW treatment. On the other hand, post-consumer FW is typically resultant from consumption behaviours and the waste tends to be a lot less varied in composition due to homogenisation in households and catering facilities. For these reasons, it is easier to identify overarching methods in which to reduce losses and optimise FW treatment. Moreover, as post-consumer FW makes up the majority of the FW generated and landfilled in the UK and India, as well as a large proportion in generated and landfilled in China, it represents a promising area for optimisation.

Table 2.1. Food waste quantities per type in the UK, India and China

Availability and type	**Food waste categories**	
Food Waste Type	**Pre-consumer waste**	**Post-Consumer FW**
Literature sources	Davison et al., 2022; WRAP, 2022	
Quantities available in India (MT/year):		
Total	33.25	68.76
Landfilled	18.1	54.01
Quantities available in UK		
(MT/year)		
Total	2.7-5.3	7.7
Landfilled	-	1
Quantities available in China (MT/year)		
Total	290.87	170
Landfilled	119.25	96.07

2.1.2. Food waste treatment and disposal

The main environmental problem with FW disposal is that it is made of organic material and that a large proportion of the waste is landfilled. If landfilled, the waste anaerobically decomposes, forming methane, a particularly potent greenhouse gas (GHG), around 28 times more potent than carbon dioxide as a climate forcer (IPCC, 2014). While some of this methane is captured and used as a renewable energy source, this process does not capture all the methane and is not adapted ubiquitously throughout the world (Rajaram et al., 2011). Other than environmental issues with FW production, disposal is also costly and wasting food results in substantial economic losses throughout the food sector chain. Further to this, FW

antagonises such socio-economic issues as food and water security as well as land use change (Vision 2020, 2013).

The way in which we create and manage FW at present is incredibly unsustainable. It is not always apparent as to what is the best way to proceed in improving sustainability in FW management however. WRAP came up with a waste hierarchy model for sustainability (Figure 2.1.) that has generally been accepted as the descending order of most to least preferable waste management options. It can be seen that the prevention of FW is perceived as the most sustainable management option. This is followed by redistributing the food. Concerning the redistribution of surplus food, redistributing food to humans is considered more sustainable than using it to feed animals (WRAP, 2018a). Hereafter, recycling of FW was considered the best option. Recycling of FW is the process of segregating the FW stream at source. This typically diverts the food waste away from the general waste stream to be treated in a way that utilises the properties of the FW to generate useful products such as soil amendment products and energy (WRAP, 2018a). When recycled, anaerobic digestion (AD), is regarded as the best option, a process that produces biomethane (for energy production) and digestate (organic fertiliser) by breaking down organic waste in the absence of oxygen. Following this, composting is regarded as the next best option, where organic waste is decomposed in oxygen to create compost (an organic fertiliser/peat substitute). When not recycled, FW generally ends up with other wastes in general waste and is treated/disposed in a sub-optimal way. Incineration with energy recovery (burning the waste to generate energy) is considered the best option when FW is not recycled, with the disposal of FW via landfilling considered as being the least sustainable waste management option. With this being said, there are limitations to how much FW can be prevented and not all surplus food can be redistributed, as some of the food that is wasted is classified as inedible, thus unavoidable, and other surplus food becomes spoilt and thus unfit for human, or animal consumption (Vision 2020, 2013). Moreover, there is some debate about the environmental credentials of the different FW management options (Salamdeeb et al., 2017; Kim et al., 2011; Takata et al, 2012; Kim & Kim, 2010).

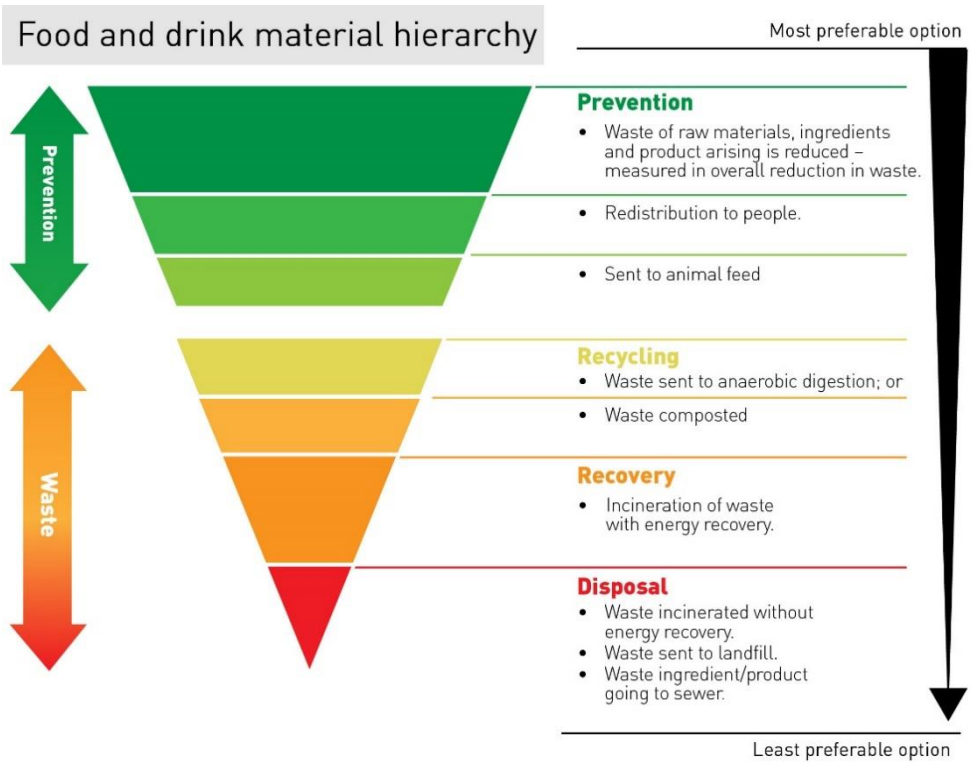


Figure 2.1.

When gaining background information as to the general FW situation, it becomes apparent the sheer scale and extent of the issue and how pertinent it is to the larger issues of climate change, land use change, and food security. It is clear that FW has a wide range of environmental, social and economic based issues associated with it. Moreover, there is no clear obvious solution to FW related issues. FW is thus clearly a very important issue, as well as one where much still needs to be investigated in order to mitigate FW related issues. It is therefore a very interesting and worthwhile topic of study.

2.2. Food waste in the UK

2.2.1. UK Current situation

In the UK vast quantities of food is being wasted per capita with serious implications on society. Regarding the production of FW, 74.7kg of FW is produced per person annually (Statista, 2019), equating to a total of 14.8million tonnes each year in the UK as a whole, resulting in the equivalent of around 30 million tonnes of carbon dioxide being released into the atmosphere (EC, 2010). 60% of the food wasted is avoidable, meaning that it was previously edible. Unavoidable FW includes inedible foodstuff such as banana skins and bones. Regarding food production, 30% of all vegetables farmed in the UK go unharvested and are instead left to decompose or are ploughed into the soil. Because of the food wastage, 550 billion cubic meters of water is used on uneaten crops (Vision 2020, 2013). Excluding the agricultural industry, around 70% of all FW is produced in the household, with 17% being

produced in manufacturing, 9% coming from the hospitality and catering sector, and 2% arising from the retail sector (WRAP, 2017). In the UK, 17% of all food and drink purchases end up as waste, totalling 4.2 million tonnes per annum. This is a figure worth £12.5 billion (WRAP, 2013), costing the average UK family between £470 and £700 per year (WRAP, 2017).

When considering FW management, in the UK, 710,000 tonnes of uneaten food is redistributed to the food charities, with a further 660,000 tonnes being diverted to feed animals. Further to this, each year, 2.2 million tonnes of food by-products are used as animal feed, with a further 2 million tonnes of animal by products (ABP) being utilised in rendering plants (Vision 2020, 2013). In addition, over 1.8 million tonnes of FW are recycled annually through either AD, or composting. The most common FW treatment and processing method however, comes in the form of heat recovery, with over 3.8 million tonnes of waste being incinerated each year. The most common way FW is dealt with however is through disposal, primarily by landfilling, but also maceration (shredding the waste and disposing it down the drains). This is the least sustainable method to treat waste, but over 4.1 million tonnes of FW is still processed in this way each year (WRAP, 2017). It is apparent therefore, that some waste is being managed in a sustainable manner, yet there is still significant progress that needs to be made.

2.2.2. UK Current trends

Regarding current trends, it does appear that there has been some progress in improving sustainability in FW management. Between 2007 and 2018 total annual FW generation dropped by 15% in the UK (WRAP, 2019). A large proportion of this was down to an 18% reduction in household FW over the same period (WRAP, 2019), as household FW makes up approximately 70% of post-farm FW in the UK (UK Government, 2021). Increased social media initiatives, information and education platforms have helped increase awareness of the FW generation issue (Vision 2020, 2013).

There has been a major reduction in the proportion of biodegradable waste being sent to landfill in the UK, with a steady decrease equating to a 78% reduction between 1995 and 2015; however this reduction has levelled off after 2015 (DEFRA, 2018). While almost no FW is sent to landfill during the production, processing and manufacturing, and distribution stage, an estimated 23% of post-consumption FW is still landfilled in the UK (Jeswani et al., 2021). Furthermore, there have been increases in FW diversion, with increasing FW recycling rates (DEFRA, 2022). Specifically, there have been increases in AD, with energy generation from AD almost doubling from 5.7TWh to 11.1TWh (DEFRA, 2021). Further to this, incineration of FW with energy recovery has also increased rapidly, with the UK increasing its capacity for

processing waste this way from 9.8 million tonnes to 1.4 million tonnes between 2016 and 2018 (DEFRA, 2022). These improvements have primarily come as a result of policy changes such as the landfill directive targeting a reduction in landfilling (DEFRA, 2020) and the renewable heat incentive, promoting renewable heat from waste (Lowes et al., 2019).

2.2.3 Legislation and policies

There are particular policies and legislation that shape the waste management landscape in the UK (Vision 2020, 2013). There are economic instruments designed to promote certain waste management strategies (Ofgem, 2018), whilst others are created to dissuade specific waste management types (DECC, 2013), for reasons of sustainability (WRAP, 2018a) and safety (FSA, 2018). Some of these policies are well informed such as the renewable heat incentive and landfill directive, whilst others such as strict policies on use of FW as animal feed should perhaps be reconsidered (Salamdeeb et al., 2017). There are also some noteworthy policy gaps that should be addressed, such as for surplus food redistribution (DEFRA, 2017b; ReFED, 2018c).

2.2.3.1. New food waste policy

The UK government has introduced plans to have separate weekly collections of FW in every household and select businesses in England by 2023, in a bid to eliminate all FW from landfill by 2030 (DEFRA, 2020). This will include having separate FW caddies in each household, to allow the segregation of FW from other waste types. The idea is to send most of the waste to be anaerobically digested (DEFRA, 2018a). The UK government has also pledged £15 million towards a scheme to reduce FW through getting food manufacturing and retail companies to donate surplus food to FW charities to help reduce food poverty (DEFRA, 2018c).

2.2.3.2 Health and safety

AD and composting are allowed in the UK given that a number of requirements are met. These include pre-treatment in the form of heating with a specified residence time and particle size. There are also requirements based on the length you can store the compost and digestate for and where you can apply it.

For producing animal feed from surplus food, there are even stricter regulations in the UK. The organisation must register with the Animal and Plant Health Agency (APHA) if you handle or use animal by-products (ABPs) as part of your operations (DEFRA, 2013). Currently, you are not allowed to use any catering or household waste as animal feed for farmed animals, regardless of whether it contains ABPs or not (DEFRA, 2014). It is possible under strict regulations in S.Korea, Japan (Salamdeeb et al., 2017) and USA however, as long as the food has been treated to the required standard and given to the appropriate animals (ReFED, 2018b). With

this being said, efforts are being made to make it easier for organisations to produce animal feed from surplus food (WRAP, 2018b) and cases are being made for the laws to become more relaxed. Moreover, given that these are EU derived policies, it is possible that they could change in the UK after BREXIT (DEFRA, 2011; FSA, 2018; Salamdeeb et al., 2017).

2.2.3.5 Incentives

The transition to sustainable FW treatment has been aided by the European regional development fund (ERDF), which offers grants to help support the capital and installation costs for setting up projects that are in line with a shift to a low carbon economy. This can include localised sustainable waste management systems such as small-scale AD (Ofgem, 2017). These policies also help support schemes that generate energy from waste such as AD, incineration of waste and landfill gas collection and utilisation (HMRC, 2016; Ofgem, 2017).

2.2.3.6 Taxes

Landfilling has decreased over recent years primarily due to UK national and EU governmental directives to reduce the amount of waste that goes to landfill, through taxation, to mitigate some of the negative effects landfilling has on the environment. The EU set a target for the UK to reduce the amount of waste landfilled from 100% to 35% between 1995 and 2016. Moreover, in keeping with these targets, the UK introduced the landfill tax, where it costs £80 in tax, per tonne of organic waste landfilled. This has made the total cost of landfilling (including gate fees) much less competitive and often higher than numerous more sustainable options (such as composting and AD), (HMRC, 2016; DECC, 2013).

2.2.3.7 Policy gaps

Despite their being the aforementioned policies in place in the UK, there appear to be some noteworthy policy gaps. Whereas France and USA have Incentives and tax levies for companies redistributing food, leading to significant reductions in FW production, the UK lacks similar policies (DEFRA, 2017b; ReFED, 2018c). This means that companies are financially incentivised to incinerate, or anaerobically digest their FW instead of redistributing it. Additionally, there are no current specific incentives in place for composting either, as it does not produce energy (DEFRA, 2018b UK, 2017). This is despite composting being higher up the FW treatment hierarchy than incineration (WRAP, 2018a). To bring about general improvements in FW management in the UK, these policy gaps need to be filled.

2.2.4 UK summary

It is clear that the UK is making improvements regarding the way FW is treated, yet much is still needed to be done regarding making such improvements, as vast quantities of food is wasted each year, large of proportions of which being avoidable FW. Additionally, a large

proportion of FW is still processed using FW treatment technologies that are low down in the FW management hierarchy (WRAP, 2018a). There are clear strategies and policies geared to effectively utilising FW, with a key focus on energy production, although there is little impetus on increasing FW distribution (DEFRA, 2018b), or composting (LeAf, 2009). Moreover, the new policy strategies to have separate collection of FW, will dramatically increase the FW management landscape in the UK, with major projected increases in AD and decreases in landfilling. It should also open up major opportunities in the FW treatment sector. Further to this, targets to reduce FW (in-line with the Courtould agreement) could also lead to the increased prominence of behavioural change strategies to decrease FW and increase FW segregation (DEFRA, 2018a). These recent developments make the UK a very exciting country to study FW management optimisation strategies.

2.3. Food waste in India

2.3.1 India current trends

As opposed to the UK, it is very difficult to quantify the exact amount of food that is wasted every year in India. With this being said, it is estimated that India produces around 51kg of FW per person annually (Statista, 2019). Moreover, India produces 143,449 tonnes of municipal solid waste (MSW) daily in India (2014-2015), which equates to around 53 million tonnes of MSW per year in the country. 40-60% of MSW in India is organic, of which the greatest share is FW. Only 82% of MSW is officially collected in India, when compared to all of the MSW being collected in the UK. Moreover, only 22.9% of the MSW is formally processed, or treated, with the majority (over 90%) of the waste being dumped in open landfill sites. Although there is a lack of data for informal organic waste treatment, in small towns and villages much of the waste generated is recycled informally by small companies and the self-employed (Harriss-White, 2020)

When MSW is sorted and the organic fraction is separated, this waste is typically composted, anaerobically digested, made into refuse-derived fuel, or incinerated; however, vermi-composting is also relatively established in the country. In Maharashtra state for example, there are six large composting sites, two vermi-composting sites, five AD plants, five RDF plants, and two waste to energy facilities for treating organic waste (Andreadou, 2017). Many of these facilities have been run sub optimally however, due to a lack of understanding of the feedstock, processes and range of products created (Breitenmoser et al., 2019)

In India, MSW is increasing at a current rate of 5% per annum. It is expected to rise from 71 million tonnes per year in 2021 and to 436 million tonnes in 2050. Increasing MSW is causing clear issues regarding GHGEs, as methane emissions from landfilling has more than doubled

from 404Gg in 1999-2000 to 1084Gg in 2015 (Singh et al., 2018). On the other hand, MSW collection and segregation figures have been increasing (CPHEEO, 2016). Maharashtra produced the largest quantity of MSW out of all of the Indian states, a figure that more than doubled between 2000 and 2012. Maharashtra produces 23,450 tonnes of MSW per day, with 98% of the waste being collected, a figure much higher than the national average (Joshi and Ahmed, 2016). Given that Maharashtra has such a vast and rapidly increasing quantity of MSW, with such high waste collection figures when compared to other states, it is a very interesting location to study FW management optimisation, with a major scope to increase associated sustainability and reduce GHGs. For these reasons, Mumbai in Maharashtra is the area in India where FW research will be carried out.

2.3.2 India policies and legislation

Whereas the UK's waste related policies are mostly governed at a national level, states, municipalities and Urban Local Bodies (UBL) set out most of the guidelines.

Regarding, general countrywide policy, India's MSW Rules (MSWR) (Management & Handling (M&H), 2000) were last updated in 2016 (Andreadou, 2017). They have set goals for India to have 100% door-to-door collection of MSW, with source segregation of waste (including organics). They have also targeted the treatment and scientific disposal of all MSW, with a drive to reduce the proportion of organic waste that is landfilled and increase the use of more sustainable treatments such as composting and AD. They are also looking to encourage public private partnerships (PPP) in developing integrated waste treatments, with a regional approach to waste management. They plan to have public awareness campaigns and encourage community-composting schemes (CPHEEO, 2016).

On a state-based level, the national Indian government is looking to encourage resource sharing among municipalities (Andreadou, 2017). They want governments to draft bylaws and legislation such as a landfill tax to discourage landfilling in states, similar to that of the EU Landfill tax. On the other hand, the national government have asked states to come up with incentives for by-products of sustainable organic waste technologies, such as compost. They also have outlined that municipalities should have a quantification of daily waste generation in the area. Furthermore, they require states to come up with effective sanitation policies and laws, concerning waste production and management (CPHEEO, 2016).

While India is certainly making progress regarding centralising and formalising waste management, it is clear that the country is a long way behind developed countries such as the UK regarding waste policy and management. Whereas the UK already collects all of the waste in the country, and all of the waste is processed and disposed of properly, with only a small

fraction of the waste being landfilled, a large proportion of Indian waste is not collected, and of that collected, most is not treated in a sustainable manner. India clearly has a lot of progress to be made before it can achieve its targets regarding 100% collection, widespread source segregation, and sustainable treatment. Lack of training, public knowledge, waste infrastructure and available funds, alongside an increasing, urban migrating population, with increasing MSW production creates key barriers to progress to achieving 100% collection. It should however be determined whether centralised formalised waste collection would be beneficial when compared to the widespread informal waste recycling already taking place.

2.3.3 India food waste summary

The vast majority of FW in the country is not segregated or disposed of properly. Only a very small proportion of the countries FW is treated in a sustainable way such as through composting or anaerobically digestion. Moreover, MSW and total FW quantities contained within MSW are increasing yearly at a rapid rate. On top of this, there are issues of population increase and urbanisation. Despite these major concerns and difficulties, MSW management and, by association, FW management are showing signs of improvement, through the development of strategies and policies that are pushing Indian municipalities to improve their waste management, in terms of increasing segregation, collection and sanitary disposal of waste. Moreover, efforts are being made to improve the utilisation of FW and increase the sustainable treatment of FW in the country through increasing composting and AD. It is clear that, as with the UK, India is a country where FW related management is rapidly changing and looks set to significantly improve in the near future (Kaushal et al., 2012). On the other hand, when comparing FW management in India (a developing country), with the UK (a developed country), there are clearly significant differences in the waste management landscape. Levels of strategical FW policy development, organisation, technological and logistical development, as well as public awareness of FW related issues, are much more progressed in the UK. Conversely, per capita FW production is significantly lower in India when compared to the UK. Further to this, it is possible that the comparatively lax FW related policies could produce interesting FW management opportunities that would not be possible in the UK (Kumar et al., 2017). For all of the abovementioned reasons, India is a very interesting country in which to investigate FW management optimisation, and as a country offers a very interesting comparison to FW management in the UK. While other developing countries were considered for study, there are very good links between the UK University and Indian institute A, and there is funding available for conducting research in India, through the UK-India Education and Research Initiative (UKIERI). When considering this and the current FW landscape in India, it

was chosen as the country in which FW management optimization would be studied in comparison with the UK.

2.4. Food waste in China

2.4.1 China current trends

As with India, it is very difficult to quantify the exact annual FW produced in China. With this being said, it was estimated that around 172 million tonnes of FW was produced in China in 2013 (Wen et al., 2016). Additionally, it is thought that around 44kg of FW is produced per person annually, less than both India and the UK (Statista, 2019). Moreover, around 215 million tonnes of MSW was produced in China in 2017 (Xiao et al., 2020), a significant amount more than India. It is believed that FW makes up around 51% of the share of China's 242 million tons of residential MSW (Liu, 2013; Yang et al., 2021), a similar proportion to India. China as a country has a particularly large source of FW coming from the catering setting, with 90% of FW coming from restaurants and canteens as around 25% of all meals consumed away from home in cities is being thrown away. Conversely, only around 10% of FW is estimated to result from household waste in the country (Liu, 2014), which is in stark contrast to the UK, where household waste is the biggest contributor to FW (Vision 2020, 2013).

As of 2014 all MSW is treated in China, bringing it in-line with developed countries such as the UK. While a large proportion of MSW is still landfilled (Yong et al., 2015), an increasing amount is being incinerated with 48.5% being treated this way in 2017 (Xiao et al., 2020). A small proportion of MSW is composted, or anaerobically digested (Yong et al., 2015). MSW is rising in China yearly with annual increases of almost 4% witnessed in Shanghai (Huang et al., 2014). Additionally, FW has been increasing in China in part due to rising incomes and consequential reduced economic concerns (Liu, 2014).

2.4.2 Chinese policies and legislation

Numerous waste management strategies are made at the national level in China, but as with India, specific provinces and cities govern many specific policies and initiatives. Regarding general countrywide policy, the Ministry of Housing and Urban-Rural Development (MOHURD) is in charge of treating and disposing solid waste, The National Development and Reform Commission (NDRC) is responsible for investing and funding MSWM development plans. The Ministry of Environmental Protection (MEP) governs prevention and control of environmental pollution, while The Ministry of Agriculture (MOA) supervises and manages the reuse of FW as an agricultural fertilizer and animal feed (Li et al., 2019).

China sets out five-year plans that sets out targets and objectives in the waste management sector in the country (Zhou et al., 2019). The 12th 5-year plan (2011-2015) set aside over 10 billion Yuan for the construction of 242 treatment facilities across 31 provinces to treat over 30,000 tons of FW. This included 100 pilot projects, primarily in developed cities in Eastern China developing the greatest treatment capacity in the country. AD was the main FW treatment technology implemented, with composting and animal feed also adopted. Meanwhile, the 13th annual five-year plan (2016-2020) has set out over 18 billion Yuan, to add an additional FW treatment capacity of almost 35,000 tons per day, that will bring the total nationwide capacity up to almost 65,000 tons per day, almost doubling the amount of FW that can treated in the country when compared to the end of 2015. Eastern China would have the highest FW treatment capacity with over 30,000 tons per day), whilst other regions would have a capacity of between 5,000 and 15,000 tons per day. AD, other energy recovery technologies and animal feed are main treatment technologies being considered. Key specifications will need to be adhered to when treating the FW, as set out in the Technical Code for Food Waste Treatment, while MSW sorting particularly in households are key components to the strategy (Li et al., 2019). With this being said, it is noted that there is a lack of mature policy support for FW recycling in China, poor implementation of laws and regulations countrywide, alongside issues resulting from low technical expertise, low processing efficiency, alongside high treatment costs that are limiting progress (Wen et al., 2016).

China also has a number of ongoing strategies designed to reduce the amount of FW produced in the country. High levels post-harvest losses of vegetables and grains have been noted in China, primarily due to poor storage. Numerous policies have been set up to reduce post-harvest losses, such as the 'The Programme for Mid- and Long-term National Grain Security'. It was also noted that there was a significant amount of FW produced during extravagant banquets among government employees, as paid for by expenses. Efforts were made to reduce this stream of FW by limiting the size and extravagance of publicly funded meals, termed the 'Eight Rules on Improving Style of Work and Enhancing Close Ties with the People' (Liu, 2013). Moreover, there has been a nationwide campaign to reduce FW in canteens through use of educational and prompt messaging, as well as social media posts, termed the 'Clean Plate Campaign (Mirosa, et al., 2018). Both have noted positive results, however issues specific to China such as particularly high proportions of meals being catered and a perceived need to over-order food as a way of showing respect to guests and displaying generosity present in the culture means that FW generation remains high in the catered sector (Liu, 2013).

2.4.3. Chinese food waste summary

As with India, it is clear that China has major issues concerning FW management. As with India and unlike the UK, only a very small proportion of the countries FW is treated in a sustainable way such as through AD, or composting. Moreover, MSW is increasing yearly at a rapid rate. Despite these major concerns and difficulties, MSW management and, specific FW management are rapidly improving, through the rapid ramping up of sustainable FW treatment capacity and the movement of MSW treatment from landfilling to incineration. It is clear that, as with India and the UK, China is a country where FW related management is rapidly changing and looks set to significantly improve in the near future, and is arguably seeing the most rapid improvements of the 3 countries (Li et al., 2019).

On the other hand, when comparing FW management in China (a higher-middle income country), with India (a lower-middle income country) and the UK (a higher income country), there are clearly significant differences in the waste management landscape. Levels of strategical FW policy development, infrastructure and technological, as well as public awareness of FW related issues are much more progressed in the UK. Conversely, per capita FW production is significantly lower in China when compared to the UK and even below that of India. Further to this, it is possible that with the scale of positive change in the FW landscape China will even progress to having a superior FW management landscape than that of the UK in the coming decades (Zhou et al., 2019). In addition, cultural factors in China such as particularly high catered FW and low household FW strikes a significant contrast with UK FW generation. For all of the aforementioned reasons China is a very interesting country in which to investigate FW management optimisation, and as a country offers very interesting comparisons to both the UK and India concerning FW management. When considering this and the current FW landscape in China it was chosen as the country in which FW management optimization would be studied in comparison with the UK and India.

2.5. Impacts of Covid-19 on food waste

2.5.1. Emergence of Covid-19 in the UK, India, and China

In December 2019, a novel coronavirus (Covid-19) outbreak epi-centred in Hubei province, before reaching the majority of the countries around the world and being declared a global health emergency by the WHO on 30 January 2020 (Velavan & Meyer, 2020). By March 2020, the pandemic had become prominent in both the UK and India causing all affected countries to adopt social distancing rules. National lockdowns were imposed in all of the aforementioned countries as a measure to combat the initial spikes in infection in the countries. Different countries were impacted at different times and to differing degrees. China was first affected

and had a very strict lockdown but quickly lowered the case numbers and returned to a 'new normal'. On the other hand, the UK and India imposed less strict lockdowns with a mixture of regional and national restrictions, and incurred more prolonged impacts of Covid-19 (Freedman, 2020; Golechha, 2020). Due to the major changes the pandemic incurred upon the general running of daily life in these countries, it has had a significant impact on FW generation, composition and waste management (Aldeco et al., 2020).

2.5.2. Impacts on food waste generation and composition

It has been observed that Covid-19 has affected FW generation in the household (Principato et al., 2020) and catering setting (Burlea-Schiopoiu, 2021) due to Covid-19 related changes in behaviour. Aldaco et al. (2020) identified that there was an initial increase in FW in a number of countries when lockdown restrictions were imposed. The study attributed this to panic buying and food hoarding because of fears that food may run out or may become inaccessible due to Covid restrictions. Aldaco et al. (2020) observed a 12% increase in household FW in Spain in the first few weeks of lockdown when compared to the same period in the previous year, while Naughton (2020) reported household organic waste to have increased by around 13% in New York. Additionally, studies by Principato et al. (2020), Amiarelli and Bux (2021) identified self-reported reductions in household FW during lockdown after an initial period of panic buying which was explained by households having more time available to plan shopping, improve cooking skills and use up any leftovers. It is clear that there were significant FW related impacts caused by the emergence of the Covid-19 pandemic, however, the long-term impacts of the pandemic in both the household and hospitality sector are yet to be seen.

Covid-19 has also been perceived to influence eating habits, thus changing the composition of FW. It was reported that during lockdown, the overall amount of food consumed generally increased by around 6%, while households also changed what they ate. During lockdown there was a reduction in beverage consumption, while there was a slight increase in eggs and red meat bought and a substantial increase in the purchasing of plant-based foods in particular processed veg, fruits, nuts, as well as pasta and rice. The altered diet was reported to be less nutritious, more energy rich, and had a greater environmental impact concerning global warming potential than the typical pre-Covid diet (Batlle-Bayer et al., 2020). Furthermore, an increase in online buying led to an increase in the generation of food packaging (Naughton, 2020). This research was carried out in higher-income countries in Europe and North America, with a lack of literature in India and China. For this reason, these trends are likely to be reflective of the situation in the UK, but may not be representative of India and China.

2.5.3. Impacts on food waste treatment

The pandemic also generated new logistical challenges in FW management. It created issues concerning collecting FW because of unpredictable FW generation rates and limitations on movement caused by the Covid-19 pandemic. Moreover, Covid-19 created challenges in FW treatment due to FW compositions changing with diets, increased packaging materials, and in certain cases reductions in recycling rates due to scaled down service and closure of recycling sites (Naughton, 2020).

2.5.4. Covid-19 summary

It is clear therefore, that Covid-19 had a major impact on FW generation, composition and treatment. On the other hand it remains unclear which of the impacts will remain, what lasting opportunities and challenges will emerge regarding FW reduction and treatment, and generally how Covid-19 impacts will change the FW landscapes in the studied countries over time. These are questions worthy of further exploration.

2.6. Waste management options

There is a wide range of different waste treatment options that can be carried out with differing levels of sustainability. These include finding ways to reuse the surplus food, different methods to process the waste, creating energy, recycling nutrients, or end disposal of waste (WRAP, 2018a).

2.6.1 Surplus food redistribution

The most sustainable method for utilising still edible surplus food is to redistribute it. If the food is still of a suitable quality, yet does not, or will not meet (at time of sale) the required standards for selling the product, it can be redistributed to those who need food. Typically, such surplus food is donated to charities, soup kitchens and food shelters. Food redistribution is considered the most sustainable waste management option besides waste reduction. This is due to the fact that waste processing emissions are avoided, and that food redistribution reduces over all resource use pressures and helps decrease food poverty (Midgley, 2014). Shops selling food, as well as catering and hospitality organisations benefit from redistributing their food by reducing their FW costs and improving their reputations (Alexander & Smaje, 2008). Meanwhile, the needy receive free, unspoiled food (Midgley, 2014).

In France and USA financial incentives are in place to encourage organisations to donate surplus food, these are not currently in place in the UK however (DEFRA, 2017a; ReFED, 2018c). In the USA, for example they began to offer federal tax incentives from 2005 allowing companies to gain tax incentives for food donation. General tax deductions include offering just under the cost value of food donated in tax deductions, up to 30% of taxable income.

Alternatively, enhanced tax deduction is available for companies giving food away free as a charitable donation to organisations such as soup kitchens. These organisations can apply to get the lower figure of twice the cost value of donated food, or the cost value and half of the expected profit margin based on market value. The deduction can be up to 15% of the company's taxable income. These measures resulted in food donations across the US rising by 137% in the year proceeding the introduction of the policy (ReFED, 2018a). There have been calls for similar policies to be introduced to the UK, as currently FW policies incentivise the production of renewable energy from FW particularly through AD, when redistribution is seen to have greater social and environmental benefits (DEFRA, 2017a).

There are ways to reduce institutional waste besides political aids however. The Too Good To Go scheme is an app that helps reduce FW in restaurants and cafeterias. When it reaches a certain time (usually close to the eatery's closing time) if there is still food left over, the cost of the meals is reduced to less than half price. This is effective as the restaurant or cafeteria receives money for food that would otherwise be wasted, they reduce their FW disposal costs and the customer receives a heavily discounted meal (Meganti, 2017).

The redistribution of surplus food in the UK is mostly discussed on an institutional level with companies in the catering and hospitality business, but it can also be carried out on a local or individual level, referred to as peer-to-peer food sharing. Here surplus food such as leftovers can be offered to members of the local community. This can be carried out informally, for example asking your neighbours if they want any of your leftovers, or any food that you have that may go off if you are going away on holiday (Michelini et al., 2018). Otherwise, apps such as Olio can be used to facilitate food sharing for individuals who want to give away food they will not eat, or who want to get free food that would otherwise be wasted as a means to avoid economic, social and environmental issues related to FW (Olio, 2018).

In India, there is a policy to distribute poorer quality grain and food produce to the poorest citizens in the country as part of the National Food Security Act, however, there have been concerns relating to corruption and inefficiency with the policy (Banik, 2016). Moreover, a number of non-governmental organisations have been set up to try to redistribute surplus food from eateries and street vendors to the needy such as Feeding India (Feeding India, 2019) and The Robin Hood Army (Robin Hood Army, 2019). Additionally, the Indian Food Sharing Association (IFSA) is an initiative by the Food Safety and Standards Authority of India (FSSAI), which works with food-related NGOs in the country to aid in food redistribution, alongside offering advice on policies and FW reduction measures (FSSAI, 2019). With this being said, similar to the UK, there is little governmental impetus such as incentives and tax breaks for

redistribution of surplus concerning the catering, hospitality and retail sectors, driving the redistribution of surplus food in the country (Artiuch and Kornstein, 2012; Banik, 2016).

2.6.2 Animal feed production

Producing animal feed from surplus food is perceived to be less sustainable than FW reduction and human redistribution, but preferable to recycling, energy production and landfilling. A large amount of the world's land and crop resources are used to feed animals. Often food by-products typically not eaten by humans, or poor-quality food such as animal by-products that are produced in abattoirs that are not-commercially viable, are given to animals. With this being said, there are many farms that grow crops for animal consumption (McMichael et al., 2007), leading to high associated GHGs (Okin, 2017).

Producing animal feed out of surplus food used to be one of the most common ways to process uneaten food. The foot and mouth outbreak at the turn of the century, alongside other animal health related issues such as 'mad cow disease' led to a dramatic decrease in the amount of surplus food being diverted to animals (ReFED, 2018b). Stringent legislation in the EU was created to avoid such issues arising again. It is not allowed to use catering waste for animal feed in the UK due to EU legislation. Conversely, surplus food diversion to animal feed remains very common in S.Korea and Japan (Salemdeeb et al., 2017) and to a lesser extent in the US (ReFED, 2018c) due to these countries having more relaxed legislation. It has been estimated that around 800,000 extra tonnes of surplus food could be used to produce animal feed in the UK if the legislation was to change in-line with that of the other countries mentioned (WRAP, 2018). This would only account for around 0.13% of total animal feed required in the UK (ADHB, 2022) and the food would have to be adequately treated and only given to the appropriate animals, avoiding giving ABPs to ruminants (DEFRA, 2011; FSA, 2018). Legislation permitting, one option for treating surplus food would be to use a desiccation unit to heat, dry and sterilise the food (Dhar, 2016). It is clear that there are many benefits from using surplus food for the production of animal feed where it is possible, but for this to occur, the UK legislation would need to change. Safe production of animal feed from surplus food in the catering sector would need to be allowed, with new policies incentivising and guiding the production of animal feed from surplus food (Salamdeeb et al., 2017). WRAP is currently building a business case for the production of animal feed and has produced a guide to advise businesses how to produce animal feed from their food surpluses (WRAP, 2018b) and BREXIT may present an opportunity to loosen the related regulations (DEFRA, 2011; FSA, 2018).

2.6.3. Anaerobic digestion

As previously mentioned, AD is considered the most sustainable technology for treating FW that is not suitable for redistribution to humans or animals. AD is a process of biochemical conversion involving the degradation of biomass in the absence of oxygen, using microorganisms to drive the reaction. The products of this process include biogas, digestate and wastewater. Of these, the biogas (methane) can be used to produce heat (using a biogas boiler), and/or electricity with a combined heat and electricity (CHP) boiler. The digestate can also be used as a biological fertiliser. Both of these by-products can be used as to substitute fossil fuel-derived energy and chemical fertilisers, thus decreasing GHGs and recycling nutrients (LeAF, 2010). Anaerobic digesters can be fed non-lignocellulosic (non-woody) organic waste of a certain particle size, moisture content and homogeneity. Moreover, packaging must be separated from the FW and it must be ensured that there are no contaminants in the FW mixture (LeAF, 2009).

While AD has the potential to bring about substantial benefits, it is a complex process that needs to be managed properly to achieve these benefits (Breitenmoser et al., 2019). The feedstock needs to have the right chemical composition, with high nitrogen levels leading to ammonia generation, and high sulphur levels promoting sulphur-feeding bacteria reducing biomethane generation through inhibiting methanogens (Davison et al., 2023). Moreover, if chemicals such as bleach are accidentally fed into the machines then it kills the bacterial colonies, halting the biomethane generation for a prolonged period until the bacterial colonies can be regrown (Le Couteur, 2004). Furthermore, if not managed properly, fugitive emissions of methane and nitrous oxide may occur, leading to substantial GHGs with global warming factors around 28 and 296 times greater than carbon dioxide respectively (Davison et al., 2023).

2.6.4. Composting

Composting is another FW treatment option. Composting refers to the aiding of the natural process of decaying biological waste (aerobic digestion). With composting, bacteria and worms breakdown the carbon-based material alongside oxygen and water in a process that produces carbon dioxide and a nutrient rich soil. It is possible to add water, air and worms to speed up the process. Compost can be used as a peat substitute soil amendment product, thus mitigating the carbon intensive peat industry, as well as closing the nutrient loop in FW (Selincourt, 2008). On the other hand, unlike AD, composting does not produce renewable energy that can be utilised to substitute fossil fuels (LeAf, 2009). All organic waste can be composted. It is preferable to break the feedstock into smaller particle sizes (for speeding up the decay process), however this is not essential (WRAP, 2006). Little pre-treatment is

required, and feedstock contamination is not as great a concern as it is with AD for example (LeAF, 2009). Composting can be done on a large city scale, but can also be done on a very small single household scale due to its simplicity (WRAP, 2018a).

2.6.5. Incineration

Another FW treatment option is to incinerate the waste to generate heat and/or energy. The heat and/or electrical energy can then be transported to households and other end users where it substitutes fossil fuel derived heat and energy, thus reducing GHGs (Moran et al, 2006). Alternatively, the thermal energy produced can be used to heat water to drive steam turbines and produce electricity. The ash can potentially be added to soil, for nutrient recycling (Obernberger and Supancic, 2009). Conversely, incineration of municipal solid wastes such as FW is problematic as it has a very high moisture content, meaning that it requires a lot of energy to dry before it can be combusted to generate heat and energy (Kim et al., 2013). Moreover, combustion of FW results in significant air pollution, with nitrogen and sulphur contained in the food being converted into NOx and SOx, while particulate matter is also formed during combustion, all of which are harmful to human health (Liu et al., 2021; Cangialosi et al., 2008). In addition, the ash often contains hazardous material that can result in environmental issues such as water pollution when not adequately disposed of (He et al., 2004). For these reasons, as well as odour, visual and noise pollution issues, there is often large opposition from local populations to building incineration facilities near residential areas (Wong, 2016). It is these wide-ranging environmental issues associated with incineration that makes it be regarded as less sustainable than composting (WRAP, 2018a).

2.6.6. Desiccation

Desiccation is a relatively new technology (Figure 2.2.) that can be used to pre-treat high-moisture wastes such as FW (Neale, 2013). Desiccation can also be referred to as dehydration or dewatering. It is the process of removing the water from a feedstock through a process of extreme drying, by use of heat, rotation and a desiccating agent. Desiccation can reduce the weight and size of the feedstock by up to 90%. Desiccation produces an energy rich, dense product. If FW is desiccated, it maintains mostly the same level of energy and nutrient content but decreases in size and density. Moreover, it kills most pathogens and halts the decay process, thus alleviating issues of odour and vermin problems. The product can be used as compost, as a feedstock for a bio-boiler, as feedstock for AD (with the addition of water), or as animal feed. Furthermore, as desiccation greatly decreases waste size and weight, it can significantly decrease transport emissions. On the other hand, desiccating units do require

large amounts of energy to run and waste large quantities of water. The technology is not currently widespread; however, this may well change in the future (Dhar, 2016).

Figure 2.2.

2.6.7. Hydrothermal carbonisation

Hydrothermal carbonization (HTC) is a relatively novel technology for pre-treating organic materials and is typically used on high-moisture materials. It involves heating the feedstock to between 180-350 degrees Celsius in pressurised water, in order to convert it into a more stable, denser more energy dense material. If FW is hydrothermally carbonized then it can be converted into a material similar to a low-grade coal that is referred to as hydro-char (Berge et al., 2011). While the process requires large amounts of energy (Ahamed et al., 2016), the product retains most of its carbon (Berge et al., 2011) and has very desirable qualities for use as a soil amender, fertilizer and peat substitute, (Berge et al., 2011). It also has desirable attributes for combustion (Heidari et al., 2018), AD (Berge et al., 2015), bioremediation, pollution absorbent, (Falco, et al., 2013) or just as a long-term store of carbon as a carbon sink (Malghani et al., 2013). Moreover, process liquids produced can also be used AD (Berge et al., 2015). Alternatively, hydrothermal treatment can be done at different pressures, temperatures and for different durations to primarily produce a biogas that can be combusted for energy production (Kruse, 2009), or a liquid that can be used as an energy fuel (Toor et al., 2011).

2.6.8. Food waste management options summary

It is clear that there is a wide range of FW management and treatment technologies available. These all have different benefits and issues associated with them. Moreover, they are all at different stages of development regarding how established the different technologies are. Although the WRAP FW hierarchy has been created, this does not feature the novel technologies and the suitability of different FW treatment technologies can differ depending on what the desired outcomes and specific circumstances surrounding a site may be. Additionally, certain options may be more feasible than others under different conditions and under different policies. For these reasons, FW technologies need to be further explored.

Through reviewing the different FW technologies, it has helped greatly in identifying which FW treatment technologies should be studied for the PhD project.

2.6.9. Effect of composition on treatment technologies

It is important to consider the composition of FW when determining the performance of different treatment technologies. Certain FW characteristics may be preferable for certain treatment technologies but be deleterious for others. It is important to look at both the elemental and physical properties of the FW to determine what the best treatment option is for that particular FW (Li et al., 2013; Jingura and Kamusoka, 2017).

2.6.9.1. Elemental properties of food waste

Regarding elemental properties, a high carbon content is an indicator of a good fuel, and typically the higher the Carbon content the higher the energetic potential of the material is. The higher heat value of a substance is measured as the proportion of carbon in a sample. It indicates the potential energy that can be gained from combustion/incineration of a material (Li et al., 2013). Carbon is also important for soil amendment, with high Carbon contents being considered preferable for peat substitution (Salincourt, 2008). The carbon to nitrogen (C/N) ratio is important for AD. The C/N ratio refers to the relative proportions of carbon and nitrogen in the sample. The optimal C/N ratio for AD ranges between 20:1 and 35:1 (Jingura and Kamusoka, 2017). A high Nitrogen and Phosphorous content is highly preferable when producing soil amenders through providing nutrients and substituting chemical fertilisers (Salincourt, 2008). On the other hand, these elemental contents alongside Sulphur can be problematic when combusting/incinerating FW, as these elements are oxidized producing air pollution (Congialosi et al., 2008). While inorganics such as alkali metals can potentially be useful in soil amenders for reducing the acidity of soils (Vassilev et al., 2013), they can be inhibitory for AD (Jingura and Kamusoka, 2017), and cause slagging and fouling when combusted/incinerated (Li et al., 2013).

2.6.9.2. Physical properties of food waste

Regarding physical properties of FW, moisture is a very important factor (Jingura and Kamusoka, 2017). The higher the moisture content is of a material, the greater the energy requirement there is to dry it. This concerns energy inputs for desiccating FW and for combustion/incineration (Li et al., 2013). High moisture content means lower energy densities of fuels also, which means higher associated transport emissions (Kim and Him, 2010). On the other hand, a relatively high moisture content is not an issue for AD (LeAF, 2009), or HTC (Li et al., 2013), as water is required for these processes anyway, nor is it an issue for composting (Salincout, 2008). It is also important to look at ash content, as ash can damage machinery when FW is combusted/incinerated (Li et al., 2013). Ash can also be hazardous and either

result in GHGs when landfilled (Kim et al., 2013), or cause harm to the environment if not treated properly, such as the potential leaching of heavy metals contained in the ash into water bodies (He et al., 2004).

2.6.9.3. Other properties of food waste

In addition, other measurable components of FW need to be considered when identifying optimal treatment technologies including biochemical characteristics and Chemical Oxygen Demand (COD). It is important to look at biochemical components when assessing the appropriateness of desiccated FW for use as an animal feed (PFMA, 2015; Finglas et al., 2015). Biochemical composition also has an impact on Biomethane potential, with high fat content typically leading to high BMP yields when compared to protein and carbohydrate content (Jingura and Kamusoka, 2017). Additionally, a high lignocellulosic content can be problematic with AD, as lignin and cellulose cannot be anaerobically digested without pre-treatment (LeAF, 2009). COD is also an important factor regarding AD. COD is an important determinant for biomethane potential generation from a material. COD refers to the amount of oxygen that is required to chemically oxidise a material, indicating the amount of organic matter there is in a sample. The higher the COD, the higher the biomethane potential.

2.6.9.4. Implication of differing food waste compositions in the UK, India and China

FW characteristics differ significantly within the UK, India and China (Davison et al., 2017; Gupta et al., 2019; Chen et al., 2016). It is also clear that FW composition greatly effects the performance of the different FW treatment technologies. It is therefore necessary to analyse FW characteristics when assessing the viability of different FW treatment options. This section justifies the need to carry out objective 1c (characterising FW compositions), in order to complete FW management LCAs and LCCs at the UK University, Indian institute A (objective 3) effectively.

2.7. Behavioural change interventions

Numerous intervention types can be used in order to enact behavioural change. FW attitudes can be defined as the beliefs and values individuals have pertaining to food waste or generally the way they think about FW issues, while FW behaviours can be described as the actions individuals take that influences FW generation and treatment. Moreover, FW habits are the repetitive actions or tendencies individuals have in relation to FW generation and treatment (Russel et al., 2017). With this in mind, an individuals' attitude may determine their behaviour, for example, if their concern for FW increases they may change their behaviour to reduce FW. This behaviour may continue for a prolonged period until it becomes built in, and therefore

habitual. Conversely, it is also possible to change the behaviour of individuals without changing their attitudes through making infrastructural changes (Wansink and Van Ittersum, 2013).

Regarding FW management, changing individuals' behaviours can reduce the amount of food that they waste and increase the amount of FW they recycle, thus substantially mitigating GHGs. Some behavioural change intervention types are suited to bringing improvements on an institutional, regional, or even national level (Wansink and Van Ittersum, 2013), whereas other interventions can enact beneficial change on an individual level, or in residences (Abrahamse and Steg, 2013).

2.7.1. Nudge theory

Nudge theory is a behavioural change technique that can enact change on a large (national) scale, or at institutions such as restaurants. Nudge theory centres around the idea that small changes to a decision-making infrastructure can make substantial changes to the way people behave. It is typically used as an intervention to influence public behaviour in a way that does not involve incentives or coercion. It became popularly used as a policy tool for the UK and US government under Cameron and Obama respectively (Kosters and Van der Heijden, 2015), but has also been used to good effect for bringing about smaller, localised behavioural change (Wansink and Van Ittersum, 2013). Nudge techniques can be more successful, popular, efficient and cost effective in enacting change than economic tools (Barker et al., 2021). Nudge theory works on the basis that many people do not make decisions based on their best interest, due to the average person's inability to store the large amounts of wide-ranging information required to make an informed decision. Further barriers to a person making an informed decision include generosity, a lack of time and being disinterested in the subject. Insights into people's behaviour can be used to inform changes to the choice architecture to bring about improvements through subtle suggestion in a way that may not even be apparent to those it affects. Conversely, there are potential ethical problems with nudge. Through changing social behaviours through changing choice mechanisms, there is a belief that nudge interventions can subtly reduce an individual's freedom to make a conscious choice (Bradbury et al., 2013).

Nudge theory has differing levels of success depending on what methods are used (Kosters and Van der Heijden, 2015). An example of nudge theory being highly successful is changing organ donation for citizens from opt in to opt out in various countries. Swedish and Austrian citizens have to opt-out to organ donation and thus both have donation rates of over 85%, when compared to only donation rates of less than 30% in Denmark and the Netherlands where you have to opt-in to organ donation (Kosters and Van der Heijden, 2015). Moving from opt-in to

opt-out made a substantial difference as, most of the population were indifferent to the topic and wanted to choose the option that fit the social norm and required the least effort (Rodrıguez-Arias and Morgan, 2016). Nudge interventions are not always effective however. A nudge intervention aiming to reduce household energy consumption through providing feedback on average household consumption led to those with below average consumption levels increasing their consumption due to a perception that their behaviour was 'too good' (Thaler and Sunstein, 2009).

2.7.2. Block leaders

One type of behavioural change intervention that can bring about change to individuals, social groups, or tenants of a residential area is that of block leaders. Block leaders are individuals that inform others in their social group about a particular issue (Abrahamse and Steg, 2013). The theory centres around the idea that it is more effective when a member from inside the social circle informs others on a subject when compared to the information coming from someone who is perceived to be an outsider (Grilli and Curtis, 2021). Furthermore, social networks are regarded to play a very important role in information dissemination. The effectiveness of the social networks in doing this is dependent on how close and how large the group is. For example, a close family member will have a greater impact on shaping someone's ideas than an acquaintance (Abrahamse and Steg, 2013). The success of block leaders in effecting others comes down to the 'liking principle'. The more we like someone, the more meaningful the relationship is and the more likely we are to listen to information and reasoning and ultimately, the more likely we are to change our attitudes (Cialdini & Goldstein, 2004).

2.7.3. Public commitment making

Like using block leaders to change behaviour, public commitment is also typically used to change the behaviours of a small group of individuals such as those in a residential block. Public commitment making is the commitment of an individual to carry a certain opinion or follow a particular behaviour. The participants are asked to make a pledge such as to opt in to segregating FW, or start recycling. This is linked to an individual's need for consistency between attitude and behaviour. It works best as a 'foot in the door technique' where you start with small low effort pledges, then make bigger pledges until eventually they meet the target pledge. Further to this, commitment making is more effective when it is carried out in public, especially when amongst friends and acquaintances. This is because there is social pressure for them to stick to their commitment. There is also more guilt if they do not fulfil their pledge (Abrahamse and Steg, 2013).

2.7.4. Feedback on performance

Feedback on performance can be used to enact behavioural change on individuals or relatively small groups. Often giving information on how an individual or a group is doing, either compared to other individuals, other groups, or how their performance has changed over time, can drive positive behavioural change. Here the links between behavioural change and outcomes becomes clear. For example, you reduced your FW by 20% this week. This equates to x reduction in CO_2eq emissions and saved you x number of pounds. Sometimes there is only group data, such as total FW figures for a hall of residences. In this case it is impossible to give individual feedback, so group feedback can be used (Katzev et al., 1981; Abrahamse and Steg, 2013).

2.7.5. Behavioural change summary

It is clear that behavioural change is very important when studying FW management. Firstly, FW reduction is top of the WRAP hierarchy as the most sustainable FW management option. Moreover, FW segregation is highly important as a management option, as it allows the FW to be treated using a much more sustainable FW treatment technology that is higher on the WRAP hierarchy. With this being said behavioural change can be very difficult, and it is never possible to eliminate all avoidable FW, or to achieve 100% segregation when a large number of people are involved (Abramse and Steg, 2013). A number of behavioural change interventions have been mentioned which can theoretically significantly reduce FW production and increase FW segregation; however, it is important to find out what detailed methods work in practice, how they can be implemented and how effective they can be.

2.8. Life cycle analysis

LCA is a very popular and effective way to assess the environmental credentials of a system on a case-by-case basis. An LCA is a thorough assessment of all of the emissions related to a specific process or product. LCAs generally feature emission and mitigation factors from five main areas: raw materials; production and processing; distribution and transport; end use; as well as end of life/waste and disposal. The most important factors that need to be considered when conducting LCAs are; the unit of measurement, the geographic location, the data collection methodology, the assumptions made, the impacts considered and the emission partitioning method (Rebitzer et al., 2004).

It is clear that if the optimal FW management approaches at the UK University, ULB and Indian institute A are to be discovered, an LCA and LCC of the different FW management options should be carried out (objective 3).

2.9. Decision-making tools

While LCAs are very effective when assessing particular case studies, they cannot be applied effectively when assessing a particular problem at different sites, such as waste management for an entire country (Thorneloe et al., 2007). Decision-making tools can be created to tackle particular problems making it quicker and easier to make informed strategic decisions on often-complicated issues (Vigo et al., 2008). These tools involve assessing particular criteria associated with solving a specific problem. This involves assessing values related to particular parameters for different criteria involving the various potential solutions to the problem. These values need to be weighted depending on their perceived importance. A decision-making tool should be flexible to allow differing inputs to be inputted associated with various case studies to assess the same potential solutions of the particular problem, resulting in different outcomes based on each individual case. The tool will then decide upon the best solution to the problem based on the case specific factors inputted and the desired outcome (Thorneloe et al., 2007). When considering FW management and decision-making tools, specific inputs associated with the assessed site will be inputted such as FW quantity, composition and location. The tool will then assess the different waste management options, such as those mentioned in section 2.4 and 2.5, based on their respective environmental credentials. The tool will then decide the optimal waste management strategy based on the site-specific inputs (Hanandeh and El-Zein, 2010).

An LCA and LCC of the FW management options at the UK University, Indian institute A, Indian institute B and the Chinese University will determine the best FW management at these sites. They will not achieve the main aim of the PhD to find a method for determining optimal FW management approaches that could be applied to universities in the UK, India, and China as a whole however. The formation of a framework for the creation of a FW management decision-making tool for UK, Indian, and Chinese universities would achieve this goal (objective 4).

2.10. Previous studies

Section 2.4 helped establish that different waste management types have significantly different levels of environmental impacts associated with them. WRAP (2018a) have outlined the different mainstream FW management options that are possible, in order of what is theoretically the most to least sustainable opportunities. Section 3.4 then mentioned different behavioural change techniques that can be used to aid in making the more sustainable waste management options feasible. Many different studies have been carried out on the subject of FW management that have gathered data in order to quantify different GHGs related to different FW treatment options, GHGs mitigated in reducing FW, how successful different

techniques are in reducing FW and increasing FW segregation, and what the key barriers are to positive FW behavioural change.

2.10.1. Previous LCAs comparing food waste treatment technologies

There have been many LCAs that have been carried out to try to ascertain the lowest impact waste treatment methods regarding GHGs.

There have been numerous relevant LCAs on different FW treatment options including incineration. Kim et al. (2013) did an LCA comparing the GHGs associated with FW management options for a Korean municipality. They evaluated the environmental credentials of AD as well as drying and incineration of the waste. They assessed the power generated from FW treatment, along with CO_2 emissions compared to natural decomposition. They then weighed this up against GHGEs from collection, transport, treatment and final disposal of the FW. They calculated that per tonne of FW processed, the drying and incineration option reduces carbon emissions by 315kg CO_2eq, whereas AD was found to produce a net 33kg CO_2 eq. drying and incineration was therefore concluded to be the best option, regarding the environment, for the Korean municipality to process waste. On the other hand, they imputed to the LCA that anaerobic digesters on average had a conversion efficiency of 35%, instead of a typical 60% (Dhar, 2016) and factored in that the digestate produced from AD would be landfilled instead of being used as a bio-fertiliser (WRAP, 2016), thus skewing the results in favour of incineration.

Salamdeeb et al. (2017) carried out a life cycle analysis for FW treatment options for household FW. They assessed a number of environmental criteria including GHG emissions for a number of waste treatment options. They looked at dry pig feed, wet pig feed, AD and composting. They found that wet pig feed generally performed the best out of the treatment options with it topping 13 out of 14 environmental categories, and only being bettered by AD in the fossil fuel substitution category. Moreover, it performed the best for GHG mitigation due to the great mitigation potential for avoiding the agricultural emissions associated with producing pig feed. In addition, wet feed resulted in greater GHG mitigation than dry feed due to the greater emissions required to process dry pig feed.

Numerous other LCAs have been carried out looking at the environmental impact of different FW treatment options, including animal feed. The majority of the studies support the findings of Salamdeeb et al. (2017). Kim et al. (2011) found that wet animal feed (-300kg/ CO_2eq/tonne FW) resulted in significantly greater GHG mitigation than composting (-100kg/ CO_2eq/tonne FW), with AD performing poorer still with net positive emissions. Takata et al. (2012) found that dry animal feed (-100 kg/ CO_2eq/tonne FW) was the best treatment option, performing

better than wet feed and AD (both -50 kgCO_2e/tonne FW). Conversely, Kim and Kim (2010) found that dry animal feed performed the worst (200 kg/CO_2eq/tonne FW) compared to composting (just over 100 kg/ CO_2eq/tonne FW) and wet animal feed (around 50 kg/CO_2eq/tonne FW). It is clear that these studies show significantly different results. This could be due to different waste treatment processes for the different treatment options. In addition, different figures for avoided emissions such as agricultural emissions mitigated from animal feed production, fossil fuel emissions allayed from AD derived energy, and chemical fertiliser/peat substitution with composting and digestate from AD could be responsible for these discrepancies (Salemdeeb et al., 2017).

While HTC is a relatively novel technology, a number of studies have been carried out looking at the environmental credentials of HTC of FW with combustion and energy generation, when compared to other treatment technologies such as incineration, AD, and composting. Benavente et al. (2017) found HTC to perform less well than incineration. They compared the environmental impacts of HTC (for combustion), composting, AD and FW drying with combustion of olive mill waste. They found that drying and combustion of FW outperformed HTC and combustion regarding GHG mitigation, as more energy was retained in the dried FW than the hydrochar (HC). They did however find that HTC performed better than composting and AD. They did not include energy generation through AD of HTC process waters however, which would improve the environmental performance of HTC. Conversely, a study by Li et al. (2013) found that HTC can perform better than incineration, but its performance is highly dependent on FW moisture content. They conducted an LCA comparing HTC and FW drying for incineration. They found that if HTC was conducted on waste with a moisture content of more than 95%, there was a negative energy balance. On the other hand, when the moisture content was less than 80%, HTC was classed as energetically positive. The FW they tested had a moisture content of 68%. They found that if the FW was hydrothermally carbonised as received, HTC performed better than incineration regarding GHGEs. Conversely, when extra moisture was added to the FW to have a solid loading percentage of 20% (80% moisture), then drying and incineration performed better than HTC, as extra energy was required to heat the extra moisture during HTC. In addition, they identified that utilising HTC process waters for AD, or fertilizing land significantly improves the performance of HTC.

When considering the environmental performance of HTC for creating a soil amendment product, Lu et al. (2012) looked at how the overall GHGs associated with HTC and soil amendment production compared with composting. They found that there were considerably less carbon emissions associated with producing HC when compared to producing compost as

the majority of carbon is retained during HTC, whereas the majority of carbon is lost and emitted to the atmosphere during the composting process. With this being said, due to data gaps, the loss of carbon over time during HC application as a soil amender was not considered. It was however stated that these carbon losses would have to be substantial to reach the levels of emissions associated with composting.

When comparing the environmental performance of landfilling to other FW treatment technologies, Lu et al. (2012) found that landfilling resulted in considerably higher GHGs when compared to HTC, AD, composting, and incineration. This was due to a mix of methane and carbon dioxide being produced in anaerobic conditions within the landfills and the significantly higher global warming potential of methane when compared to the carbon dioxide that is primarily generated from the other FW treatment technologies. Moreover, the other FW treatment technologies mentioned mitigate GHGs through production of soil amendment products (HTC with soil amendment generation, and composting), biofertiliser (AD and HTC), and fuel generation (HTC with energy generation, incineration and AD). With this being said, many landfills collect fugitive methane and utilise it for heat and/or energy generation, thus mitigating the environmental impact of landfilling (Barlaz et al., 2009).

From reviewing LCAs on the environmental performance of AD, composting, FW drying/desiccation, HTC, and landfilling, it is clear that there are significant disagreements between researchers as to the most sustainable, lowest emission FW treatment technology. Although there have been studies into the environmental performance of FW HTC for combustion, as well as FW drying/desiccation for combustion, there is a sparsity of literature looking at the use of HC for soil amendment (Lu et al., 2012), or for FW drying for animal feed generation (Salemdeeb et al., 2017). The environmental credentials of HTC have not yet been compared with using dried/desiccated FW as an animal feed, with animal feed being assessed to be the best performing treatment technology when compared to AD, composting and incineration by Salmdeeb et al. (2017). There is also little knowledge as to how FW composition or geographical location effects the environmental performance of the different FW treatment technologies (Zhou et al., 2018).

2.10.2. LCAs on general waste treatment options

Regarding greenhouse gas emissions associated with general waste treatment of municipal solid waste (MSW) with unsegregated FW included in it, numerous LCAs have been carried out looking at different treatment options.

Numerous studies have been carried out assessing the GHGEs associated with different MSW treatment options. Cherubini et al. (2008) studied the environmental impacts of different

waste treatment options on general waste as a whole, while Mata-Alvarez and Llabres (2000) looked at the organic fraction of MSW. The assessed environmental impacts are displayed in Table 2.2. Both studies agree that landfilling has the greatest environmental impact, with sorting and AD performing the best, ahead of incineration. The studies had very different figures however, due to the studies being conducted in different regions, in different years and using different methods. Garnett (2010) also conducted an LCA on general waste treatment options, finding that recycled MSW had the lowest environmental impact. It performed better than incineration, whilst landfilling also performed the worst according to their LCA. Chen (2016) carried out an LCA on MSW in Taiwan and, while they also found that recycling performed the best regarding waste treatment, they found that there were less greenhouse gas emissions related to landfilling inorganic waste, compared to incineration.

Mehta et al. (2018) also conducted an LCA for MSW. They looked at greenhouse gas emissions, as well as relative costs and other environmental and health factors associated with different MSW treatment options in Mumbai, India. They assessed the following scenarios; dumping on open ground, sanitary landfill without leachate treatment, landfilling with leachate treatment and regional composting and landfilling with the cost of disposing one tonne of waste being 344 rupees (US$5.17), 741 rupees (US$11.13), 1367 rupees (US$20.53), and 531 rupees (US$7.97 per tonne) respectively, for the scenarios. When compared with open dumping, landfill gas flaring reduced the global warming potential by 32%. Composting and landfilling scenario was found to have the lowest GHGs associated however, with a 79% reduction in global warming potential when compared to open dumping.

Table 2.2. Comparison of LCA figures on FW treatment GHG emissions

Study	**General waste treatment technology assessed**	**Environmental impact (Kg CO_2eq/tonne waste)**
Cherubini et al. (2008)	landfilling	1.31
	incineration	0.15
	Sorting and AD	-0.23
Mata-Alvarez and Llabres (2000)	landfilling	1.97
	incineration	1.41
	combination of sorting, composting and incineration	1.19

2.10.3. Summary on food waste and general waste treatment LCAs

From reviewing LCAs on the GHGs from different FW and general waste treatment technologies, it is clear that there are significant disagreements between researchers as to the

most sustainable, lowest emission FW treatment technologies. Moreover, the novel FW treatment technologies of FW drying/desiccation and HTC of FW, are little studied, and there are major research gaps concerning the different associated GHGs of different utilisation pathways, such as soil amendment, when compared to other pathways, such as combustion, or other FW treatment technologies such as AD, composting and incineration. Further to this, there are key knowledge gaps concerning the technologies, such as carbon sequestration, and transport emissions. Therefore, this section justifies that it is vital to characterise FW compositions (objective 2), as well as fill FW technology knowledge gaps through carrying out experimental work (objective 3a, 3b and 3c), in order to complete FW management LCAs at the UK University, ULB and Indian institute A effectively (objective 4).

2.10.4. LCAs on food waste reduction

LCAs have also been carried out trying to ascertain GHG emissions related to FW production, in turn giving a figure to the mitigation potential from reducing FW.

A study by WRAP (2010), found that the GHGEs associated with food being wasted at the manufacturing/processing stage was 2.4 tonnes of CO_2eq per tonne of FW. This figure rose to 3.2 tonnes of CO_2eq per tonne of Food wasted in the distribution and retailing stages. For FW produced in households and food services (catering and hospitality) 3.8 tonnes of CO_2eq per tonne of FW were calculated to be attributed. Included in these figures was 0.45 tonnes of CO_2eq for end waste treatment. Additionally, it was calculated that emissions related to agriculture, food processing, and transport equated to 2.3 tonnes of CO_2eq per tonne of FW.

Other studies came up with different figures however, as seen in Table 2.3. It can be seen that Sander (2008) estimates FW emissions to be the greatest, assessing household FW associated emissions to be 4.29 tonnes of CO_2eq per tonne of waste. They also calculated emissions with different waste treatment options and found that when recycling FW, the emissions were lower, at 4.08 and when landfilled, the emissions rose to 4.5 tonnes of CO_2eq per tonne of waste. Interestingly, both ETC/SCP (2009) and the BIO intelligence service calculated household FW to result in 2.07 tonnes of CO_2eq per tonne of waste. Given the fact that the two separate studies came up with exactly the same number, this figure seems the most trustworthy.

Table 2.3. Comparison of LCA figures on GHGs from food wastage (EC, 2010)

Food waste stage	**Greenhouse gas emissions from food waste (kg CO_2eq/kg food waste)**				
	Source	WRAP, 2009	ETC/SCP, 2009	BIO Intelligence service	Sander, 2008
Households		3.35	1.62	2.07	2.07
Catering		3.35	1.53	1.98	-
Food waste treatment		+ 0.45	+ 0.45	Included	Included

While there is some debate over the exact GHGs associated with FW reduction, it is clear that there is an enormous potential to reduce GHGs through FW reduction. This is because there are such high GHGs associated with upstream emission factors, primarily from the production of the raw food products in the agricultural sector. When compared to FW treatment emissions, there is a far greater potential to mitigate GHGs through FW reduction (WRAP, 2010). It is therefore essential to look at FW management when concerning FW management optimisation regarding GHG reduction. On the other hand, it is much more difficult to reduce FW than to change FW treatment technologies, and there is a limit to the amount of FW that can reduced due to behavioural barriers and the fact that a large proportion of FW is unavoidable, so FW will always be produced (Vision 2020, 2013). It is therefore important to look at FW technologies as well as FW reduction for the PhD project.

2.10.5. Economic assessment of food waste management options

Besides environmental factors, the economic credentials of different FW management options have been assessed in the literature, including the cost implications of different FW treatment technologies, treating FW onsite or offsite, recycling FW, as well as reducing FW.

2.10.5.1. Economic assessment of food waste treatment options

Regarding the cost implications of different FW treatment technologies, Kim et al. (2011) researched the life cycle cost (LCC) of different FW treatment strategies in Korea including using the FW as animal feed, composting the FW, AD, as well as FW desiccation and either utilising the dried FW for energy generation, or as animal feed. They found FW drying with the utilisation of the dried FW as animal feed to be the most expensive option at $72.14 per tonne of FW, followed by composting, AD, and wet animal feed production, with FW drying for energy generation being assessed to be the cheapest option at $14.19 per tonne of FW. In addition, they found wet animal feed production to have the best environmental performance of the different options they assessed.

Concerning the cost implications of FW decentralisation, Lu et al. (2020) compared the LCC of onsite FW composting at a residential block in Australia to offsite centralised FW composting at a large industrial site around 50km away. They found that onsite composting was significantly cheaper at $22.93 per tonne of FW when compared to $71.88 per tonne offsite, with onsite composting also having a better environmental performance.

The cost impacts of FW recycling have also been investigated, with Edwards et al. (2018), comparing the LCC of unsorted FW being landfilled with general waste, when compared to FW being segregated and treated with onsite composting, offsite composting and offsite AD. After factoring the cost of household FW bins, they found both home composting and offsite composting to be cheaper than landfilling, with home composting being the most cost effective, 10% cheaper than landfilling for municipalities. Conversely, offsite AD was assessed to be more expensive than landfilling FW with general waste. Additionally, FW recycling brought about significant environmental benefits, with all specific FW treatment technologies having better environmental performances than landfilling and AD performing the best in this criteria.

2.10.5.2. Economic assessment of food waste reduction

The cost savings of avoiding FW have also been studied, with Salemdeeb et al. (2017) investigating the cost implications of UK household FW, and the potential savings that could be made through FW avoidance. They divided FW into avoidable, potentially avoidable and unavoidable. They found that avoidable FW cost on average £2,284 per tonne; while potentially avoidable FW and unavoidable FW cost £959 and £1475 per tonne respectively, illustrating the significant economic benefits that could be achieved by reducing FW. The study also highlighted the significant environmental benefits associated with FW reduction.

2.10.6. Previous surveys, interviews and focus groups

There have been a number of studies that have used interventions to change FW related behaviour in households and canteens, where behavioural and attitudinal changes have been assessed through conducting and comparing pre and post intervention surveys (summarised in Appendix A6). Interventions such as providing group feedback on FW production, as well as educational information on FW issues and how to reduce and recycle FW can be highly effective in bringing about behavioural change. These interventions have resulted in increased awareness of FW related issues and concerns. They have also seemingly led to positive changes regarding FW reduction and segregation behaviour. This signals that such interventions can help result in positive changes that may lead to a reduction of FW related issues amongst participants in households and canteens.

A number of studies have also been carried out conducting interviews and focus groups to try to improve understanding of FW related attitudes and identify key opportunities and barriers in improving FW management in different households and institutions (summarised in Appendix A6). It seems clear that carrying out FW themed interviews and focus groups can greatly increase our depth of understanding in why FW issues persist, what motivates individuals and organisations to try to mitigate FW related issues, and what barriers limit improvements in doing so. It appeared that ethical concerns and a desire to conduct good practice regarding FW behaviour helped motivate individuals and organisations to make related improvements, while having the appropriate infrastructure helped facilitate those improvements. Key barriers however resulted from individuals finding it difficult to minimise their FW whilst trying to be seen as a good provider to their families and to extend generosity to guests. In addition, a lack of knowledge and skills regarding FW reduction and recycling combined with the perceived inconveniences related to recycling FW and trying to minimise FW limited the levels of improvements that could be sought.

Looking at the previous surveys offers an insight into where food is wasted, how it is wasted, why it is wasted and what can be done to reduce the waste. The interviews and focus groups help provide a more detailed understanding into all of the aforementioned aspects. The pre and post intervention surveys then show how behaviours and attitudes can positively change with interventions and how this relates to FW reduction and FW recycling. With the interviews carried out by Lueke (2015), adding a deeper insight into how and why such interventions worked through increasing awareness and how the medium in which informative interventions are carried out is vital, with text messaging not being perceived as an effective mode of information provision.

2.10.7. Previous interventions

Numerous studies have been carried out assessing how different awareness campaigns can help reduce FW in catering settings. Additionally, many studies have been carried out assessing how different infrastructural interventions, as well as a combination of infrastructural and awareness campaigns can help reduce FW in catering settings, (summarised in Appendix A6). Many studies have also been carried out assessing how different behavioural change interventions help increase FW segregation in households and residential blocks (summarised in Appendix A6).

Numerous awareness-based behavioural change interventions can reduce FW and increase FW segregation. Regarding FW reduction, awareness interventions resulted in decreases of between 4% and 20% in canteens (Ellison et al., 2019; Manomaivibool et al., 2016). Infrastructural interventions also have proven to be highly effective in reducing FW. Reduced

plate sizes led to large FW reductions of between 20 and 60% in buffet restaurants (Kallbekken and Saelen, 2013: Wansak and Van Ittersum, 2013) and going trayless led to FW levels falling by between 25 and 30% in university canteens (Arramark, 2008). Moreover, changing or standardising menus can reduce FW by up to 28% (Schwartz et al., 2015) while implementing food demand estimation can reduce surplus food by over half (Leverenz et al. 2021). It is also clear that canteen type has major implications on FW levels, with self-service buffets potentially generating more than eight times more FW per customer than set meals with table service. This is in part due to table service making it more convenient to take more food. A further consideration is that buffets tend to be all-you-can-eat with no cost implications of taking too much food, whereas table service canteens tend to be pay-as-you-go meaning the more you waste, the more you pay (Papargyropoulou et al. 2019).

Concerning FW segregation interventions, information provision led to segregation increases of up to 28% when a block leader (member of the same social circle) was involved (Burn, 1991), meanwhile, improving the appearance of FW bins and having FW volunteers increased FW recycling rates by 32% and 44% respectively (Lin et al., 2016). While the other studies do not have statistical data on post-intervention FW recycling increases, they found that the interventions led to participants continuing to recycle their FW for longer, as opposed to starting to recycle their FW and quickly giving up (Geislar, 2017; Cobern et al., 1995; Li et al. 2017). On the other hand, the study by Caraza (2018) also shows how difficult it can be getting residents to segregate FW in university residences and how interventions do not always have a significant positive impact on FW segregation. Furthermore, the study by Wood (2019) both showed the real likely recycling figures that could be expected in UK university residences (2 tonnes of FW segregated annually by 350 students), as well as the key barriers to segregating FW, primarily odour issues and effort needed to recycle waste.

It is clear therefore that a wide range of techniques can be used to reduce FW in canteens and cafeterias and to increase FW segregation in households and apartments. On the other hand, different studies used different techniques to assess the extent of the impacts on FW behaviours. Additionally, these studies were conducted on populations with differing circumstances in different areas. For these reasons, it is difficult to say definitively that all of these interventions could be tried at university residences and eateries in in the UK, India and China with the same outcomes. With this being said, looking at studies that have been carried out at universities helps identify what has been done and could potentially be done in very similar sites, under comparable conditions to the Universities that will be studied. Reviewing the different FW related interventions that have been conducted, offers good ideas on what interventions could be done, how these interventions could be carried out and what results could be expected. Conversely, there is still significant uncertainty as to precisely how effective these interventions will be in those universities that will be studied during the PhD project. For

this reason, it is essential to fill in the knowledge gaps on FW behavioural change at the universities being studied to ascertain what the most effective interventions are, and how they affect FW behavioural change, concerning exact levels of FW reduction, changes in FW segregation and changes in the FW related attitudes of the studied population.

These previous interventions offer insight into the situation regarding FW production at canteens and residences including at universities and offers some thought as to possible behavioural change related FW reduction and segregation options at the Universities being studied in this research in the UK, India and China. It will offer insight into their expected impacts, costings and the practicalities associated with them. In turn, assessing these FW intervention proposals helps progress the behavioural change part of the PhD (objective 2) through informing FW segregation and reduction methodology choices.

2.11. University feasibility studies

Studies have been carried out looking at the feasibility of different FW management options at universities to bring about improvements in sustainability. These look at FW generation, possible FW treatment options, along with the environmental, economic and practicality related issues associated with the FW management options.

2.11.1. Food waste treatment studies

2.11.1.1. UK University studies

New York University (NYU) did one such study quantifying the environmental benefits of AD in 2016. This study assessed the feasibility of having an anaerobic digester on campus to process FW. They sent 180 tonnes of FW 230 miles away for composting. They found that through producing renewable electricity and heat and reduced transport emissions with on-site treatment, the change in waste processing would result in massive GHG reductions in FW management (NYU, 2016). The 230 miles for waste treatment is significantly greater than typical decentralised waste treatment distances however (LEaF, 2010). Moreover, AD was not compared to composting (the method of treatment at the time), but landfilling, to accentuate the benefits of the change.

Concerning UK Universities, a feasibility study was carried out by Davison et al. (2017), looking at the best technologies for processing organic waste at the UK University. Through extensively searching the literature, three technologies emerged as being the most suitable for processing the University's waste. AD, composting and desiccation (as a pre-treatment option) were chosen. These three technologies were included in a scenario analysis alongside business as usual (BAU), with the current waste contract being with Olleco. BAU involves Olleco collecting the FW from the University and transporting it around 20 miles, with biodiesel fuelled lorries,

to a composting site. The first scenario was BAU with desiccation (Oleco, 2017). The second scenario was having onsite AD, with the third scenario involving on-site composting. These scenarios were analysed individually for their environmental impacts, economic performance and relevant social considerations. This assessment of the different options helped ascertain the most preferable feasible organic waste treatment option. Regarding GHG mitigation, scenario 2 performed the best, due to low transport emissions and high mitigation from energy and digestate (bio-fertiliser) production. Scenario 1 showed the best economic performance, as it had the shortest pay-back time (2 years) due to the desiccator unit costing much less than an AD, or composter, and the 80% reduction in food weight, resulting in large annual waste collection savings. Scenarios 2 (AD) and three (composting) had longer payback times, due to considerably higher initial investment fees. Furthermore, had a low financial burden mostly due to economies of scale. On the other hand, BAU performed poorly regarding social aspects, as it did not allow for much research, innovation or outreach.

The report advised the University to carry on with the Olleco contract in the short term (next 5 years) due to contract agreements. It also advised that the University should set up an AD research facility with a pilot scale anaerobic digester that is in storage, as this would allow for the social benefits BAU could not offer. Moreover, the anaerobic digester should be scaled up if funds were made available. There were major difficulties in sighting the anaerobic digester, and very high costs associated with it however, which would form a significant barrier to this. They also recommended that the University should focus on behavioural change, in decreasing FW and increasing segregation, in order to reduce GHGEs, costs, create research opportunities and engage better with students. They found that, besides general, campus-wide FW reduction, the most significant opportunities for impact regarding behavioural change was with the University accommodation and increasing segregation. This was because there was a very low level of segregation of FW, with the general waste collection being twice the cost of FW collection. Additionally, the general waste was mostly being sent to Northern Europe for incineration. Therefore, there would be a large potential to bring about substantial benefits from behavioural improvements in waste management in the Halls of Residences.

2.11.1.2. Indian university studies

Concerning Indian Universities, a study by Chokhani et al. (2015) looked into the possibility of substituting Liquefied Petroleum Gas (LPG) with Biogas in hostel canteens at a University in Mumbai, (Indian institute A), instead of using LPG in hostels and either landfilling the FW or burning the waste. They looked at the environmental and economic implications of substituting LPG with biogas compared to BAU. They found that per day utilizing the FW for biogas would result in 8.361 tonnes of CO_2eq, when compared to 2758.438 tonnes of CO_2eq

using LPG and landfilling the FW and 172.079 using LPG and landfilling the FW. GWP is calculated under a 20-year timeframe. GWP figures were 7.970, 1108.893 and 171.038 tonnes of CO_2eq respectively for over a 100-year time horizon. They also found that, assuming that the biogas plants would run for a total lifetime of 30 years, there would be net economic savings from installing the biogas plants when compared to BAU. These savings increased with capacity biogas plants from 24 million rupees with eighty-eight individual one MT capacity plants to 95 million rupees with six 15 MT capacity plants, over the 30 years.

2.11.1.3. Chinese university studies

Concerning Chinese universities, an LCA conducted by Gao et al. (2017) looked into the environmental impacts of adopting different FW treatment technologies at a canteen in one of the campuses (Xinglongshan campus) at Shandong University. The canteen served around 3,000 students and produced around 2 tonnes of FW per day, which then is transported to around 33 miles to a treatment plant where it is anaerobically digested. They compared the GHGEs that would be associated with anaerobically digesting, landfilling, incinerating, composting as well as a heat-moisture reaction, and considered a reduction in FW production. The study found that reducing FW was the best way to reduce GHGEs, and they found that transport emissions were a large source of GHGEs due to large distances being required to take the FW to the treatment sites. They also found that landfilling had a climatic impact almost 10 times larger than the next worst performing technology, incineration. AD was found to be the best performing technology, followed by composting, a heat-moisture reaction, incineration and then landfilling. Consequently, they concluded that the University should continue with AD as the FW treatment technology that they use.

2.11.2. Food waste reduction studies

Furthermore, regarding FW reduction at the UK University, Maganti (2017) carried out a feasibility study. Based on the ARAMARK (2008) study (see section 2.9.8), it was proposed that going trayless could be feasible and successful at the refectory and cafeterias at the UK University. Going trayless was proposed due to it being perceived to be a cost effective, easy to implement strategy that could significantly reduce FW. Action points were then outlined showing how the University could put the intervention into practice. They suggested removing trays but making them available for anyone who asks for one, or who has a special needs requirement. Moreover, staff would need to be converted to being supportive of the changes through education of the benefits, and retraining if needed. Furthermore, a pilot scheme should be put in place first. A survey should then be carried out, providing feedback on the perceived benefits and issues of the scheme by the staff and customers. After this the scheme should be slowly rolled out across campus, alongside information about the benefits provided

by going trayless, to increase support. Another intervention that they considered for reducing FW on campus was the Too Good To Go app. This app aims to reduce FW in eateries by discounting surplus food close to the closing time of the establishment (discussed in section 3.31). A strategy was created for, if the University cafeterias were to adopt the use of the Too Good To Go App. It was judged that each cafeteria would need to purchase an IPad mini for £420 each, as well as an IPad stand costing £16 each. On the other hand, it was assessed that the Too Good To Go App would lead to an extra monthly revenue of an increased food sale equating to 6-7 meals at the end of each day, resulting in £325 per month in extra revenues on top of reduced FW disposal costs, meaning a very short payback time. Additionally, through avoiding 90 wasted meals per month, it was estimated that around 90Kg CO_2eq would be avoided monthly through using this app. The University has now adopted the Too Good To Go app at certain campus cafeterias.

2.11.3. University feasibility study summary

Looking at FW management feasibility studies at universities helps identify different aspects that need to be considered when assessing the performances of different treatment technologies and reduction methods, as well as underlining the importance of identifying the practical feasibility of FW management options on site. Specifically, the Davison et al. (2017), the Chokhani et al. (2015), and the Gao et al. (2017) studies help offer invaluable insights into the FW management situation at the UK University, Indian institute A and the Chinese University respectively, providing information on FW production quantities and sources, thus helping progress the resource assessment part of the PhD (objective 1). It also includes a light touch economic and GHG assessment for having different possible FW treatment technologies at the UK University, such as BAU, AD, composting, desiccation with BAU and incineration. The study found that AD performed the best regarding GHGEs, and desiccation performed the best regarding economics. Moreover, the study by Magnati (2017) identified the feasibility and viability of adopting FW reduction interventions, as well as useful technologies and outlining steps on how to integrate such changes and related costs and benefits. Overall, these studies offer good insights into what to expect for the FW treatment and behavioural change related scenarios in the full LCA that will be carried out as objective 4.

2.12. Typical university characteristics in the UK, India and China

As mentioned, universities including the UK University, Indian institutes A and B, and the Chinese University in China were chosen as case studies for this research. Findings from these Universities will then be used to infer general findings for universities in the country relating to FW management optimisation through assessing the environmental and economic credentials of behavioural change interventions and treatment technologies, and will be used as the basis

of a FW management decision-making tool. It is however vital to understand how representative these studied Universities are on a national level, in order to justify using them to infer general FW management opportunities and challenges in FW management at universities across the UK, India, and China. Table 2.4. shows the key characteristics of the studied Universities concerning student numbers, annual FW generation, daily FW generation per capita, FW treatment technology, catering style, and the presence of self-catered students with FW recycling at self-catered residences, and how these compare to other universities in the chosen countries.

2.12.1. UK university characteristics

When considering UK universities, generally speaking, the characteristics of the UK University appear to be relatively similar to other UK universities included in Table 4. When compared to other universities, the UK University has slightly more students and generates a greater total quantity of FW, but does not have the largest student population, nor is it the greatest overall FW generator. On the other hand, the UK University has a slightly below average FW generation per capita, but far from the lowest generation rate out of the selected Universities. Regarding FW treatment, the UK University has the most common treatment strategy of offsite AD, with seven other selected Universities adopting this strategy, while two universities use onsite composters to treat their FW. The UK University also has a typical catering infrastructure of mostly on campus pay as you go canteens, and offers catered accommodation, while all of the selected universities have pay as you go campus canteens and five offer catering in certain university residences. Additionally, as with the UK University, all of the UK Universities had self-catered students, with six universities offering optional FW recycling in at least some of their self-catered residences like the UK University, and three not offering FW recycling in these residences. It is also important to mention that most students are self-catered at all of the selected Universities, and most self-catered FW was not recycled due to self-catered recycling being optional or unavailable, therefore most self-catered FW is disposed of in general waste where it does not contribute to FW generation figures as a consequence. This meant that FW generation figures were calculated to be considerably lower than they would be in reality, with greater levels of FW remaining unmeasured in universities with a higher proportion of self-catered students, and offering no self-catered FW recycling, leading to deceptively low rates of FW generation levels.

2.12.2. Indian university characteristics

Looking at a number of selected Indian universities, as shown in Table 2.4, Indian institute A and B appear to represent the different FW landscapes at Indian universities, in most cases. Indian institute A represents an average sized Indian University, whereas, Indian institute B has

a lower student population than the average, but greater than some of the other selected Universities. Indian institute A generates considerably more FW than any of the other Indian Universities, while Indian institute B has a FW generation rate that is below the average, yet notably larger than the other selected Universities. In addition, Indian institute A has the greatest FW generation per capita rate out of any University, while Indian institute B has a per capita generation rate very similar to the average for the selected Universities. This indicates that, while Indian institute B FW generation levels may be typical for an Indian University, Indian institute A may generate unusually high levels of FW. Regarding FW treatment, Indian institute A's strategy of onsite AD and composting, as well as Indian institute B's strategy of onsite composting appear to be common practice in Indian universities, with all of the selected Universities opting for onsite AD, composting, or a combination of both, except one university, which utilises the FW on campus as animal feed. Indian institute A and Indian institute B both have mostly pre-paid buffet catering systems with a limited number of pay as you go canteens, which appears to be typical for Indian universities as all of the selected Universities have the same catering systems in place. In addition, as with Indian institute A and B, all students were catered at the selected Universities, while any staff that lived onsite were self-catered with compulsory FW recycling.

2.12.3. Chinese university characteristics

When comparing the Chinese University to other selected Chinese universities, as shown in Table 2.4., it appears that the University characteristics and FW management approach is in line with other universities in the country. The Chinese University appears to be an above-average size University, but does not have the highest student population of the selected Universities. When looking at FW generation levels, the Chinese University has slightly below average total FW generation levels, as well as daily FW per capita rates, although both figures are very close to the average rates. Regarding FW treatment strategies used, the Chinese University and all of the selected Chinese Universities had their FW collected and anaerobically digested offsite, other than one university that had its food waste collected and used as animal feed offsite. Concerning catering styles, the Chinese University and all of the other Universities had only pay as you go canteens on campus, while all students were catered and none of the universities offered self-catered residences.

2.12.4. Representativeness of the studied universities

Overall, it appears that the studied Universities are representative, when considering how their FW management related characteristics compare to other universities in the country. The only University that shows any characteristics that differ from other selected universities in the respective country is Indian institute A, with its particularly high total FW generation and daily

per capita generation rates. With this being said, the other Indian University being used as a case study, Indian institute B, appears to have relatively typical total FW generation, and daily per capita generation rates. Therefore, there is at least one university in each country exhibiting representative FW characteristics in each key category.

2.12.5. Contrasting characteristics of UK, Indian and Chinese universities

In general, it appears that UK and Chinese universities appear to have greater student populations than Indian universities do. In addition, Chinese universities appear to generate the greatest total and per capita FW quantities, with Indian universities having considerably greater total and per capita FW levels than UK universities. On the other hand, Indian and Chinese students are all catered, with all catered FW typically being recycled, and UK universities mostly having self-catered students with low self-catered FW recycling rates. This may explain UK universities appearing to waste less FW. Concerning FW treatment, UK and Chinese universities tend to have their FW treated offsite, with AD being the most common treatment technology. Conversely, Indian universities tend to treat their FW onsite through either AD or composting. Indian universities likely treat their FW differently due to policy requiring them to process their FW sustainably onsite (CPHEEO, 2016a). Regarding types of catering, UK and Chinese universities mostly have pay as you go canteens, whereas Indian universities tend to have pre-paid buffet style canteens, creating different challenges and opportunities for FW management improvements.

Table 2.4. Review of FW characteristics at UK, Indian and Chinese Universities.

Category	UK Universities	Indian universities	Chinese Universities
Universities included	The UK University, Leeds Beckett University, Liverpool Hope University, University of Wolverhampton, University of Manchester, University of Edinburgh, University of the West of England, University of Bradford, University of Liverpool	Indian institute A, Indian institute B, NITIE, IIT Mandi, IIT BHU, University of Delhi, Anna University, IIT Madras	The Chinese University, Huazhong University of Science and Technology (HUST), East China Normal University, Hunan Agricultural University, Taiyuan University of Technology, 6 averaged Beijing Universities, 7 averaged Wuhan Universities, 15 averaged Universities across China.
References	Liverpool Hope University, 2022; University of Wolverhampton, 2022; University of Manchester, 2022; University of Edinburgh, 2022; University of the West of England, 2022; University of Bradford, 2022; Edge Hill University, 2022	Dwivedi et al., 2019; Navin, 2012; Latha et al., 2019; Maheshwari, 2017; O'Shea et al., 2017	Qian et al., 2021; Wu et al., 2019; Zhou et al., 2021; Pan et al., 2022; Zhang et al., 2020; Li et al., 2021; Zhang et al., 2021
Number of students *	**The UK University:** 36,300 **Others:** 4,958 - 40,250 **Others average:** 20,553	**Indian institute A:** 10,000, **Indian institute B:** 2,300 **Others:** 1,000 – 25,315 **Others average:** 10,211	**The Chinese University**: 57,500 **Others:** 600 – 61,700 **Others average:** 29,865.4
Quantities of FW generated *	**The UK University:** ~160 tonnes/year **Others:** 22.8 - 200 tonnes/year **Others average:** 90.8 tonnes/year	**Indian institute A:** ~1,862 tonnes/year **Indian institute B:** ~83 tonnes/year **Others:** 37.5 – 788.4 tonnes/year **Others average:** 251.5 tonnes/year	**The Chinese University**: ~3148 tonnes/year **Others:** 32.3 – 7,557 tonnes/year **Others average:** 4,007 tonnes/year
Approximate FW per student *	**The UK University:** 12.1g/capita/day **Others:** 0.26 – 48.6g/capita/day **Others average:** 15.35g/capita/day **Other average/yr:** 5.6kg/capita/year	**Indian institute A:** 510.1g/capita/day **Indian institute B:** 98.9g/capita/day **Others:** 4.3 – 242 g/capita/day **Others average:** 95.75 g/capita/day **Other average/yr:** 34.9kg/capita/year	**The Chinese University**: 150g/capita/day **Others:** 41.5 – 406 g/capita/day **Others average:** 191.1g/capita/day **Other average/yr:** 69.8kg/capita/year
FW treatment technology *	**UK:** AD offsite **Others:** 7 have AD offsite, 2 have Onsite composting (Rocket composters)	**Indian institute A:** AD, composting and animal feed onsite, landfilling offsite **Indian institute B:** Composting onsite **Others:** 1 has onsite composting and AD, 2 have onsite composting, 2 have onsite AD, 1 has onsite animal feed.	**The Chinese University**: AD offsite **Others:** 3 use offsite AD, 1 uses offsite animal feed.
Types of catering	**The UK University:** Onsite pay as you go canteens, catered residences **Others:** All have canteens onsite, 5 catered residences	**Indian institute A:** Onsite mostly pre-paid catered buffet, some pay as you go **Indian institute B:** Onsite mostly pre-paid catered buffet, some pay as you go **Others:** All universities have onsite mostly pre-paid catered buffet, and some pay as you go	**The Chinese University**: Onsite pay as you go canteens **Others:** All have pay as you go canteens onsite only.
Self-catered students and recycling	**The UK University:** Self-catered residences. Optional recycling in some residences **Others:** All have self-catered residences, 6 have optional recycling in some residences, 3 have no recycling in residences	**Indian institute A:** Students all catered. Staff self-catered with compulsory FW recycling. **Indian institute B:** Students all catered. Staff self-catered with compulsory FW recycling. **Others:** All students catered at all universities. Staff self-catered with compulsory FW recycling, where staff live onsite.	**The Chinese University**: Students all catered. **Others:** Students all catered.

*University of Bradford, University of Liverpool and Leeds Becket University excluded from calculations, due to lack of data availability.

*For all averaged Chinese Universities, there is no information on food waste treatment technologies used.

*For Chinese student numbers, the seven averaged Wuhan Universities, and 15 averaged Universities across China were not included in the figures.

2.12.6. Contrasting food waste generation in UK, Indian and Chinese universities

Universities in the UK, India and China generate vast quantities of FW. Table 2.5 shows that university FW generation is highest in China, then India, with substantially less being generated in the UK. While FW generation levels are high in universities, this only makes up a relatively small proportion of total post-consumer FW in the different countries. Indian universities contribute to the greatest proportion of total nationwide generation (1.76%), followed by China (1.24%), but the proportion is substantially lower for UK Universities. This is due to the UK having substantially fewer students and a lower per capita FW generation in universities, with both China and India having markedly greater student numbers and per capita food waste generation levels.

Table 2.5. Total food waste quantities from universities in the UK, India and China

	UK	India	China
Literature sources	WRAP, 2022; Statista, 2022;	Davison et al., 2022; Zhou et al., 2021	Davison et al., 2022; Zhou et al., 2021
Total post-consumer food waste (Mt)	7.7	68.76	170
Total food waste in universities (Mt)	0.02	1.21	2.11
Proportion of post-consumer food waste in Universities (%)	0.26	1.76	1.24

2.13. Waste management decision-making tools

Although there have not been any FW management decision-making tools for universities, there have been waste management decision-making tools designed to aid organisations and governments to decide upon the best waste management strategies for them. This in turn helps them choose appropriate waste management strategies (Vego et al., 2008) and informs policy development in waste management (Lin et al., 2010). It is clear from reviewing the literature that decision-making tools have been created to aid with waste management. However, these tools seem to have a focus on larger scale waste management systems, such as city to country scale MSWM, as opposed to institutional scale, as is the case for FW management optimization at universities, the topic of this PhD research.

Lin et al. (2010) created a decision-making tool with an aim to analyse the effectiveness of waste management options for electric waste (e-waste) in Taiwan with an aim to inform e-waste policy for the area. They had an aim to increase the performance of the region in recycling, using a decision-making tool called Analytic Hierarchy Process (AHP) to assess the different waste management possibilities and to decide what particular e-wastes to focus on in order to make the greatest improvements in waste management. This model took into account factors such as the hazardousness of the waste, the quantity of waste produced, the willingness of the population to recycle, as well as economic and feasibility related issues. They conducted interviews and field investigations to better understand social behaviour, and waste management priorities in Taiwan. They then inputted this information to the AHP model. The

model then grouped different electrical appliances based on their characteristics. They found that the waste management of compact disks, mobile phones and computer keyboards should be prioritised due to their environmental impact and high feasibility for recycling. This information was then used to inform Taiwan's waste management policy.

Vego et al. (2008) tried to ascertain the best MSW management strategies in Croatia by applying multi-criteria waste management decision-making tools. They used the tools Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) and Geometrical Analysis for Interactive Aid (GAIA) to try to work out the best MSW strategies based on ecological, economic, social and functional criteria sets. PROMETHEE is a decision-making tool that does not use parameters. It uses a ranking system to assess BAU against alternatives. It ranks the performance of waste management systems flows, based on different inputs and outputs. It also weighs the different outputs according to desired outcomes and preferences. Positive flows indicate the waste management system outperforms the alternatives, whereas negative flows show that the management system is outperformed by the alternatives. The GAIA model however, assesses different parameters such as transport distance, capital costs and general feasibility of different waste management strategies, attributing different performance scores to each. The results showed that current waste management strategies were not effective, and that MSWM would be improved if there were more centralized MSW treatment facilities in the country, arguing that cooperation multi-national MSW treatment facilities would improve waste management performances. The paper suggests that national waste policy should be changed to facilitate MSWM cooperation with neighbouring countries.

Hanandeh and El-Zein (2010) developed and applied a further multi-criteria waste management decision-making tool in order to select the optimal waste management option for the organic fraction of MSW in Sydney, Australia. They modified the decision-making tool ELECTRE III, through introducing a ranking index (RI) to create ELECTRE-SS, allowing for effective assessment of MSWM options, even when incomplete or uncertain data is present. The model was used to compare ten waste management options to the existing BAU strategy for the organic fraction of the city's MSW, using 11 criteria. They looked at various combinations of AD, windrow aerobic composting, and incineration, landfilling with energy recovery and recycling for FW, garden waste and paper waste streams. They found that, for paper waste, recycling performed best. They also found that AD was likely to out-perform incineration where a market for heating did not exist. Additionally, landfilling was considered a good MSWM option when overall performance and conditions of uncertainty were considered.

Firstly, the abovementioned tools appear to be primarily geared towards affecting policies, as opposed to deciding upon individual changes to waste management strategies. Secondly, the reviewed studies look at general waste management, as opposed to segregated FW, and do not consider both treatment options and behavioural aspects in conjuncture with one another. Thirdly, these decision-making tools appear not to look at waste management in both developing countries, such as India, and developed countries, such as the UK, (El Hanandeh and El-Zein, 2010; Vego et al., 2008; Lin et al., 2010). For the above reasons therefore, it appears that the design of methodological framework for a decision-making tool for FW management optimisation at Universities in the UK and India (objective 4) would be novel on a range of levels. With this being said, it is very useful to see what decision-making tools already exist and review their methodologies to gain ideas and insight into how it may be possible to create the FW management decision-making tool for the PhD.

2.14. Literature review summary

This chapter covers a wide range of topics associated with FW management related issues in the UK and India and in particular FW management at universities.

It provides an insight into the situation regarding FW management in the UK, India and China, regarding technological and infrastructural considerations, as well as policies. It is clear that the UK is much more progressed concerning FW policy development and management, while new policies in all countries look set to bring about rapid changes in the FW management landscapes, making the UK, India and China ideal countries to compare and contrast FW management optimisation assessments.

When looking at FW management options in the literature, a range of established FW treatment technologies, AD incineration and composting, and novel technologies, HTC and desiccation, with varying strengths and weaknesses were identified as interesting options to include in the project. A number of effective FW reduction and segregation methods were also identified in the literature. Major knowledge gaps concerning key issues associated with the assessments made concerning the different management options are clearly present however, which reduce the validity of such studies. Knowledge gaps typically included carbon sequestration, transport emissions and specific FW characteristics, related to different treatment options. Knowledge gaps will be filled through conducting a preliminary assessments of FW management infrastructures (objective 1), and FW related behavioural change experiments (objective 2).

Additionally, it was clear that FW related behaviours, FW characteristics, and technological feasibility differs in different countries. It is clear therefore that site specific LCAs and LCCs

need to be conducted to accurately assess FW management options in different sites, as will be carried out in LCA conduction for the UK University, Indian institute A, Indian institute B, and the Chinese University (objective 3).

Waste management decision-making tools have been created to make waste management assessments without needing to conduct full LCAs. Although no such tool has been developed specifically for FW management, or on an institutional scale, using similar techniques as for the existing tools based on the statistical modelling LCA results (objective 4), it should be possible to create a tool that can help optimise FW management in universities easily and effectively without needing to conduct a full LCA.

All in all, the literature review has helped justify the rationale of the objectives set out for the PhD project, as well as providing insights into what methods should be used in conducting the objectives and what results can be expected.

CHAPTER 3: ASSESSMENT OF INSTITUTIONAL FOOD WASTE GENERATION AND MANAGEMENT PRACTICES

3.1. Introduction

This Chapter aims to understand how the studied institutes are managed and why they are managed that way. As explained in the literature review, many universities have greatly differing FW management approaches, with different FW generation levels and FW treatment approaches having substantial implications on the environmental, economic and social impacts of FW. Understanding institutional FW generation and management approaches can help assess the extent of the food waste issues in the studied sites, specific issues, strengths, barriers and opportunities for improvements and site-specific issues encountered.

The assessment of institutional FW generation and management practices looks at a large UK University in Yorkshire UK, one large Indian University (Indian Institute A) and a smaller more specialised University (Indian Institute B) both of which are in Maharashtra India, as well as a large Chinese University in Shandong. All of these Universities can be considered broadly representative for their countries to a certain extent, as shown in table 2.8; however, each university is unique to a certain degree.

The specific aim of this Chapter is to gain fundamental data on what the current business as usual FW situation is at the studied sites, and the reasons why it is this way in terms of FW generation and infrastructural management strategies. This knowledge and understanding will provide the core data and insights required to conduct research in the later chapters. This chapter has the specific objective of quantifying current FW generation levels which will then be used to understand the scale of behavioural change opportunities from FW reduction, and recycling, as well as specific FW treatment requirements for FW treatment options such as FW inputs, outputs, and machine capacity requirements. A further objective is to gain an understanding of current food waste management differences between institutions. Differences in FW treatment technologies will influence opportunities associated with FW treatment changes that will be assessed in Chapter 5. Catering system and infrastructure factors will influence opportunities associated with FW reduction, while Self-catering system and FW recycling approaches will influence opportunities regarding increases in FW recycling

both of which are explored in Chapter 4 and assessed in Chapter 5. Moreover, data on the varying composition of FW in the different studied institutions will influence opportunities associated with different FW treatment technologies assessed in Chapter 5. Additionally, understanding the impacts of Covid-19 on FW generation and management will facilitate the forming of a Covid-19 scenario in Chapter 5, helping increase understanding of the influence of the global pandemic on FW management in the University setting.

This Chapter will outline the methods used, before providing an overview into the current FW infrastructures at the different Universities. The Chapter will then cover the rationale for these systems and approaches, as identified in interviews with FW managers and focus groups with students at the Universities. Following this, Infrastructural implications of Covid-19 on food waste management at the different Universities will be discussed. Finally, the Chapter compares compositional differences in the FW at the different Universities and discusses the potential implications of these differences.

3.2. Methodology

3.2.1. General infrastructure

FW quantities and sources were taken from digital waste generation logs at the UK University and the Chinese University, with FW being weighed by waste contractors at the point of collection for each site. In addition, FW quantities and sources were taken from handwritten logs at Indian institute A and B, with daily recording of FW weights by weighing FW bins at the end of the day at each canteen and self-catered residence.

Key stakeholders and current FW treatment technologies used were identified through conducting informal meetings and discussions, official waste management documents, as well as semi-structured interviews with those involved in FW management at the Universities. Potential FW treatment options were identified from waste management documents, policy assessments, and discussions with key stakeholders in FW management.

3.1.2. Catered food waste management infrastructure

Details on catered FW management, such as numbers of students at canteens, catering structures and other important aspects were gained from discussions and semi-structured interviews with canteen and residential staff, focus groups with catered students, as well as official documentation.

3.1.3. Self-catered food waste management infrastructure

Details on self-catered FW management, such as information on which residences segregate FW, numbers of students at self-catered residences (both residences that segregate and do not segregate FW), how FW segregation works at the residences (compulsory, or optional FW segregation) and other important aspects were gained. This information was acquired though conducting discussions and semi-structured interviews with canteen and residential staff, focus groups with self-catered students, as well as official documentation.

3.1.4. Interviews and focus groups (infrastructural insights)

Four semi-structured interviews were carried out, three in the UK University and one in Indian Institute B and focus groups were carried out on students at the UK University as well as Indian institute B. The semi-structured interviews were conducted with canteen staff at the UK University and Indian institute B, as well as Residence managers at the UK University, to gain insights from key stakeholders in FW management at the Universities. They were selected, as they were the key stakeholder in charge of vital aspects of FW management at the Universities. Questions were adapted from studies by Papargyropoulou et al. (2014) and Ofei et al. (2015) which carried out similar research regarding aims and settings (see appendix D). The focus groups included five catered students at Indian institute B (no self-catered students participated, as all Indian institute B students are catered), and six students at the UK University, one catered, five self-catered. The focus group questions were based on questions and responses from a survey that was conducted, that will be discussed in more detail in the next section. The interviews and focus groups focussed on both infrastructural aspects of FW management relevant to the resource assessment section, and behavioural change aspects (relevant to the behavioural change section, that will be discussed in the next section). Concerning the infrastructural aspects, there was an aim to gain a deeper understanding into the infrastructural reasons for FW generation, not recycling FW, chosen FW treatment strategies, as well as the infrastructural opportunities to improve FW management.

Interviews and focus groups were conducted with the informed consent of the participants and in accordance to data protection after ethical approval was granted. They were conducted in person in English at the UK University and Indian institute B and were recorded using a dictaphone. They were then transcribed, analysed and coded into themes on Nvivo, before being written up and discussed with the use of illustrative quotes.

3.1.5. Infrastructural impacts of Covid-19

Information regarding the impact of Covid-19 on FW management factors was compiled. Such factors included the following: The date the Universities shut, the date the Universities

partially reopened, and the impacts on student numbers, FW generation (catering and self-catering), catering services, self-catering services, FW treatment strategies, alongside other noteworthy impacts from Covid-19 at University sites. This information was ascertained through various methods. Covid-19 impacts on FW generation levels were identified using up to date figures on FW generation at the sites, using the same methods mentioned for gaining the data during normal times. Dates for when the Universities closed, and partially reopened, as well as changes to student numbers due to Covid-19 were gained from official websites, and informal discussions with relevant University staff. Impacts on catering were gained from informal discussions with canteen staff, implications on self-catering were gained from discussions with residential staff, and implications on FW treatment were gained from informal discussions with waste contractors, with these stakeholders also mentioning any other relevant impacts Covid-19 had on FW management.

3.1.6. Food waste composition

FW composition for each University was gained either from the literature where possible (for Indian institute A, & the Chinese University) or from my colleague Jaime Borbolla Gaxiola (for the UK University). Where it was not possible to gain precise FW compositional data from the specific studied University, the literature, or colleagues, data was taken from Universities in a similar geographical location with similar style cuisines. For Indian institute B, data was used from Indian institute A, as it is from a university in the same city and assumed to be similar in composition. For the Chinese University, data was taken from BUCT in Beijing, as the cuisine in Beijing is typically similar to that of Shandong (China highlights, 2022). FW compositional data was taken for physical qualities, such as moisture and ash content, elemental qualities, such as carbon and nitrogen content, as well as biochemical qualities, such as protein and carbohydrate content.

3.2. Current food waste management infrastructure

3.2.1. General infrastructure

Information on University size, FW generation, treatment strategy and FW management is detailed in Table 3.1. While the UK University is a larger university with considerably more students than Indian institute A, FW levels produced are considerably lower than Indian institute A. FW production levels per person are also much higher at Indian institute B than the UK University. The Chinese University is the largest University in terms of population, while it also generates the largest quantities of overall FW. The Chinese University students generate more FW per capita than the UK University and Indian institute B, but less than Indian institute A.

The different universities treat their FW using different technologies and strategies. At Indian institute A much of the FW is treated on site by AD, which is perhaps the most sustainable method of treating FW. With this being said, a large proportion of their FW that cannot be processed on site in reality is sent away for open dumping, perhaps the least sustainable FW treatment option. Indian institute B has its FW composted along with green waste on site and used in green spaces on site, something which is also highly sustainable. Combining the FW with green waste also means that a greater quality and quantity of compost is produced. Meanwhile, at the UK University FW is also treated by AD; however, this is done offsite, with the products utilized offsite. This leads to higher transport emissions associated with this waste treatment. With this being said large quantities of unsegregated FW from self-catered residences is converted into RDF and sent large distances to be used as fuel produce. Finally, segregated FW at the Chinese University is also sent offsite for AD; however, related transport distances are much greater when compared to the UK University. When looking at the key stakeholders in FW management in the universities, it is clear that the UK University has the most diverse range of trained employees working on FW management. With this being said, Indian institute A appears to have a more active group of students engaging in the topic to improve the sustainability of FW management in the university. Both Indian institute B and the Chinese University do not have active student engagement groups promoting FW awareness. In addition, it is not possible to use FW as animal feed in the UK, whereas it is possible to treat the waste and use it to feed livestock in India and China. This may present a specific opportunity for Indian and Chinese Universities, especially at Indian institute A where they have livestock on campus and thus would have no related transport emissions. Additionally, separation of vegetarian FW in place at Indian institute A would make it even more feasible for use as animal feed.

Table 3.1. Key general information on the studied universities and the FW management situations at these sites

General Information on FW management	**UK University**	**Indian institute A**	**Indian institute B**	**Chinese University**
Country	UK	India	India	China
Number of students	~ 36,300 students	~ 10,000 students	~ 2,300 students	~ 8,000 students at campus
Quantities of FW produced	• ~160 tonnes per year	• ~1,862 tonnes per year	• ~83 tonnes per year	• ~438 tonnes per year at campus
Key stake holders in food waste management	• Residential services in charge of waste management in residences • Estates in charge of waste management in other University sites (such as faculty buildings) • Sustainability services in charge of promoting sustainability • Cleaning services in charge of taking waste from residences	• Public health officer in charge of waste management on campus • Sustainability cell and zero waste organizations campaigning for sustainability	• Hostel and Mess committees in charge of waste management	• Canteen managers and waste directors. • Jinan Shifang Solid Waste Treatment Co., Ltd FW treatment contractors (AD)
FW treatment technology	• All FW combined and stored in FW bins • 152 tonnes per year segregated FW sent for AD off site (ReFood) • 8 tonnes AD off site (Olleco and ○ Check distances • Unsegregated FW sent for RDF ○ 25% Ferry Bridge • 75% Rotterdam and Oslo	• Raw FW, veg and non veg catered and non-catered FW separated and weighed • Biogas plants onsite: 0.5TPD (theoretically up to 4TPD) • Raw FW composted with green waste: 0.35TPD (self-catered FW) • Open dumping: 4.25TPD	• FW combined in wet waste bins • All composted on site alongside green waste. • Compost used as soil amendment at plant nursery and on vegetation on site	• FW pre-processed and sorted first to extract grease. • Collected, transported and anaerobically digested. • Biogas injected into national grid • Digestive used as organic fertilizer for agriculture • Oil processed biodiesel and aviation fuel.
FW treatment types possible	• Desiccation • HTC • Incineration • Composting • AD	• Desiccation • HTC • Incineration • Composting • AD • Animal feed		• Desiccation • HTC • Incineration • Composting • AD • Animal feed

3.2.2. Catered food waste management infrastructure

Most FW segregated in all of the universities comes from a catered setting, especially in the Chinese University and the Indian universities where all of the students are catered, as seen in Table 3.2. On the other hand, most students at the UK University are self-catered, not catered.

When all students are catered it is easy to estimate numbers of catered students; however, it is difficult in the UK as only very few students are officially catered, with many eating sporadically at the University canteens. In India, all catered food is pre-paid and all you can eat buffet style system, which typically results in high levels of waste, due to issues of over producing food and overfilling plates. On the other hand, these types of canteens have major opportunities to reduce FW through reducing plate sizes and having signs saying to avoid overfilling plates. The UK University has a mixture of pre-paid set meals at the UK University residence and pay as you go meals at the other canteens, while the Chinese University has pay as you go meals, as is typical for Chinese universities (Wu et al., 2019). In the pay as you go canteens in the Chinese University and some of the UK University canteens, it is possible, to an extent, for students to plan their meals to not over-order, to reduce plate scrapings and also to have reduced meal prices at the end of servings to reduce surplus food. On the other hand, with the set meal pre-paid catered system at the UK University residence less FW tends to be generated, although there a far fewer options regarding FW reduction. This is because students feel that they are not getting value for money spent if they have smaller portions, it is not a commercial canteen, so reduced meal prices are not appropriate, and there are typically limited amounts of surplus food left over meaning that redistributing food is not always viable.

There are specific strengths regarding each catering system at all of the studied sites. The UK University's residence and the Chinese University's Jinan campus canteen have catering teams that are very effective at minimizing surplus food by making informed meal choices, based on student feedback surveys. In addition, the UK University residence minimizes surpluses further by using leftovers and batch cooking to minimize catering FW, while other UK University canteens use the Too Good To Go app to reduce the amount of surplus food they produce. Meanwhile, Indian institute A have very active student volunteer groups that educate and inform students about FW and in return reduce FW quantities. Despite efforts to reduce surplus food, they redistribute this stream to a food charity 'Feeding India', something that reduces their FW by approximately 11%. While this stream helps mitigate impacts of this waste stream through providing free food to those who need it, it is better to avoid surplus food altogether wherever possible. Indian institute B has very experienced catering staff who, like the UK University residence are effective at minimizing FW through use of good practices, however, as of yet do not have any redistribution of surplus food.

Table 3.2. Catering information on the studied universities and the related FW management situations

Catered FW	**UK University/residence**	**Indian institute A**	**Indian institute B/Mess C**	**Chinese University**
Number of catered students	Total, unknown and variable UK University residence ~200	Total ~ 10,000 students	Total ~2,300 students Mess C ~375 students	Total 57,500 students
Type of catering	**UK University residence** • Prepaid meals • Set meals • Self-service salad bar • 3 meals a day • 7 days a week **Refectory and other university canteens** • Pay as you go meals • Open all days, up to 7 days a week	**Hostel canteens** • Prepaid meals • Buffet/all you can eat • 4 meals a day • 7 days a week **Other canteens** • Pay as you go meals • Open all days, up to 7 days a week	**Hostel canteens** • Prepaid meals • Buffet/all you can eat • 3 meals a day • 6 days a week (excluding Sundays) **Other canteens** • Pay as you go meals Open all days, up to 7 days a week	**Canteens** • Pay as you go meals • Open all days, up to 7 days a week
Specific strengths	**UK University residence** Canteen staff using FW prevention measures such as batch cooking, freezing food, and safely using leftovers. **Refectory and other university canteens** Use of Too Good To Go app offering reduced prices for meals near closing time.	Large range of student engagement activities aimed at reducing FW. Surplus food diverted to Feeding India, a food charity. Diverts around 11% of food that would otherwise be wasted to those in need.	Canteen staff highly experienced and using FW prevention measures such as batch cooking.	Informed menu choices, as based on student feedback on social media platform WeChat. FW awareness campaign by canteen staff, questioning why student waste their food.
Specific issues	Issues estimating number of students that will eat on any given day and consequential over-catering.	Issues of over-catering for students wanting non-vegetarian food. Issues with taste preferences and cultural diversity.	Issues estimating number of students that will eat on any given day and consequential over-catering. Issues with taste preferences and cultural diversity.	Issues with inflexible meal sizes leading to overserving and large amounts of plate scrapings. Issues with taste preferences and cultural diversity.

3.2.3. Self-catered food waste management infrastructure

The UK University is the only university studied to have self-catered students. When considering self-catered FW recycling only one halls of residences, out of 23 halls of residences and 15 extra smaller residences in the UK University is currently recycling their FW, with all FW produced in all of the other residences being put in with general waste. Even at the UK University residence, FW recycling is in an opt-in basis, with the majority not opting in to segregate their FW. The Chinese University does not have any self-catered accommodation for students, as all students are catered at all of the campuses. When looking at specific issues at the different sites, if all self-catered residences at the UK University had FW recycling available, much more FW would be segregated. Additionally, if FW recycling was compulsory as it is at the Indian universities, recycling rates would likely be much higher. Concerning the Indian and Chinese universities, while all students are catered, students can still buy food from shops and get takeaways. Some of this food will then inevitably be wasted, yet there are not the facilities for these students to recycle their FW.

Table 3.3. Self-catered information on the studied universities and the related FW management situations

Self-catered FW	the UK University	Indian institute A	Indian institute B	Chinese University
Who segregates	• Only one halls of residence segregates their food waste. • A proportion of 350 students. • Most Residences do not segregate	• No students self-catered	• No students self-catered	• No students, or staff are self-catered
How FW segregation works	• Segregation on an opt-in basis	• N/A	• N/A	• N/A
Specific strengths	• High levels of student engagement with sustainability representatives at the UK University residence	• N/A	• N/A	• N/A
Specific issues	• Low uptake due to FW recycling being opt-in and not compulsory • Not available in most residences due to financial and practical issues	• N/A	• N/A	• N/A

3.2.4. Infrastructural insights from Interviews and focus groups

To gain further insight into students' food waste related behaviour focus groups with students at the UK University, Indian institute B, and the Chinese University, were conducted. At the UK University the focus group consisted of six catered and self-catered students, including residents that opted in to segregate their FW and those who did not, at Indian institute B the focus group consisted of six catered students and at the Chinese University the focus group consisted of eight catered students. The first part of the session concerned participants' general views on and attitudes relating to FW. The second part discussed FW reduction strategies and impacts related to the interventions. It was not possible to conduct the interventions at the Chinese University however, so the interventions were shown and explained, with the students being asked how effective they thought the interventions would be if conducted. The third part considered FW recycling and related interventions at the UK University. The final part inquired about their views on the current FW management that is in place in their University.

Additionally, to gain further insight into FW management practices, semi-structured interviews were carried out with managers at the three Universities. This included interviewing the head caterer at the UK University Halls of Residences, a mess secretary at one of the canteens at Indian institute B, as well as the canteen manager at a canteen at the Chinese University. These interviews were carried out with an aim to give an in-depth insight into the roles of different key actors at the Universities, the specific challenges and opportunities they have in their specific job roles, the key policies and drivers regarding sustainable FW management practices and the rationale behind current practices at the Universities. This also helped understand how things compare and differ between UK, Indian, and Chinese Universities (see appendix A2). The characteristics of the participants and themes identified are displayed in Table 3.4. and Table 3.5. respectively. The themes are discussed below.

Table 3.4. Key characteristics of participants

Number	Country	Organization	Role	Format
1	UK	UK University/Residence	Students	Focus group
2	UK	UK University	Residential property manager	Semi-structured interview
3	UK	UK University	Senior residences manager	Semi-structured interview
4	UK	UK University/Residence	Residences head caterer	Semi-structured interview
5	India	Indian institute B/Mess C	Students	Focus group
6	India	Indian institute B/Mess C	Mess secretary	Semi-structured interview
7	China	Chinese University/Jinan canteen	Students	Focus group
8	China	Chinese University/Jinan canteen	Canteen manager	Semi-structured interview

Table 3.5. Key themes identified

Theme	Description
(1) **Reasons for FW**	Concerns how FW is produced, where it is produced and why.
(2) **Reasons for not recycling FW**	Considers what the key barriers are for rolling out FW recycling across the UK University and what the main reasons are for residents not recycling their FW when the option is available.
(3) **Motivations to tackle FW issues**	Considers why residents and responsible staff at the Universities see FW as a problem and what they hope to gain by actively trying to tackle FW issues.
(4) **Key opportunities to mitigate FW issues**	Identifies ways in which FW management could be improved at the organizations.
(5) **Effect of behavioural change interventions on FW reduction and recycling**	Explores the impact of FW interventions on FW related behaviour.

Interviews and focus groups were used to look deeper into how their infrastructures affect their management styles to gain further insight into how food waste management is carried out at these sites, why it is carried out this way and what the related implications are.

3.2.4.1. Key stakeholders and interviewees

At the UK University the facilities directorate is in charge of managing everything concerning the general running of the UK University facilities. The facilities directorate includes residential services that manage the UK University residences, the estates team that is responsible for University owned property, the sustainability services that are involved in promoting sustainability throughout the University (including FW related sustainability) and the cleaning services that clean University sites, including residences, and collect waste on-site. However, they currently do not collect FW. At the UK University, the studied residence is the only catered residence at the University. It provides catered and self-catered accommodation. There is a head caterer in charge of purchasing food and planning meals and estimating how much food to cook, as well as being in charge of the cooking staff, who was interviewed.

At Indian institute B, wardens are in charge of managing the specific hostels, with various councils that are in charge of different parts of food waste management, such as canteens and composting. At Mess C, there is a head caterer in charge of purchasing food and planning meals, as well as being in charge of the cooking staff. There is also a mess secretary in charge of the general running of the canteen, who was interviewed, and a menu secretary in charge of choosing the daily menu at the canteen.

At the Chinese University, FW is only collected from the canteens. The canteen managers are the key FW stakeholders at all of the canteens at the Chinese University campuses and are in charge of running the canteens, planning meals, recording waste statistics and organising how the waste is treated (offsite).

3.2.4.2. Infrastructural reasons for food waste

There are several comparative and contrasting reasons for FW at the studied canteens that relate to their infrastructures and how the canteens are run. Plate scrapings resulting from students taking too much food was identified as one of the biggest reasons for FW at the UK, Indian and Chinese Universities; however, the specific reasons for these plate scrapings varied at the different Universities. At the UK University, student portions were the same for main meals, so some students took too much food; however, plate scrapings were mostly attributed to behavioural issues related to taking too much from the self-service counter, particularly bread.

> The main sources of food waste are when people overfill their plates [4].

In the Indian canteen at Indian institute B, FW from plate scrapings was also an issue due to a lack of standardization of meals, meaning that students often took large quantities of a particular dish that they had previously liked only to find that the taste was not to their liking, leading them to waste food. Additionally, at Indian institute B, no feedback was taken on student meal preference to inform menus, prioritise popular dishes, and remove dishes that were unpopular, unlike at the UK University and the Chinese University. This further contributed to FW generation associated with the food not meeting students' taste preferences. A further issue was the overfilling of plates, as it was reported to be inconvenient to return for seconds, due to large queues waiting to take food.

> You may think that you'd like the food, so you take a lot and when you taste it doesn't taste how you think it would and when the taste is not good you throw away all of it [5].

In the Chinese University canteen, FW from plate scrapings was identified as the main cause of FW. The primary issue was that inflexible meal portions led to students not being able to gain the variety and food quantity they desired to satisfy their eating requirements, without wasting food.

> I take a lot of kinds of food of food, not just one, but each special type of food has a huge serving, and that makes it impossible for someone to eat all of them [7].

On the other hand, it was noted by both the focus group and the canteen manager at the Chinese University, that a lot of the FW is actually liquid from broth and inedible dregs at the bottom of soups. For this reason, a lot of the FW is mostly water, or inedible dregs, which the students argued was either unavoidable, or with a much lower carbon footprint than other FW such as meat and vegetables (Canellanda et al., 2018). For this reason, the quantities of FW recorded may be a bit deceptive when compared to the other studied Universities.

> I think most of the food wasted is liquid, the fat and the salt. There is a large quantity of it, but it can't be eaten anymore [7].

Besides FW from plate scrapings, surplus unserved food was also considered a key issue at the canteens. At the UK University's residence canteen, a major cause of FW identified by the head caterer was difficulty estimating the numbers that will eat at the canteens on a daily basis and thus how much food to cook to avoid a surplus. This was because numbers showing up varied greatly with many catered students eating out and not showing up, however, the University does not have an effective system to estimate how much food to cook.

> To monitor waste, we keep note of the numbers of students coming through each day and try to stick to the numbers as closely as we can [4].

Likewise, a lack of an effective system to estimate FW was also a key cause of surplus FW at Indian institute B, as identified by the students and mess secretary, with many catered students eating out and not showing up.

> The main constraint is unpredictability of students eating in the mess [6].

The focus group and interview at the Chinese University did not discuss surplus food generation; however, it may still be an issue to a lesser degree.

In the UK, self-catered students also pointed to accommodation-specific infrastructural reasons for FW, while UK, Indian and Chinese students all pointed out systemic issues related to the food industry as a whole causing FW to be generated. Food going bad be it shop-bought or cooked food was a key reason for FW mentioned by the UK University self-catered residents. A lack of freezer space meant food often could not be stored long enough for food to be fully consumed.

> A lot of our stuff is chucked because it couldn't fit in the freezer [1].

All focus groups and interviews considered companies involved in the food sector as a key reason for FW. One specific example raised was the UK University students having serious concerns about supermarkets, believing food labels to be misleading, resulting in perfectly good food being wasted because it went past the date on the label. It was also advocated that this food should be redistributed to feed the needy, rather than being discarded.

> All of this is still very edible, but it's just a bit stale or something. Why can't supermarkets just cook up all that food and make it into a soup for homeless people [1].

3.2.4.3. Infrastructural reasons for not recycling food waste in the UK

As mentioned, the UK University is the only studied University that has self-catered students, and within the UK University residence is the only residence that recycles its FW. This is due to issues of feasibility, financial aspects and health and safety concerns. Central Village previously had food waste recycling but stopped due to students not taking their FW bins out, causing hygiene and safety issues. The UK University residence operates on an opt-in basis for food waste recycling. Students can opt-in to recycle their FW and collect a FW bin, which they need to take out to a FW depositing site. Participants of the UK University focus group and residential service staff interviewed expressed some concerns regarding the current system and ways in which things may be improved. When considering institutional 'reasons for not recycling FW' for the UK University self-catered students, the key barriers that were mentioned included effort, hygiene and safety, practical issues, financial factors and policy barriers.

Effort was considered a key barrier in recycling FW. Many students stated concerns that while cleaners collected other bins, FW bins were not collected. They also stated that bins were often not located in convenient locations, with the FW disposal point often being located around a 5-minute walk away from flats. To compound the issue further a number of students reported that they were the only person within the flat taking the FW bin out on a regular basis. As a result, the effort required to recycle FW was considered highly prohibitive.

> The biggest hurdle was that I don't want to take it out on a cold January night when the bin is all the way over there and secondly, I know I would be the one doing it all of the time [1].

It was also advocated by residential services that if students were not committed enough to the recycling of their FW, then there could be significant hygiene and safety risks associated with not emptying FW bins that would outweigh the benefits gained from recycling FW.

> What we don't want is the downside of putting food bins in kitchens becoming a cleanliness issue, smell issue and a pest control issue, ultimately [3].

Students and residence staff identified practical issues as another key barrier. It was reported that there was limited space in kitchens to fit FW bins, but there were also logistical concerns regarding providing enough bins for each flat wanting to recycle FW.

> If we were able to do it then there are layout issues of the buildings with physical constrains such as to where we can put in bins and how many we can put in there [2].

Financial costs associated with FW recycling formed a major barrier to residential services staff. Buying FW bins for residents and contracting cleaners to collect FW would be a significant expense. Policy issues exacerbate this. Waste collection for some of the University's residences is under the jurisdiction of the local municipality. Specific FW collection is not currently offered by the local municipality, which means that FW collection would be an additional cost, whereas general waste collection is offered at no charge.

> There is no effective collection from the government as of yet as it is not legislated for and therefore, we would have to look at contract cleaners and that is a cost [2].

Additionally, the majority of UK municipalities (Iacovidou et al., 2012) do not offer FW recycling. If it were to be offered everywhere, it would likely become the social norm in society. This may then be something that students would follow through to university residences increasing those opting in to recycle FW.

> I think if it was culturally and socially the norm, which it might well be one day, I think it would be easier to adopt and to monitor in the residences [3].

3.2.4.4. Infrastructural factors in food waste treatment

FW at Indian institute B is sorted, weighed daily, and then composted on site. This compost is then used around campus for growing plants and topping up soil for on-site trees. This FW treatment scheme was regarded to be very sustainable by the Indian institute B focus group. For food waste treatment, they are quite good.

> When I found out what they were doing with the food waste I was quite impressed [5].

At the UK University, segregated FW is collected, transported to local sites and anaerobically digested, producing renewable energy and organic fertiliser that is used locally. This is a system that was regarded to be very sustainable by all participants that were aware of the scheme and was chosen for because it was considered as cost effective and environmentally friendly.

> It was chosen because of sustainability and for economic factors [4].

At the Chinese University FW is sorted, weighed and collected daily.

> Meal waste is collected uniformly and transported away by the city management every day [8]

The FW is collected by a waste treatment company, which anaerobically digests the waste and operates in a very similar way to the UK University. Grease is segregated and used for creating transport fuel, FW is anaerobically digested, and the resultant biogas is injected into the natural grid, while the digestate is used as an organic fertilizer.

> Food waste is handled by a specific waste treatment company. The food waste is pre-processed and sorted first to extract grease. Then, the remaining slurry is subjected to anaerobic fermentation, and the biogas produced after fermentation is purified into natural gas and enters the pipeline network of China Resources Gas. The biogas residue produced is turned into green organic fertilizer, which is used for the cultivation of rice, wheat and other crops. The extracted oil is processed deeply, and finally made into raw materials such as biodiesel and aviation fuel [8].

FW recycling was noted to be of particular importance to FW management at the Chinese University. When asked which FW related factors the Chinese University cared about most, the canteen manager gave a specific mention to FW recycling.

> We are mainly concerned with management issues, especially recycling [8].

3.2.4.5. Infrastructural opportunities to reduce food waste

Key infrastructural opportunities for reducing FW plate scrapings were identified through implementing informed menu choices, flexible meal portions and increasing the cost of food.

Implementing informed menu choice through surveying students on the desired meal options, which food they like most, and which food they like least has been reported to have led to significant reductions in FW at the UK and Chinese Universities.

> We frequently update dishes and learn about the satisfaction of students with new dishes through WeChat groups. We improve the quality of dishes in a timely manner based on the feedback of the students [7].
>
> There's no point in redoing that meal if they're not eating it [4].

On the other hand, informed menu choice has not been implemented at the Indian University. Therefore, adapting the menu based on the preferences of the students could lead to major FW reductions from plate scrapings at the Indian University. Moreover, the Indian mess secretary and students also suggested that standardizing the menu and even having different meal plans for different students, based on their preferences could be implemented to great effect.

> Definitely feedback should be done [5].

There were also opportunities to reduce FW from plate scrapings through having flexible portion sizes. The Chinese University canteen operates as a pay-as-you-go system. During Covid-19, while some dishes can be bought in either full, or half portions, students could not have the variety of food they wanted without ordering too much food. If the canteen instead offered flexible portions, perhaps from full size, down to quarter-sized portions or even less, then students could get the variety they wanted without over-ordering. This would also allow them to have smaller portions if they typically eat less than the average student eats, or do not have a large appetite at that moment of time. This would in turn, likely reduce plate scrapings substantially.

> How much food you can eat is highly related to your emotion. When you feel happy you can eat a lot, but if you feel sad you can only eat a little [7].
>
> The canteen could provide the food serving to half or more or less and this will be good for reducing food waste [7].

Opportunities for flexible portion sizes to reduce FW are not so applicable to the UK and Indian universities however due to their differing systems. In the UK University residence, students have fixed-price set meals, with students desiring good value for money. However, they do have a self-service salad bar with flexible portions and the possibility to return for seconds, allowing some flexibility. Moreover, Indian institute B, Mess C has a buffet self-service canteen, thus the portions are entirely flexible.

Increasing the cost of food, and thus the personal expense of wasting food, was also considered an opportunity for reducing FW from plate scrapings. In China, due to the low cost

of food at the canteen and related FW at the Chinese University, increasing the cost of the food at the canteen was considered as a potential opportunity for reducing FW, as it would increase the personal economic consequences of FW.

> I think they [the canteen] can make the food's becoming more and more expensive, then everyone will try their best to reduce the amount of food they waste [7].

With this being said, it is possible that an increase in food costs in the canteen may drive students to eat outside the campus and would just drive the FW problem elsewhere (Nadzirah et al., 2013).

As catered food is prepaid at a set price at the UK and Indian canteens, increasing the cost of food would not have any impact on the personal cost of FW for the students at these canteens, and therefore would not present an opportunity at these sites.

There were also significant opportunities identified in reducing surplus food through surplus food distribution. In India, sharing surplus food was a key opportunity identified by the Indian students to reduce FW. They considered the possibility for surplus food produced by the canteen to be collected by a local FW charity and redistributed to those in need.

> If there is food left over, we could transport it to food shelters or take it to NGOs to redistribute the food. There are NGOs who take this [5].

Alternatively, the UK University students identified opportunities for sharing surplus self-catered food to reduce FW. They discussed how surplus food from self-catered residences could be shared to stop this food from being wasted, however the exact means in which this could be done was deliberated. Ideas included having specific designated social media groups and a communal fridge in a common area for redistributing the food among fellow residents. Another idea was to use the APP Olio, which allows those registered on the app to donate, or collect surplus food from others in the locality within the network (Olio, 2018).

> We should have a common scheme for food that you don’t want that could be shared [1].

Sharing surplus food was not discussed in the Chinese interview, or focus group, but the redistribution of surplus catered food to charities may also present an opportunity at the Chinese University, albeit perhaps to a lesser degree than at Indian institute B.

Further opportunities to reduce FW were also identified in the form of improved food demand estimation, by having a system to identify how many students require meals on every given day. In India, both the focus group and the mess secretary at Indian institute B made suggestions on how to improve the estimation system to reduce the amount of surplus food that is also produced. Students suggested that the canteen should be informed during exam periods to cook less food, as there would likely be a lower demand for food. Furthermore, the

mess secretary suggested taking head counts during weekends and national holidays, so that food would not be produced for those who were away.

> Head count system on weekends or special days where we expect less attendance could help [6].

While these similar suggestions were not mentioned at the UK and Chinese Universities, such changes to food demand estimation could potentially bring about FW reductions in catering at these Universities.

3.2.4.6. Infrastructural opportunities to increase food waste recycling

As previously mentioned, due to all of the Indian and Chinese students being catered, and the canteen waste being recycled by the staff, there are only noteworthy opportunities to improve FW recycling at the UK University. At UoI, the main opportunities identified to improve FW recycling were changing the cleaning system at the UK University so that cleaners collected FW from residents' flats, potential new government policies making FW recycling compulsory and available through municipalities, and emerging FW treatment technologies.

Cleaning contract changes could present a key opportunity to increase FW recycling at the UK University, as advocated by the students and residential services. If cleaners collected FW regularly that would mitigate hygiene risks with residents not taking out bins and efforts needed to empty the FW bins. The UK University residents argued that if FW were to be collected by the cleaners, there would be no reason why residents should not recycle their FW, and that the scheme should change from being op-in to opt-out to make it a social norm at the residences and increase uptake. There will be the possibility to change the cleaning contracts in April 2021 when the current contract is up for renewal.

> It would make so much sense to have the cleaners empty the food waste bins as well. I think they were talking about this at some point. In which case our flat would definitely opt in [1].

Policy changes could also present a key opportunity for FW recycling at the UK University. Waste collection for some residences is under the remit of the local municipality. If the council does not offer FW collection for these residences then it is economically unviable. The residential managers believed that enormous benefits would come about from FW collection being rolled out across the country. Further still, if FW segregation were to become compulsory for large-scale institutions, as it is in India, FW recycling at the UK University would increase significantly.

> There's no legislation at the moment urging people on [2].

3.2.4.7. Infrastructural opportunities to improve food waste treatment

Numerous opportunities for improving FW treatment that were recognized at the different Universities. In the UK, at the UK University, FW treatment technology was also something that was identified as a key opportunity by the residential manager, with emerging technologies being seen to offer the potential to improve FW treatment.

> We're always on the lookout for technological advancements [3].

In China, the students and canteen manager went into more detail about the specific opportunities there may be in the field of sustainable FW treatment. The focus group suggested that the canteen could utilize the FW sustainably such as using it for feeding animals.

> The campus should take some action to treat this waste, or to feed pigs [8].

Alternatively, the canteen manager suggested that, the canteen has a specific issue with high-moisture FW, due to much of the FW being leftover broth, or soup. This in turn causes issues, as high-moisture FW is collected and transported long distances (33km), resulting in high transport emissions from FW treatment. They mentioned that they are considering purchasing a FW drying unit, similar to the desiccator being studied in this thesis that would separate the FW into a low moisture solid waste, and wastewater.

> We plan to install waste compression treatment equipment in the future to directly convert food waste into solid waste and wastewater [8].

The resultant, low moisture processed FW would lose most of its mass and volume. This would substantially reduce transport emissions associated with FW collection. Additionally, this processed waste could also potentially be used for incineration, or as an animal feed (as mentioned in section 2.6.6., describing potential uses of desiccated FW).

3.2.5. Current food waste management infrastructure conclusion

Differing FW management infrastructures in the Universities means that the extent of opportunities for improvements in different areas of FW management, such as FW reduction, FW recycling and FW treatment changes differ in each of the studied sites. The studied sites also have vastly different circumstances regarding how the universities function, how the waste landscapes differ in terms of policies, technologies and infrastructure, and how the wider cultures differ, creating different specific barriers and opportunities in optimizing FW management. The UK University has specific opportunities for improving the scale of FW recycling offered by the university to students as well as the uptake in FW recycling among students, due to most students being catered, whereas this is not a key opportunity in the other universities where most students are catered. Major economic and practical feasibility related issues occur because of UK-wide infrastructure and policies, meaning that a

governmental shift towards nationwide FW collection would be needed to see major progress. FW reduction however presents a greater opportunity in the Indian and Chinese Universities, as there is a greater level of FW produced on site per student, with all students typically being catered and large amounts of food produced by buffet style canteens in India, and pay as you go canteens in China. With the buffet system in India, larger amounts of surplus food can be distributed, and more FW reduction options are available such as reduced plate sizes. While in China, the ability to implement flexible portion options, with smaller portions being cheaper, could help reduce FW from plate scrapings accordingly. In the UK, at the UK University residence however, as meals are pre-paid, have a set price, it would be difficult to reduce FW from plate scrapings through flexible meal sizes due to students expecting good value for money.

The Indian universities typically treat their segregated FW in the most sustainable manner on site; however, any FW that cannot be treated on site is sent for open dumping, a process even less sustainable than landfilling. There is little to no opportunity for them to improve their FW treatment onsite therefore, but there could be a key opportunity in them having a better safety net in regards to treating FW that is not processed on site more sustainably, perhaps having their FW collected by a contractor and anaerobically digested, or composted offsite. On the other hand, the UK University and the Chinese University have their FW treated in using a sustainable technology; however, treatment is conducted offsite with substantial transportation. Transport emissions are particularly high in the Chinese University, as the treatment site is much further away when compared to the one treating the FW at the UK University. Here the greatest opportunities could be in investing in systems such as AD and composting that can process the FW on site. Furthermore, while it is not possible to process FW in the UK to make animal feed, it is possible to do this in India and China, thus this could offer a different and potentially more sustainable FW treatment option specifically in these countries.

3.3. Infrastructural implications of Covid-19 on food waste management

The Covid-19 pandemic has had major impacts globally causing large-scale lockdowns and other safety precautions in China from January, and in the UK and India from March (see section 2.5). At the times in which Covid was most prevalent in each country, the pandemic caused the universities to shut, or almost shut. All of the universities gradually started to reopen to differing degrees with various precautions being put in place before regional and national lifting of restrictions. These Covid-induced changes had significant impacts on FW

management styles, FW generation levels, the ability of universities to recycle their FW, and has led to numerous Covid-19 safety measures. Key Covid-19 impacts have been displayed in Table 3.6.

3.3.1. UK Covid-19 impacts

The UK University moved to remote learning and working in March, just before the national lockdown, while a very small number of mostly international students remained in their university accommodation including the UK University residence between March and August. The University reopened to near full capacity in September, when the University term ordinarily starts. A slightly reduced number of students returned to the University and their accommodations in September upon the start of the new academic year.

3.3.1.1. Impacts on campus-wide food waste generation

Regarding the impact of Covid-19 on total University-wide FW generation, Figure 3.1. shows pre-Covid FW generation before mid-March 2020 was higher (based on number of bin collections) than the levels recorded in 2019 with significantly higher numbers of collections between January and mid-March 2020. There was a steep reduction in FW collections since mid-March however, as Covid-19 became more prominent in the UK, culminating in a national lockdown being announced on the 23rd of March 2020, which resulted in the near total shutdown of the university. Between May and August 2020, the vast majority of the students had left the University and the University canteens were either shut, or running at a highly limited capacity meaning that FW generation and collection was negligible, when compared to the levels seen in the previous year.

In August, FW levels increased however with a gradual reopening of University canteens and then rapidly increased in September 2020, with the majority of students returning to the university. Overall, collection levels were higher in September and October 2020 than they were at the same time the previous year.

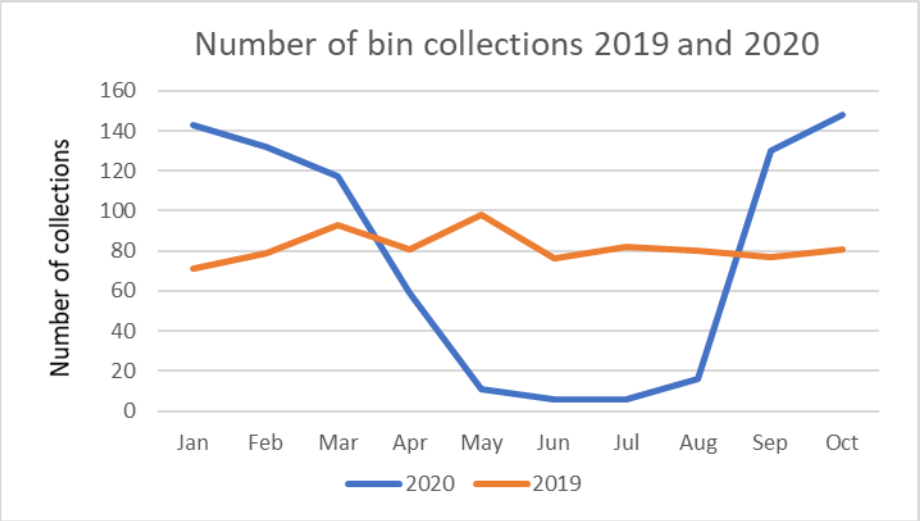


Figure 3.1.

Overall, it was estimated that there was a reduction in FW generation of over 75% in the most affected months between March and September 2020, due to significantly lower numbers of students and very limited catering services across the University, as shown in Figure 3.2.

3.3.1.2. Covid-19 related changes to campus-wide catering services

Regarding changes in catering at university canteens across the campus, all areas had to be signed off by Health and Safety as operating in a "Covid-safe" manner prior to reopening. Customer flow routes were all changed to ensure social distancing throughout the canteen routes. Queuing systems were also created outside the cafes with sanitising stations at the doors. As a result of the changed footfall and need to move customers through quickly, food offers were changed to adapt to this, with less 'build-your-own' type offers and more 'ready to go' options. In the Refectory, the number of serving stations were reduced due to the number of customers and social distancing requirements. Numbers of staff working in the front and back of house also had to reduce to enable safe working. A couple of FW minimisation strategies were adopted to limit FW while Covid-19 impacts were witnessed. The chefs switched to batch cooking, cooking smaller amounts at a time, which was reported to have reduced FW substantially. In addition, changes were made to use smaller display dishes due to the reduced customer numbers, so that less quantity of each dish is on display at a time, which also led to less wastage due to spoilage. Furthermore, food suppliers had limited stocks, which, in turn, determined menu choices. Moreover, since the start of the pandemic there has been an added emphasis on value for money and a need to secure good value food for students at a reasonable price.

3.3.1.3. Impacts on catering at the UK University residence

Regarding the impact of Covid-19 on FW generation specifically at the UK University residence, Figure 2 shows how FW generation changed at the UK University residence since the start of the pandemic.

The UK University residence FW initially increased at the time of reported panic buying, potentially due to self-catered students buying too much food, but then decreased significantly and became so low that collection was unviable during lockdown, due to low numbers of students remaining on site. This FW generation trend is in-line with the literature that showed initial increases, followed by decreases in FW post Covid-19 (Principato et al., 2020; Burlea-Schiopoiu et al., 2021). FW collection then restarted in September after the students returned for the new academic year. FW was at below average quantities due to changes regarding catered and self-catered residents, which will be discussed.

For those catered students who remained, there was a massively scaled down catering service delivering meals from central catering between March and September 2020. A number of Covid-19 measures were put in place, such as social distancing, mask wearing when unseated, sanitizing stations and the option to have food delivered to student's rooms. Since September 2020, the UK University residence canteen has been serving much lower numbers, with significantly less incoming students deciding to take a catered contract (80 instead of over 200), and with half of those catered students (40) requesting to be served their dinners in their rooms in the first few months of the 2020/2021 term. The head caterer observed that there was a lot less FW at the canteen, due to it being a lot easier to control the amount of food students require because of lower numbers of catered students. Thus, this reduced the amount of surplus food and plate scrapings. On the other hand, the canteen reported using a lot more food packaging due to meals being delivered to rooms; however, they were only using sustainable and compostable items. This means therefore, that there will have been an increase in highly lignocellulosic organic material within the food waste bins, which is suitable for composting, but not AD.

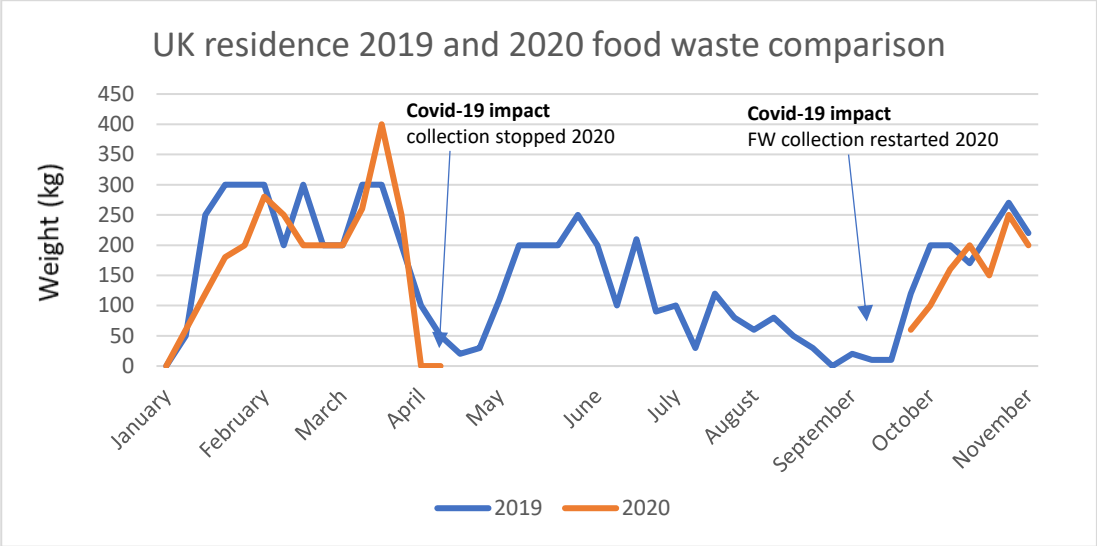


Figure 3.2.

3.3.1.4. Covid-19 impacts on self-catered students at the UK University residence

Regarding the impact of Covid-19 on self-catered students, FW segregation and collection ended in March, due to Covid-19. The vast majority of students left the UK University residence and the other University residences between March and September, with it mostly being international students remaining. There was a delay in giving FW bins to flats opting in to segregate their FW, due to Covid related health and safety concerns, meaning FW recycling was suspended for around a year. Additionally, there were more regular general waste bin collections and bins left outside the flats for those who were self-isolating due to suspected Covid cases. Another important development regarding catered students at the UK University was that the residential services collected unused non-perishable food from the University residences and were able to donate in excess of 565kgs of food to a food charity called the Horsforth Food Hub between March and August 2020. This in turn helped feed the hungry and greatly reduced FW on the sites, thus reducing related GHGs by over 1 tonne of CO_2eq (EC, 2010).

3.3.2. India Covid-19 impacts

3.3.2.1. Covid-19 related changes to campus-wide catering services

Indian institutes A and B shut in March 2020, with a limited number of postgraduate students and staff remaining on campus during the pandemic (until present). The canteens remained running at a very limited capacity, with reduced staff. Indian institute B was closed between the 24th March 2020 and 31st August 2020, with it partially resuming its functions on 1st September 2020 after easing of the lockdown restrictions, catering at around a third of its typical capacity. During this period, unfortunately, waste generation data was not recorded due to labour limitations and complexities in managing the work schedule, however it is

presumed that FW was lower than a third of the normal levels, due to the reduced number of students and other impacts of Covd-19. During the partial reopening of the Mess, COVID-19 measures were put in place, such as social distancing, glass compartment installation on tables, and a change from self-service to table service.

3.3.2.2. Impacts on food waste generation

Overall, it was observed that food waste generation decreased due to a number of reasons. Plate scrapings greatly reduced as table service made students feel more responsible to take appropriate amounts of food, as opposed to over filling it. Additionally, table service also made it more convenient for students to refill their plates, resulting in less plate scrapings from taking too much food. Limited food items on the menu meant that students were less likely to take food items they disliked and throw it away. Mess staff reported that Covid-19 led to increased awareness of the importance of health and an appropriate diet, resulting in more conscious food choices and reduced plate scrapings. The production of surplus food was also reported to have reduced due to Covid-19 related factors. A reduction in the amount of students being catered for meant that an exact account of students who were expected to have meals on given days could be made and thus lead to appropriate amounts of food being prepared in total. In addition, the reduced availability of options in which to take outside food meant that far fewer students skipped meals at the mess to eat outside, resulting in a significant reduction in over-catering. FW reduction interventions that were put up prior to the effects of Covid in the country were also noted to decrease FW, by increasing FW awareness.

3.3.3. Covid-19 impacts on China

China, being the country in which the first major outbreak of Covid-19 was detected, was the first of the studied countries to shut down, with a very strict lockdown and university closures being imposed in February 2020. The campus was shut from February 1, 2020 to May 19, 2020, and slowly reopened in May 20, 2020. In the first month, the students were asked to order meals in advance, pick them up from the canteen and eat in their accommodation. In the next 3 months, the students were asked to buy food in the canteen, but were not allowed to eat in the canteen. After that, the students were allowed to eat in the canteen with social distancing being observed, but nearly half of the students still chose to take out. The canteen manager observed that even by the end of 2021, figures dining in the canteen were around half of what they were pre-covid, with FW from the canteen also approximately halving. Social distancing was still being implemented by the end of 2021 also. The canteen manager also drew attention to the fact that, because around half of the food was being eaten outside the canteen, this waste was no longer being recycled. It is possible that FW will have stayed the same, but the

FW would instead would be put in general waste bins and be landfilled, rather than anaerobically digested, thus leading to an overall increase in associated GHGs

Table 3.6. Key general information on infrastructural impact from Covid-19

Covid-19 impacts	UK University and residence	Indian institute A	Indian institute B	Chinese University
Date of closure	March	Assumed same as Indian institute B	24th March 2020	from February 1, 2020
Date of reopening	September	Assumed same as Indian institute B	1st September 2020	May 19, 2020
Impact on number of students	The UK University significantly reduced. Mostly international students remaining (around 95% of all students). • 28/03/20: 1,366 all residences, 51 at the UK University residence. • 03/04/20: 705 all residences, 34 at the UK University residence. • Aug 2020: 578 all residences, three at the UK University residence.	Assumed to be similar to Indian institute B	Empty during lockdown (March-August) About 1/3rd students returned after lockdown (Sep) Full functioning expected December 2020	Reduced capacity of around 5% of total during initial reopening (Spring). Returned to around half capacity during summer 2020, and stayed at this level until early 2023.
Impact on FW produced	A lot less food wasted between March and September, as less students and FW easier to control.	Assumed to be similar to Indian institute B	A lot less FW, as easier to control and impact of FW reduction interventions	A lot less food wasted when reopening, due to serving less students. FW at canteen halved after canteen fully reopened (compared to pre-covid), as half FW taken out of canteen (takeaway).
Impact on catering	The UK University • Reduced capacity, Covid-safe, shut during lockdown. • Numerous Covid-19 safety precautions • Reduced choice of food supplies resulting in reduced menu options • Increased emphasis on value for money The UK University residence • Limited service and delivered meals from central catering during the pandemic due to low numbers • Serving a quarter of our usual numbers (Usually up to 260 this year about 80) · 40 students had food delivered to rooms.	Assumed to be similar to Indian institute B	Mess-C was partially functional under COVID-19 restrictions • such as social distancing, • glass compartments installed on tables, • Self-service changed to table service • 3rd capacity of students • Less surplus food as limited options for students to eat outside Limited food items on plate, meaning less plate scrapings	Covid-19 restrictions implemented: • Such as social distancing • Initially all meals needed to be pre-booked • Initially all meals needed eaten elsewhere (takeaway) • Lasting demand for takeaways, and subsequent reduction of students eating in canteen
Impact on self-catering	• Delay in giving FW bins, due to health and safety. • More regular collections and bins left outside door due to isolating flats.	N/A	N/A	N/A
Impact on FW treatment	• Specific FW collection became unviable and stopped at certain sites (i.e. the UK University residence) for 5 months. o Led to reduced FW recycling with FW in general waste.	Impact on AD and composting	Less FW for composting Less staff for conducting composting	Half of canteen FW not recycled, as food is taken away, out of canteen and put in general bins, where FW is landfilled.

3.3.4. Covid-19 impacts conclusion

Covid-19 clearly had a great effect on how FW has been managed in the different universities being studied. In all countries, Covid-19 has led to a number of adaptations needing to be made in the way FW management is run, including changes in catering and self-catering. In all of the countries, overall FW levels were reported to have decreased among catered students due to a combination of Covid-19 related measures. In India, a switch to table service, a lack of alternative eating options and a simplified menu led to reduced plate scrapings and food surpluses, while in the UK a reduction of students on campus and canteen closures led to reduced FW, and implementing new FW minimization strategies allowed for further decreases in FW levels. At the UK University residence, the introduction of room service allowed for better portion control, which led to reduced plate scrapings, and food surpluses that was reported to have led to FW reductions. With this being said, food packaging has increased changing the composition of the organic waste produced, thus creating more material that is compostable. Similar to the UK University, FW in the Chinese University canteens has reduced since Covid, with there being fewer students eating at the canteen immediately after reopening, while FW collected in the canteens has approximately halved post-covid as around half of the customers takeaway their food and dispose any FW in general waste bins on campus.

Regarding self-catered UK students, FW initially increased with reported panic buying, but then decreased with fewer students being on site and with surplus food being redistributed to a local food charity. A change in behaviour, with students wasting less food due to increased awareness of FW has been anecdotally reported by canteen managers and reported amongst households in the literature (Principato et al., 2020; Burlea-Schiopoiu et al., 2021). However, this is something that needs to be further explored. On the other hand, the reductions in FW generation made FW collection unviable for waste contractors, leading to FW collection being suspended at the UK University residence for around 5 months while most students were away from the university. In addition, self-catering FW recycling was suspended in the UK University residence for around a year, due to Covid-19 and safety concerns, meaning a significantly lower proportion of FW has been recycled on site since the pandemic started. Additionally, at the Chinese University around half of the FW from canteens is being disposed of in general waste bins post-covid, meaning that this FW is being treated much less sustainably (landfilled as opposed to anaerobically digested). Overall, it is clear that Covid-19 has brought about a range of benefits, as well as challenges to FW management at Universities in the studied countries. Moreover, it is unclear whether the pandemic will have long-term consequences on FW management in universities in the future and if so, what the nature of these may be.

3.4. Food waste characterization

Composition of the FW in the different sites may affect the performance of the different FW treatment technologies being assessed at the respective universities. Table 3.7. shows the different physical, elemental and biochemical properties at the UK University and Indian institute A. It also includes figures for BUCT, a Beijing based University which was deemed to have a similar food waste composition to that of the Chinese University, due to it being a large, diverse university, located in a similar area (a large city in N.E China near to the coast) (Chen et al., 2016).

3.4.1. Physical food waste properties

Physical FW properties include moisture contents, volatile solids, ash and more. Regarding physical properties, the FW from the UK University has the lowest moisture content of the countries studied. This means that the FW will require less energy to dry, thus making it likely that the UK FW would be more suitable for straight incineration, or desiccation and subsequent use for combustion and AD. Comparatively, the Indian and Chinese Universities have higher moisture contents. With high moisture FW, desiccation will lead to greater reductions of transport emissions, especially with the longer transport distances associated with FW treatment at the Chinese University. As a result, if the energy required for desiccation was gained from renewable energy, desiccation could show the greatest benefits at the Chinese University. Additionally, as the carbon and nitrogen contents in the table are measured on a dry basis, the higher moisture content of the Indian and Chinese FW will mean that, if landfilled emissions from the degradation of the carbon and nitrogen will be lower than if it had a lower moisture content.

3.4.2. Elemental food waste properties

Elemental properties concern what elements the material is made from, such as carbon, hydrogen and nitrogen. The FW from the UK University and BUCT have higher levels of carbon than Indian institute A in India. High carbon levels indicate good fuel products in terms of having a higher energetic potential, while high carbon levels are also preferable for soil amendment products, meaning the UK FW would likely perform well when assessing desiccation, HTC, combustion, AD and composting. However, the C/N ratio is also important for AD and is ideally between 20:1 and 35:1. The Chinese FW is closest to the middle of this range (23:1) therefore this FW may be the best suited to AD, however the Indian and UK FW is also within the preferred range, 20.5:1 and 22:1 respectively, thus C/N ratio should not be an issue at any of the studied universities. In addition, UK FW at the UK University has the highest nitrogen levels. High nitrogen levels are preferable for soil amendment and fertilizer

production, meaning that the UK University FW may be more suitable for composting and HTC for soil amendment. Conversely, High nitrogen levels are problematic when combusting the materials, due to a production of noxious gases, meaning that the combustion of the Indian and Chinese FW would be less problematic than with the UK FW in this regard. Additionally, high nitrogen and carbon levels result in higher GHGEs when landfilling the waste, meaning that landfilling the UK University FW would result in particularly high GHGEs, as it has both the highest carbon and nitrogen content. With the Chinese and Indian FW having comparatively lower nitrogen contents than at the UK University, lower noxious emissions and GHGEs would be expected with combustion and landfilling respectively, while the lower carbon content of the Indian FW means it would have the lowest landfilling emissions from degradation.

3.4.3. Biochemical properties

Biochemical composition concerns the presence of biological molecules such as proteins, fats and carbohydrates. Regarding biochemical composition, the Chinese FW has a particularly high fat content. Typically, high levels of fat typically indicate high energy densities, therefore the Chinese FW is likely to be a good feedstock for AD and combustion. Additionally, the Indian FW has high protein levels. Hydrochars with high protein and fat contents typically produce more energy (Li et al., 2020). This means that biochemical factors could improve the performance of both HTC with combustion, as well as desiccation with AD with the Chinese and Indian FW. On the other hand, the UK FW has a comparatively low fat and protein content that may make it more suitable for conversion into a soil amendment product, or animal feed (Salemdeeb et al., 2017).

3.4.4. Energy content

Energy content concerns the amount of chemical energy that can be released from the FW through chemical processing. It was only possible to gain the actual HHV of the UK FW, however it was possible to gain the theoretical HHV through using Friedl et al. (2005) (Equation 3.1.) equation and adjusting the HHV based on the difference between actual and theoretical HHV for the UK FW. It was assessed that the Indian FW has the highest HHV and thus would theoretically produce the greatest amount of energy when desiccated and combusted, while the UK FW was assessed to have the lowest HHV and would generate the lowest levels of energy per dry kg of FW. With this being said, the UK FW has the lowest moisture content, thus would have the potential to generate the greatest amount of energy per tonne of FW as received.

$$HHV = 3.55Cx^2 - 232C - 2230H + 51.2 \times H + 51.2C \times H + 131N + 20600 \qquad (3.1.)$$

Table 3.7. Key differences in FW characteristics

Lab work type		**UK University**	**Indian institute A** Gupta et al., 2019	**BUCT, China** Chen et al., 2016
Proximate Analysis	Moisture (%)	70.3	75 ± 0.93	75.7
	TS/VS	92.87	93.2 ± 0.11%	92.59
	Fixed Carbon	4.85	5.0 ± 0.21	
Ultimate analysis,	Carbon %	52.14	50.6 ± 0.46	53.39
	Hydrogen %	8.43	6.6 ± 0.25	6.93
Ultimate analysis, Biochemical analysis	Nitrogen %	2.54	2.3 ± 0.36	2.31
	Sulphur %	0.09		0.22
	Oxygen %	44.3	39.0 ± 0.60	29.75
	C/N ratio	20.52	22	23.11
	Protein	15.87%	20.4%	14.42%
	Fats	19.70%		24.1%
Biochemical analysis Energy content	Ash	2.28	5.0 ± 0.21	1.8*
	HHV	21.29MJ/Kg	20.34 MJ/Kg*	20.33MJ/kg*
	HHV adjusted*	21.29MJ/Kg	21.3356 MJ/kg*	21.3214 MJ/kg*

*HHV for Chinese FW estimated using equation from Friedl et al. (2005)

*HHV adjusted based on the difference between estimated and actual HHV for the UK University

3.4.5. Food waste characterization conclusion

It is clear that the different universities have significantly different FW characteristics. As the UK FW has the lowest moisture content, it would logically perform significantly better when incinerated, especially if it was desiccated, or hydrothermally carbonized prior to incineration. On the other hand, as the Indian FW would have the highest estimated HHV when dry, it could also be well suited for incineration after desiccation, or HTC. The high carbon and nitrogen levels in the UK FW means that the UK FW should perform the best as a soil amender too, while Chinese FW may also be well suited for conversion to a soil amender, in particular peat substitution, due to it having the highest carbon content of the FW. Additionally, the Chinese FW would likely be well suited to AD, due to it having the most optimal C/N ratio. Furthermore, it is likely that the environmental impacts from landfilling per quantity of Chinese and Indian FW (as received) would be less than the UK FW, due to the higher moisture contents.

3.5. General conclusion

At the UK University there appear to be significant opportunities for increasing food waste recycling, which are not applicable at the Chinese and Indian Universities, due to there being no self-catered Chinese and Indian, and all university canteens recycling their food waste. With this being said, the creation of new governmental policies could ensure food waste recycling is offered by all municipalities in the UK and to insist that all organizations recycle their waste, so

that the FW recycling opportunities can be achieved. There also may be particularly good opportunities for treating the food waste at the UK University for use as soil amendment, or as a fuel after hydrothermal carbonisation, or desiccation, because of the composition of UK food waste.

At the Indian Universities (Indian institute A and B), there are particularly good opportunities to reduce food waste, due to the fact that all students are catered and have a buffet style system meaning that the introduction of a greater variety of food waste reduction interventions would be possible. In addition, there are substantial opportunities to reduce food waste at Indian Universities by starting to redistribute plentiful end of service food surpluses to local charities. Concerning food waste treatment opportunities, there are significant opportunities for animal feed production, in particular at Indian institute A, due to source separation of vegetarian food waste and having livestock on campus. Additionally, there are major GHG reduction opportunities at Indian institute A for having food waste that cannot be processed on site collected and being anaerobically digested, instead of open dumped.

In regards to the Chinese University, there are significant opportunities to instigate flexible meal portions in their canteens to reduce food waste from plate scrapings. Additionally, due to the large distances associated with getting the food waste to the treatment site at the Chinese University and the high moisture levels, there would be particularly large benefits with processing the food waste sustainably on site, or desiccating the food waste on site using renewable energy. Alternatively, food waste desiccation, a technology Jinan campus canteen is considering implementing, could also provide a substantial opportunity to reduce transport emissions due to the high moisture nature of the food waste and food waste treatment transport distances. Furthermore, as a lot of canteen food waste is now disposed of outside the canteen post-covid, due to an increase in takeaways, improvements in the treatment of general waste at the University, such as incineration, as opposed to the current choice of landfilling could bring about significant environmental benefits for food waste disposed in general waste bins on campus.

The Covid-19 pandemic has affected student numbers and catering systems. The pandemic has led to reduced number of students and reduced FW in the institutions. This appears a positive development; however, it is possible that much of this FW is still being generated just outside the university system with takeaways and students remaining off campus. This would mean that the FW may instead be moved to public and household bins where the FW is likely not recycled. Additionally, issues regarding health and safety and small quantities of FW have led to practical and logistical issues with FW treatment, leaving a lot of FW on campus to be

unsegregated and treated less sustainably. It has also resulted in an increased stream of food packaging. In addition, the long-term implications of Covid-19 on food waste management remain unclear; however, the literature and anecdotal information suggests that Covid-19 may make individuals more aware of food waste, leading to food waste reductions. Covid-19 may also reduce demand for eating out thus increasing those eating at home. Specifically, there has been a reduction in catered students at the UK University post-Covid, a trend that may be seen across universities where self-catering is an option. Covid-19 has also led to significant reductions in per capita food waste at the Indian University, while it has led to increases in takeaways at the Chinese University. While the impacts are different across the Universities, Covid-19 has generally led to a reduction in food being disposed of specifically in the studied canteens, and thus reduced the amount of food waste that needs to be collected at the canteens. Covid-19 also may lead to changes in food waste composition, due to differing diets, that may make the waste a better fuel source. The longevity of these trends remains uncertain however.

This chapter has helped glean insights into food waste management issues, opportunities for improvements and site-specific issues encountered at the studied sites. It is however necessary to go deeper into food waste related behaviours in the Universities and understand the precise impact of food waste reduction and segregation interventions at the sites. In addition, the specific impacts of Covid-19 on food waste behaviour need to be further studied. Moreover, the implications of site-specific differences in food waste and food waste management, as well as Covid-19 related impacts need to be studied further through conducting thorough environmental assessments.

CHAPTER 4: BEHAVIOURAL CHANGE

4.1. Introduction

Vast quantities of FW are generated at UK, Indian and Chinese university canteens and residences with a lack of recycling in residences, leading to substantial environmental and economic issues (Reynolds et al., 2019; Abrahamse and Steg, 2013). There is little consensus however as to the best FW reduction and recycling strategies to implement, as FW related behaviour is little understood and differs in different countries (Mattar et al., 2018; Mak et al., 2020). Concerning FW reduction at university canteens there is a dichotomy that students are expecting value for the money they are paying for their catering; while in residences universities need to balance sustainability with student satisfaction. Consequently, some of the more orthodox FW reduction measures may be seen to decrease student satisfaction and the quality of the service provided (Zhang et al., 2021; Matzembacher, et al., 2020).

With this in mind, this Chapter aims to achieve objective 2 of the thesis by gaining experimental behavioural change data at a UK University, Indian institute and Chinese University. This comprised of three sub-objectives. The first sub-objective of this study was to gain insights into the food waste generation behaviours of students, how they differ between the different institutions and how they are affected by the interventions. This was done through use of surveys and focus groups on students, as well as semi-structured interviews on canteen staff at both universities. The second sub-objective was to assess the percentage of total FW that could be reduced by introducing printed informative and prompt information on FW generation, through assessing changes in FW generation after introducing the interventions. The third sub-objective was to assess the percentage increase in FW segregation that could be achieved through behavioural change interventions. This was measured through assessing changes in FW generation (assumed any FW generation increase was due to FW being diverted from general waste) after the introduction of oral information, fridge magnets, reminder emails and public pledges in the UK university residence.

Following this introduction section, the experimental design of the study is explained, including the study setting, survey, focus group and interview methodologies, alongside what the behavioural change interventions and covid-19 impacts comprised of, and how FW generation and recycling levels were measured. The qualitative and quantitative results gained are then presented. Following this, the results are then discussed, including differences between the UK, Indian and Chinese universities, and the study findings are then compared to literature.

4.2. Methodology

As discussed in the literature review, it is possible to change the behaviour of individuals in order to improve waste management, through reducing FW and increasing segregation. Surveys and interventions were carried out in order to achieve objective 2 and address one of the project aims which was to understand the feasibility, environmental and economic issues associated with behavioural change. Methods were based on similar studies in the literature.

4.2.1. Setting

The work was carried out in the UK University Halls of Residences in Leeds, as well as in an Indian University canteen in Mumbai (Indian institute B, Mess C), and the Chinese University canteen, in Jinan.

In the UK, the residence researched is a mixed gender residence and has a population of around 550 students, comprising of both catered and self-catered residents. No significant FW reduction strategies had been carried out prior to this research at the UK University residence. The UK University residence carried out FW segregation on an opt-in basis but without interventions to increase segregation prior to this research. The FW reduction interventions involved the catered students and was based in the residents' canteen, whereas, the FW segregation interventions were introduced to the self-catered residents in the communal areas, as well as the self-catered flats. The catered students eat at the residence canteen with set meals and a self-service salad bar paid for as part of their accommodation package.

In India, Mess C (Indian institute B) is a male only canteen in a male only residence and has a population of around 400 students. FW reduction interventions were carried out on catered students. No significant FW reduction strategies had been carried out prior to this research. Catered students have semester fees in advance for all you can eat buffet style catering.

In China, the canteen at the Jinan campus of the Chinese University is a mixed gender canteen and typically caters for over 1000 students each day. It was not possible to carry out FW reduction interventions there due to Covid-19 related travel restrictions. No significant FW reduction strategies had been carried out prior to this research. Catered students bought food on a pay-as-you-go basis.

4.2.2. Survey

A 20-question survey was developed and carried out to try to ascertain FW related behaviour (Appendix A1). The survey was adapted from a study by WRAP (2007) that looked at FW related attitudes and behaviours in UK households, and was revised based on feedback after pilot testing. It comprised of three sections. Section 1 involved shopping habits and assessed

how frequently individuals went shopping such as weekly and top up shopping. Section 2 involved shopping habits and routines where participants were assessed for their shopping habits and FW minimisation skills. Section 3 involved cooking and eating habits in the home, which helped in understanding the behaviours and FW attitudes of the participants. This included how much they wasted and what caused them to waste food. Section 2 and 3 helped identify why food was being wasted and what more could be done to reduce FW. Finally, there were some questions regarding socio-demographics that were adapted from a study by Bernstad et al. (2013) that looked at the impact of providing educational information on FW related attitudes.

Both pre and post-intervention surveys on self-catered students were conducted in person at the UK University residence in the common area at food waste events where free pizza was offered, while pre-intervention surveys on catered students in the UK and India were conducted in person at the canteens. On the other hand, all post-interventions surveys on catered students, as well as pre-intervention surveys in China were carried out online on JISC; an online survey tool designed for academic research, as conducting surveys in-person was not possible due to Covid-19 social distancing rules. A random mixture of male, female and non-binary undergraduate students were surveyed in the UK University, including UK, EU and non-EU nationals with the socio-demographics displayed in Table 4.1. Random mixtures of catered students were also surveyed in China and India; however, Indian students only comprised of male Indian nationals, while Chinese students comprised of male and female Chinese nationals with a mixture of undergraduate, master's and PhD students. Socio-demographics are displayed in Table 4.1. The survey results focus on the pre-intervention surveys only, as all of the post-intervention had under the 31 required to be statistically viable.

Table 4.1. Socio-demographics of students surveyed.

Socio-demographics	UK self-catered	UK catered	Indian catered	Chinese catered
Sample size (n)	39	31	32	52
Gender				
Male (%)	43.5	48.5	100	71.2
Female (%)	56.5	45		28.8
Non-binary (%)	0	6.5		
Level of study				
Undergraduate (%)	100	100	100	5.8
Masters' (%)				59.6
PhD (%)				34.6
Nationality				
UK (%)	82	48.5		
EU (%)	13	31		
Non-EU (other than UK) (%)	5	20.5		
Indian (%)			100	
Chinese (%)				100

4.2.3. Semi-structured interviews and focus groups

Semi-structured interviews and focus groups, as described in section 3.1.4. were conducted in order with an aim to gain insights into behavioural change and FW management. The semi-structured interviews with canteen staff, as well as the focus groups with students at the UK University, Indian institute B and the Chinese University helped gain a deeper understanding into behavioural related reasons for FW generation. They also helped offer insights into why students do, or do not recycle FW**,** what impact the FW reduction and segregation interventions had, and what behavioural change-related opportunities there are in FW management. The interviews and focus groups were conducted in person in the UK and India, but online on Zoom in China, due to Covid-19 travel restrictions.

In the UK, the focus group consisted of six catered and self-catered students, including students that opted in to segregate their FW and those who did not. In India and China, the focus group consisted of five and eight catered students respectively. The first part of the session concerned participants' general attitudes relating to FW.
The second part discussed FW reduction strategies and impacts of the related interventions. The third part considered FW recycling among self-catered students and related interventions, but this section was only included in the UK University, due to their being no self-catered students in India and China. The final part inquired about their views on the current FW management strategy that is in place in their University. Additionally, to gain further insight into the institutional FW management practices, semi-structured

interviews were carried out with the head caterer at the UK University Hall of Residence being researched, as well as residential managers at the UK University. In India, an interview was conducted with the mess secretary, while the canteen manager was interviewed at the Chinese University. These interviews were carried out with an aim to give an in-depth insight into the roles of different key actors at the University, the specific challenges and opportunities they have in their particular job roles, the key policies and drivers regarding sustainable FW management practices and the rationale behind current practices at the University (see appendix D). The categorization of the participants and themes identified are displayed in Table 4.2 and Table 4.3 respectively. The themes are discussed below. Where appropriate, post-intervention survey results are mentioned to support the findings of the interviews and focus group.

Table 4.2. Key categorization of participants

Number	Country	Organization	Role	Format
1	UK	UK University/residence	Students	Focus group
2	UK	UK University	Residential property manager	Semi-structured interview
3	UK	UK University	Senior residences manager	Semi-structured interview
4	UK	UK University/residence	Residences head caterer	Semi-structured interview
5	India	Indian institute B/Mess	Students	Focus group
6	India	Indian institute B/Mess	Mess secretary	Semi-structured interview
7	China	Chinese University canteen	Students	Focus group
8	China	Chinese University canteen	Canteen manager	Semi-structured interview

Table 4.3. Key themes identified

Theme	Description
(1) **Reasons for FW**	Concerns how FW is generated, where it is generated and why.
(2) **Reasons for not recycling FW**	Considers what the key barriers are for rolling out FW recycling across the University and what the main reasons are for residents not recycling their FW when the option is available.
(3) **Motivations to tackle FW issues**	Considers why residents and responsible staff at the University see FW as a problem and what they hope to gain by actively trying to tackle FW issues.
(4) **Key opportunities to mitigate FW issues**	Identifies ways in which FW management could be improved at the University.
(5) **Effect of behavioural change interventions on FW reduction and recycling**	Explores the impact of FW interventions on FW related behaviour.

4.2.4. Food waste reduction interventions

4.2.4.1. Awareness campaign

Four interventions were carried out at both the UK University and Indian institute B to try to reduce the amount of FW generated in the university canteens, with specific aims to ascertain

the extent to which FW interventions can reduce FW in cafeterias, and which of the interventions are the most effective.

The interventions included informative place cards, salient signs, and poster prompts, as well as posters providing group feedback [examples shown in Appendix A4]. The difference between the baseline and experimental FW generation quantities showed the extent to which the interventions affected FW generation in the canteen. The post-intervention survey asked which of the interventions the participants noticed and which they found most effective, with an aim to identify which of the interventions was the most influential.

Four informative table cards were placed on each table in the canteen to reduce FW, as based on a study conducted by Manomaivibool et al. (2016). Salient signs telling students not to overfill their plates were placed by the serving tables and bins, as based on a study by Kallbekken and Saelen (2013). In addition, a mixture of A3 and A2 prompt posters telling students to reduce their FW, and posters with group feedback on quantities of FW generated in the canteens with relatable environmental and social impacts were displayed throughout the canteen to reduce FW, as based on a study conducted by Whitehair et al. (2013).

4.2.4.2. Covid-19 implications in Indian University canteen

At Indian institute B, the same interventions were carried out with the same aims and using the same methodology as was used for the UK University canteen, as described in the UK FW reduction interventions section. With this being said, as the post-intervention data was gained post-Covid-19, infrastructural changes related to the running of the canteen were introduced due to Covid-19, that were reported by canteen staff to have had an impact on FW generation. The Covid-19 pandemic led to numerous changes. This included a change from self-service to table service, with portion control from serving staff and increased ease in refilling plates. It also led to limited food items being on the menu, increased FW awareness due to the Covid-19 situation, improved food demand estimation due to Covid-19 and an exact account of students' whereabouts, reduced outside catering options, leading to fewer students opting for external catering. These changes were reported to have led to a reduction in FW generation in the canteen.

4.2.5. Food waste Segregation interventions

Four interventions were carried out in order to try to increase the amount of FW that is segregated in the UK University residences. The data gained was used to ascertain to what extent FW interventions could increase FW segregation in the Halls of Residences, and which of the interventions was the most effective.

The interventions included the provision of oral information, conducting public pledges, placing fridge magnets in apartments and sending email reminders, whilst working with a block

leader to try to increase FW segregation in the residences [examples shown in Appendix A5]. These interventions were carried out after gaining the typical FW generation levels for the previous month. The pledges and oral information provision were conducted immediately after the baseline data was gained and pre-intervention survey was carried out, while the fridge magnets were also put up at this time. The email reminders were then run bi-weekly. The experimental data was gained for 1 month. The difference between the baseline and experimental FW generation quantities showed the extent to which the interventions affected FW segregation in the residences, with it being assumed that any increases in FW generation were resultant from an increase in segregation leading to FW being placed in the FW bin as opposed to the general waste bin. The post-intervention survey asked which interventions participants noticed and which they found most effective, which helped identify which of the interventions were most successful.

Oral information was provided to residents of the Halls of Residences to increase FW segregation, as based on studies by Bernstad et al. (2013) and Burn (1991), (see section 2.8.6.2) where they successfully used these methods on apartments and households to increase waste segregation. Hard-hitting facts about the extent of FW, the environmental impact, economic impact and social issues were provided based on a script that was produced. This information had a key focus on the specific benefits of waste reduction, and the benefits of segregation. It also included what happened to both the general waste and FW, as well as how residents could help with FW segregation and reduction. I and a block leader (leader of the social circle at the residences) provided information for the intervention. The oral information was provided during a designated FW event in the main common area of the residence.

Public pledges were also proposed to the residents to increase FW segregation. This intervention was based on studies by Burn and Oskamp (1986), as well as Wang and Katzev (1990) where they found that public commitment making resulted in an increase in waste segregation (see section 2.8.6.2). This intervention was also conducted at the FW event in the common area. Groups of residences were approached and asked whether they would be prepared to make a pledge to reduce FW and to opt in to FW segregation. The pledges were proposed by me.

Fridge magnets were also introduced to increase FW segregation, as based on a study carried out by Shearer et al. (2016), where stickers were used to increase segregation of waste in UK households (see section 2.8.6.2). They were placed on each fridge in each flat within the

researched Hall of Residences. They prompted the residents to put FW in a FW bin instead of a general waste bin, with my contact details provided as a source for further information.

Reminder emails were sent to residents to increase FW segregation, as based on a study carried out by Hopper and Nielsen (1991), where email reminders were used to increase recycling rates in US households (see section 2.8.6.2). Emails were sent every 2 weeks reminding students to segregate FW, in order to increase FW segregation. Emails included group feedback on changes in segregation, stating increases and decreases in quantities of FW segregated over the course of the interventions.

4.2.6 Research methodology framework

A research methodology framework figure (Figure 4.1) was created to illustrate how the aims and objectives marry up to the methodology, and how the overall research methodology used in this Chapter could be adopted and replicated to increase understanding of FW reduction and recycling among dissimilar sample groups. FW reduction and recycling methods, such as those used in this research can be utilised to create quantitative data that can be analysed to calculate the extent to which these methods can reduce FW and increase FW recycling. Coinciding with this, attitude and behavioural methods, such as surveys and interviews can be used to derive quantitative and qualitative data respectively, which can then be analysed to understand how and why there are dissimilarities among different sample groups, and what implications these differences may have on improving FW minimisation in the various settings. An arrow between the outcomes is used to symbolise how the methods can be used in conjunction with each other to create more diverse and complete findings.

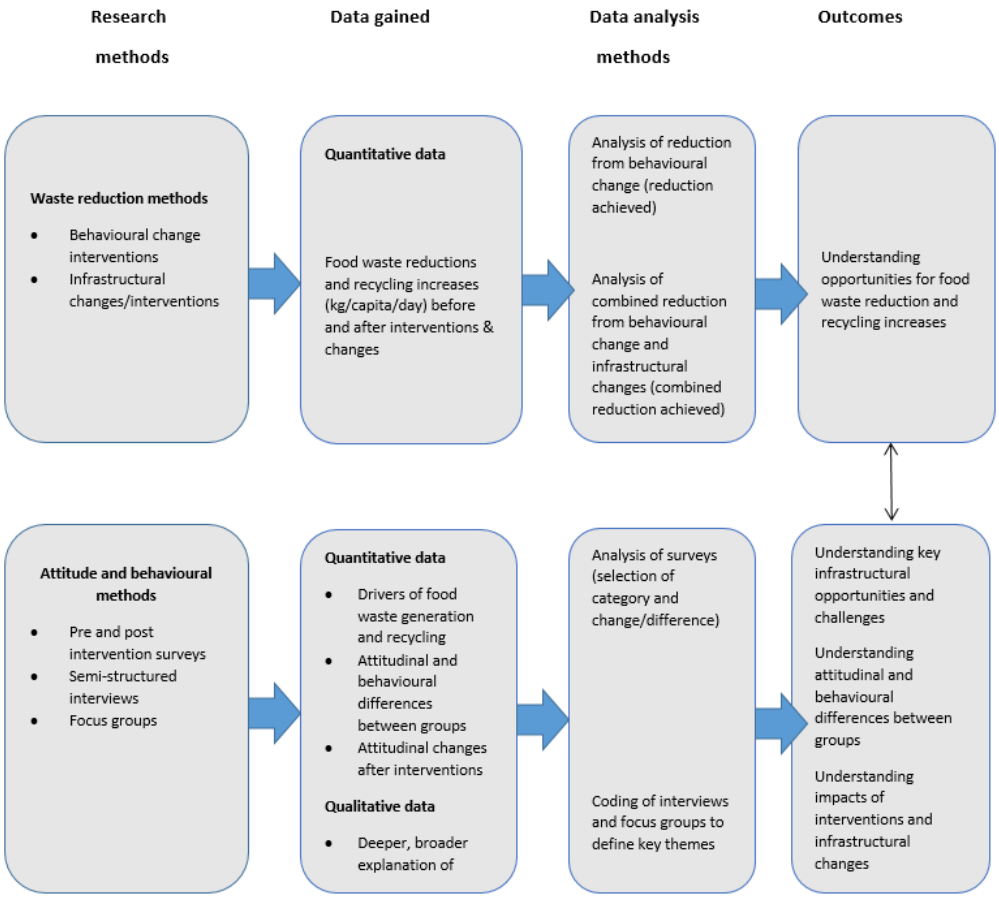


Figure 4.1.

4.3. UK

4.3.1. Survey

4.3.1.2. Self-catered UK

Causes of food waste and quantities generated

Regarding self-perceived FW generation, most self-catered students believed that they wasted small amounts, hardly any, or no food at all (66.5%) as shown in Table 4.4. This shows that a slight majority of students do not consider themselves wasteful, while around a third (33.5%) reported themselves to waste 'some', 'a reasonable amount', or 'quite a lot' of food.

Participants were asked the main reasons why they wasted food when they shopped, stored, prepared and ate food, out of a list of possible options as presented in Table 4.4. The main reason for FW generation was trying to buy more fresh food when shopping. This was followed by not eating the foods that needed to be eaten first when concerning the storage of food, allowing food to visibly go bad or smell bad when concerning the preparation and cooking of food, and food not tasting good when concerning the 'eating food and lifestyles' category.

Overall, this shows that a lack of meal planning (especially for fresh foods) and cooking skills were the key causes of FW.

Participants were asked whether they ate past the dates on the labels for food items, with the results illustrated in Table 4.4. Pre-intervention, the majority of students only occasionally ate past the date of the label, or never ate past the date (56%). This shows that most students were wary of eating food that may have gone bad, which consequently will have led to large amounts of perfectly good food being wasted.

Table 4.4. Self-catered UK students- Causes of FW and quantities generated

How much uneaten food – overall - would you say you throw away in general?	
	Pre-intervention (%)
Quite a lot	5
A reasonable amount	7.5
Some	20.5
A small amount	28
Hardly any	31
None	7.5
Which of these would you say are the main reasons why you throw away food?	
Shopping for food	
Buying too much when shopping	2.5
Not making a list before shopping	2.5
Not sticking to a list in the store	5
Tempted by "multi-packs"	5
Tempted by cheaper products approaching their "use by" date	5
Trying to buy more fresh food (that doesn't last as long)	18
Portion sizes of products are too big	10.5
Don't check the "use by" or "best before" dates in store	2.5
Buying takeaways and not eating everything	0
Storing food	
Needing to make space in the fridge/cupboards for new things	2.5
Not eating the foods that need to be eaten first	20.5
Not keeping the fridge cold enough	5
Not knowing the use by dates of products in fridge/cupboards	5
Not always sure of how to store certain products	5
Doing a 'spring clean' of the cupboards to get rid of old products	0
Not resealing/repackaging opened products so they stay fresh	10.5
Preparing and cooking food	
Not planning meals	5
Food gone past its use by or best before date	7.5
Food visibly gone bad or smells bad	25.5
Food not visibly bad but not worth the risk	0
Food burnt/ruined during cooking/preparation	0
Experimenting with new ideas/ingredients	2.5
Need more recipes and ideas for using food	2.5
Lack of confidence in combining leftovers to make a 'new' meal	2.5
Don't like cooking with leftovers/eating leftovers	2.5
Eating food and lifestyles	
Food didn't taste good	18
Made too much food	10.5
Not enough time	2.5
Plans change in the week/can't plan	13
Thinking about how you use best-before dates, which of the following statements best describes you?	
I never eat past the date on the label	23
I occasionally eat past the date on the label	33.5
I often eat past the date on the label	10.5
I don't look at the date on the label	2.5
I don't eat this food	2.5
Don't know	0

Extent to which students were bothered by food waste and why

When considering the extent to which the self-catered students were bothered by FW, the majority of those surveyed pre-intervention were bothered a great deal, or a fair amount (76%) as displayed in Table 4.5, showing residents were, overall, concerned about FW.

Participants were asked to select one, or more reasons why they were bothered about FW, they stated wasting money was the main concern (69% of all those surveyed) as shown in Table 4.5. Feelings of guilt (53.9%) and considerations for the environmental impact (46.3%) were the second and third most selected issue with FW respectively. Altogether, the students were most bothered about economic issues, followed by social/ethical issues, and then by environmental issues related to FW, with other FW-related concerns such as hygiene and wasting time being considered less important. A larger sample size would be required to understand if these behaviours are ubiquitous throughout the University however.

Table 4.5. Self-catered UK students- Extent to which students were bothered by FW and why

When you have to throw uneaten food items away, to what extent, if at all, does it bother you?	
	Pre-intervention (%)
A great deal	38
A fair amount	38
A little	11
Not very much	11
Not at all	2.5
Why does throwing away food bother you?	
It's a waste of my money	69
It's bad for the environment	46
It makes me feel guilty	54
It's dirty/makes the bin smell	15.5
It makes me feel that I haven't planned very well	20.5
I can't afford to throw away food	43.5
It makes me feel like I've wasted my time	18.0
It's a waste of good food	43.5

4.3.1.3. Catered

Causes of food waste and quantities generated

Regarding self-perceived FW generation pre-intervention, most of the students believed that they wasted small amounts, hardly any, or no FW at all (81%) as shown in Table 4.6. This shows the vast majority of the UK catered students did not consider themselves to be wasteful, while only 19% reported themselves to waste 'some', 'a reasonable amount', or 'quite a lot' of food.

When considering the main causes of FW for the UK catered students, pre-intervention, the main issue was being unable to account for plans changing in the week (selected by 28% of participants), this was followed by the food not tasting good (16%), not having enough time (13%) and making too much food (9%) as shown in Table 4.6. Overall, this shows that a lack of time planning was the key cause of FW (combined 41% saying plans changing, and not having enough time was the key issue). Additionally, 34% were not sure about the main reason why they wasted food pre-intervention, signalling FW awareness was low before the interventions were introduced.

Table 4.6. Catered UK students- Causes of FW and quantities generated

How much uneaten food – overall - would you say you throw away in general?	
	Pre-intervention (%)
Quite a lot	3
A reasonable amount	3
Some	9.5
A small amount	22
Hardly any	56.5
None	3
Which of these, if any would you say is the main reason why you throw away food?	
Food didn't taste good	16
Made too much food	9
Not enough time	13
Plans change in the week/can't plan	28
Don't know	34

Extent to which students were bothered by food waste and why

When considering the extent to which the catered students were bothered by FW, the majority of those surveyed pre-intervention were bothered 'a great deal', or 'a fair amount' (72%) as displayed in Table 4.6, showing students were, overall, concerned about FW.

When asked why the participants were bothered about FW, they stated 'wasting money' was the main concern (72% of all those surveyed) as shown in Table 4.7. 'Feelings of guilt' (59%), concerns wasting 'good food' (56%) and considerations for the environmental impact (53%) were the second, third and fourth most selected issues with FW respectively and were selected by a much higher number of students than the other categories. Overall, the results signify that the students were most bothered about economic issues, as well as social and ethical issues related to 'wasting good food' and harbouring general feelings of guilt, followed by having environmental concerns about FW, with other FW-related concerns, such as hygiene and wasting time being considered less important.

Regarding the amount of effort UK catered students made to minimise the amount of FW they produce, pre-intervention the majority made either 'a great deal', or 'a fair amount' of effort (65%) as displayed in Table 4.7, showing that the majority of the students were consciously enacting FW minimisation strategies pre-intervention.

Table 4.7. Catered UK students- Extent to which students were bothered by FW and why

When you have to throw uneaten food items away, to what extent, if at all, does it bother you?	
	Pre-intervention (%)
A great deal	31.5
A fair amount	40.5
A little	9.5
Not very much	12.5
Not at all	0
Why does throwing away food bother you?	
It's a waste of my money	72
It's bad for the environment	53
It makes me feel guilty	59.5
It's dirty/makes the bin smell	12.5
It makes me feel that I haven't planned very well	25
I can't afford to throw away food	25
It makes me feel like I've wasted my time	15.5
It's a waste of good food	56
Food could be used by others	3
How much effort do you make to minimise the amount of uneaten food you throw away?	
A great deal	19
A fair amount	47
A little	19
Not very much	12.5
None at all	0

4.3.1.4. Self-catered vs catered students in the UK

When considering the differences between the UK self-catered and catered students' FW related behaviours and attitudes, it seems apparent that the catered students surveyed believed that they wasted less food than the self-catered students did, as can be seen in Table 4.8. 25% more catered students believed that they wasted 'hardly any' food when compared to self-catered students.

When looking at why FW bothered self-catered and catered students, self-catered students appeared to be more concerned about the economic cost of FW (selected by 19% more self-catered students in comparison to catered students), as presented in Table 4.8. This could be because catered students pay a set fee for their food in advance, whereas self-catered students buy their food weekly and can perhaps see the personal economic impact of wasting food more clearly than catered students waste. On the other hand, more catered students stated that they had concerns over wasting 'good food' (selected by 13% more catered students when compared to self-catered students). This could potentially be because the quality of the catered food that is wasted may be better than the quality of the self-catered food.

Table 4.8. UK self-catered vs catered students- Quantities of FW thrown away and why are students were bothered by FW

How much uneaten food – overall - would you say you throw away in general?			
	Self-catered (%)	**Catered (%)**	**Difference (%)**
Quite a lot	5	3	-2
A reasonable amount	7.5	3	-4.5
Some	20.5	9.5	-11
A small amount	28	22	-6
Hardly any	31	56.5	25.5
None	7.5	3	-4.5
Why does throwing away food bother you?			
It's a waste of my money	69	72	3
It's bad for the environment	46	53	7
It makes me feel guilty	54	59.5	5.5
It's dirty/makes the bin smell	15.5	12.5	-3
It makes me feel that I haven't planned very well	20.5	25	4.5
I can't afford to throw away food	43.5	25	-18.5
It makes me feel like I've wasted my time	18	15.5	-2.5
It's a waste of good food	43.5	56.5	12.5
Don't know	0	3	3

The self-catered students clearly perceived themselves to have been wasting more food than the catered students. With this being said, many of the self-catered students segregated their FW, and the act of segregating FW can make individuals perceive themselves to waste more food (Cantaragiu, 2019). Consequently, while it may be possible that the self-catered students do waste more, it is also highly possible that they are just more aware of the food that they do waste than the catered students (Bernstad et al., 2013). Regarding reasons for FW, self-catered students appear to waste most of their food, due to them buying more fresh food than they need, and them not planning their meals well enough, meaning that this food goes off. Their self-perceived FW has gone down, as their effort to avoid FW has gone up, and they have started to eat food past the date of the label more readily.

Furthermore, most of the catered and self-catered students were bothered by FW. The reasons why they cared about the FW differed significantly however, with self-catered students being more concerned about economic factors than catered students were.

4.3.2. Interviews and focus groups

4.3.2.1. Introduction/rationale

4.3.2.2. Reasons for food waste

Reasons for FW in the UK are primarily linked to infrastructural factors and are discussed in section 3.2.4.2. of the resource assessment section.

4.3.2.3. Reasons for not recycling food waste

As with the above 'reasons for FW' section, the majority of the reasons for not recycling FW at the UK University residence can be attributed to infrastructural factors and are discussed in section 4.2.4.3. of the resource assessment section. With this being said, issues pertaining to awareness and communication were discussed as key barriers to recycling FW at the University.

Awareness and communication repeatedly arose as a key barrier when discussing reasons for not recycling FW. Many students reported that, while they were informed of the scheme, they were not aware of benefits related to FW recycling, as they missed related informative emails and social media posts.

> If we knew what happened, what it is being used for, I feel that people would want to use those food waste bins more because you know that you're doing good [1].

4.3.2.4. Motivations to tackle food waste issues

When considering 'motivations to tackle FW issues', the key areas that came up regularly were economic, environmental and social factors, as well as policy drivers and wanting to carry out good practice.

Economic factors were considered an important motivation by the catering team and residential team at the UK University to reduce FW. It was also the biggest concern among self-catered residents at the University on a personal level. There was a thought process that any food wasted meant money wasted.

> On a personal scale I definitely think most about the economic issues [1].

Environmental factors were the key motivation to tackle FW issues when considering the larger scale impacts of FW among the UK University students and the residence head caterer.

> On a national and larger scale, I definitely think more about the environmental issues [1].

Potential policy developments and wanting to follow general good practice were key motivations driving improved FW management for UK University residential staff. It was discussed how, while FW segregation and collection is not currently compulsory for large organisations in the UK, it could be in the future. Further to this, it was expressed that students had voiced their desire for more to be done with FW management, including having FW recycling at residences.

> We tried to keep one step ahead of the game in terms of provision of separate waste disposal with collection [3].

4.3.2.5. Key opportunities to mitigate food waste issues

When considering behavioural change related 'key opportunities to mitigate FW issues', the opportunities identified for reducing the amount of FW that is generated focussed on FW related education and promoting the use of good practices. The main behavioural change opportunities identified to improve FW recycling were student projects focussing on improving FW recycling awareness.

Educating residents and staff to follow general good practice in trying to minimise their FW was something that all of the participants at the UK University considered as a key opportunity to reduce FW. Residential services and the head caterer at the University emphasised how important it was to try to engage with students early on in their stay at the residences to try to help them understand the issues related to FW and how they can reduce the amount of FW they produce, by not taking more food than they can eat.

> A key opportunity is in engagement early on with the student population [3].

The head caterer at the University also mentioned the importance of certain practices in reducing waste from surplus food, such as batch cooking food to meet demand, reusing surplus foods wherever possible and also storing foods well to avoid waste. Self-catered residents at the University were largely citing how they adopted good practices such as freezing shop bought products and leftovers to reduce their FW.

> I'll try to go to the supermarket, buy all the food I need and bulk cook {1].

Student projects were advocated for by participants at the UK University as key opportunities to reduce FW generation and increase FW recycling. They considered how effective student representatives have been in increasing awareness around FW related issues and driving FW campaigns. Such student representatives include green reps who push forward environmental agendas relating to sustainability such as FW campaigns at their residence, with it believed that behavioural change campaigns are more effective with members of the same social circle (Burn, 1991).

> It has more resonance from someone who you are living with who is representing you [3].

4.3.2.6. Effect of behavioural change interventions on food waste generation and recycling

A number of FW behavioural change interventions were carried out to try to get students in the UK to reduce the amount of FW they generated and to get them to recycle their FW. Responses can be divided into catered FW reduction and non-catered FW recycling interventions.

All students in the focus group noticed the canteen interventions. The catered students mentioned that, while the interventions were highly visible and residents were discussing them, they were not certain that they had a significant impact in reducing FW generated at the canteen. The post-intervention surveys indicated that the table cards had a particularly high impact on FW behaviours.

> I did see that they were holding them and looking at them so I'm sure everyone has gotten the message, but I don't know if anybody has acted on it [1].

The self-catered interventions appeared to have a varying effect on different residents participating in the UK University focus group. Fridge magnets were placed on the fridges on every flat. This was observed to increase awareness of the FW recycling scheme and worked to make residents not recycling their FW feel guilty. Despite the magnets increasing awareness, many of the flats never got round to opting in to segregate their FW however. The post-intervention surveys indicated that both the public pledges and oral information provision had a particularly high impact on FW behaviours.

> When we got the magnets on our fridges to say you can have these, a couple of us in the flat said we'll definitely get one. We just never got around to doing it [1].

Conversely, the social media posts and emails promoting FW awareness were less noticeable, with many residents not viewing them due to a combination of them being too busy, as well as getting too many emails and having too many posts on the designated social media page, making it easy to miss content sent out. Attendance was relatively low at the FW events where surveys, a FW presentation and public pledges to recycle FW were carried out for the same reasons. Those who went to the events said that they had a very significant impact, in particular some of the FW statistics.

> It was really interesting to learn more about it, to put it all into context {1].

The problem was that many of the students were not aware that the events were taking place, due to not seeing the related social media posts, or emails promoting the events.

> I didn’t hear about the food waste events sorry. I would have come {1].

4.3.3. Food waste segregation

FW segregation data was collected at the UK University hall of residence, which included self-catered and catered students. FW was combined at source and weighed together including all FW derived from catered and self-catered students. FW quantities were collected at 3 points: before FW segregation was initiated; when FW segregation had been initiated, but before the FW recycling interventions had been carried out; and after the FW recycling interventions had been carried out. Changes in FW quantities upon collection over the course of 2018 and 2019 are illustrated in Figure 4.1. From comparing FW quantities in 2018 and 2019 it was

determined that FW recycled by self-catered students accounted for a rise in total FW collected of around 29%, and thus it can be assumed that self-catered FW typically accounts for 29% of the total FW generated (including catered FW).

When comparing FW segregation before and after the interventions, FW quantities collected were 58% higher in December 2019 (680kg), when compared to December 2018 (430kg). However, FW was not collected in the previous year. Assuming FW would have been 29% higher the previous year with self-catered FW recycling available, a 58% increase is double the typical self-catered FW stream, indicating that the interventions resulted in a doubling of self-catered FW segregation. On the other hand, weekly FW quantities rose by around 21% in the two weeks after the interventions (before the students left for the winter holidays), when compared to the two weeks prior to the interventions (from 215kg/week to 260kg/week). When taking into account that segregated FW from the flats of self-catered students accounts for around 29% of the total FW generated at the residences (including catered FW), then there was a bi-weekly rise of 72% in segregation that resulted from the interventions. It can be assumed that the interventions resulted in increases of between 70% and 100% in self-catered FW recycling and between 20% and 30% for total FW generated at the residence (including catered FW). With this being said, there will be other factors that relate to yearly, monthly and weekly variations, but with calculating the increase compared to the same month in previous years and the weeks just prior to and post-intervention. This signals that the interventions were highly effective in increasing FW recycling in the residence, meaning they had an impact on FW recycling behaviours, as well as attitudes among residents. The increase in recycling rates will have brought about major improvements in how sustainably the FW was treated, as the recycled FW was anaerobically digested locally as opposed to being used as RDF in N. Europe, bringing about significant environmental benefits.

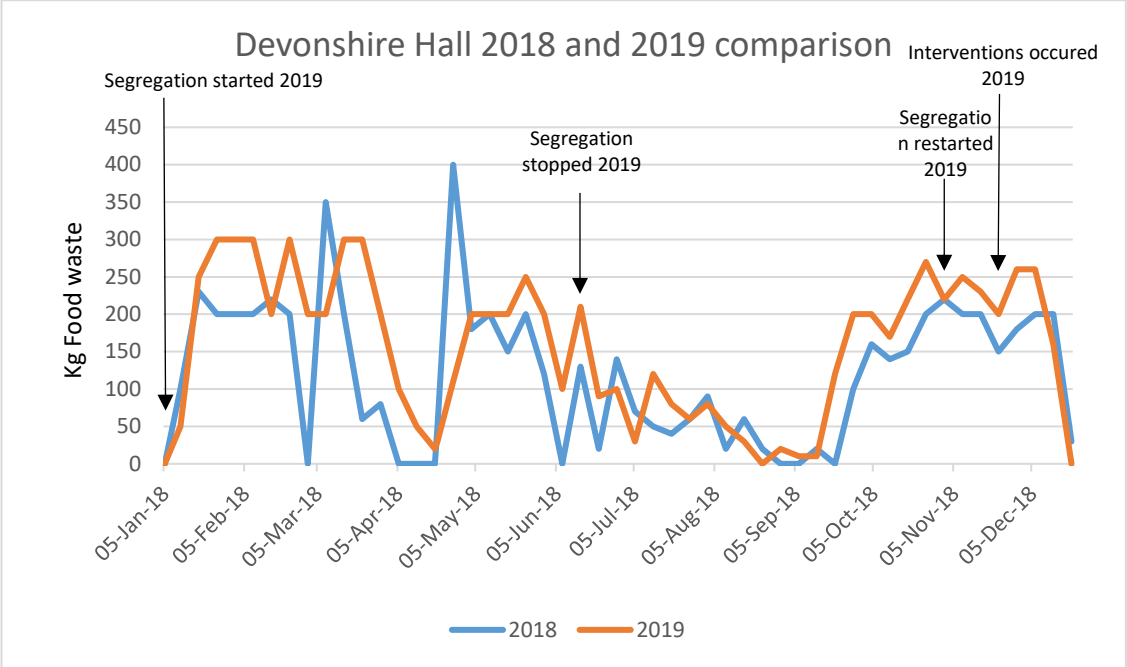


Figure 4.2.

4.3.4. Food waste reduction

Total FW weights were collected in February 2019 and February 2020. The interventions were introduced at the end of January after the final FW monthly collection. FW levels were then compared with figures for the previous year. As 2020 was a leap year, average daily FW figures were calculated, with FW quantities for February 2020 being divided by 29 days and February 2019 being divided by 28. When trying to isolate the catered FW reduction specifically (excluding self-catered FW) 180kg was taken off the FW figures for February 2019 and 2020, based on the increase from February 2018 (where self-catered FW was not segregated) to February 2019 (where self-catered FW was segregated). Total FW reduced by 11.4% (35.71kg/day to 32.07kg/day), while catered FW reduced by 13.2% (from 29.29kg/day to 25.86kg/day). This indicates that, as with the FW segregation interventions, the interventions were effective in reducing FW in the canteen, meaning that they affected the FW reduction behaviours as well as the attitudes of the residents. The FW reduction will have brought about significant environmental benefits, as the environmental impacts associated with producing the food that would have been wasted will have been mitigated.

4.4. India

4.4.1. Survey

4.2.1.1. Catered

Causes of food waste and quantities generated

Regarding self-perceived FW generation pre-intervention, most catered students believed that they wasted 'small amounts', 'hardly any', or no FW at all (66%) as shown in Table 4.12. This shows the majority of them did not consider themselves wasteful, while around a third of the students (34%) reported themselves to waste 'some', 'a reasonable amount', or 'quite a lot' of food.

When considering the main causes of FW pre-intervention for the Indian catered students, the main issue resulting in FW was the food not tasting good (56%), followed by making too much food (22%) as shown in Table 4.9. Overall, this shows that the food not meeting taste requirements was the key cause of FW, followed by a lack of portion control.

Table 4.9. Catered Indian students – Causes of FW and quantities generated

How much uneaten food – overall - would you say you throw away in general?	
	Pre-intervention (%)
Quite a lot	3
A reasonable amount	19
Some	12.5
A small amount	40.5
Hardly any	22
None	3
Which of these would you say are the main reasons why you throw away food?	
Food didn't taste good	56.5
Made too much food	22
Not enough time	6.5
Plans change in the week/can't plan	3
Took too much food	9.5
Food spoilt	9.5
Inedible herbs and spices	0
Don't know	9.5

Extent to which students were bothered by food waste and why

When considering the extent to which the Indian catered students were bothered by FW, the majority of those surveyed pre-intervention were bothered 'a great deal', or 'a fair amount' (78%) as displayed in Table 4.10 showing students were, on the whole, concerned about FW.

When asked why the participants were bothered about FW, the most selected issue was feeling guilty (72% of all those surveyed) as shown in Table 4.10. Following this, concerns related to wasting money, as well as 'good food' (both 41%) were the joint second most selected concerns. Overall, the results signify that FW makes them feel very guilty, while also

being concerned about social and economic issues related to FW. Overall, the results signify that the students were most bothered about social and ethical issues related to 'wasting good food' and harbouring general feelings of guilt, followed by economic issues related to FW, with other FW-related concerns such as environmental concerns, hygiene issues and wasting time being considered as less important.

Regarding the amount of effort Indian catered students made pre-intervention to minimise the amount of FW they generated, the majority made either a great deal, or a fair amount of effort (72%) as displayed in Table 4.10, showing that the majority of the students were consciously enacting FW minimisation strategies pre-intervention.

Table 4.10. Catered Indian students – Extent to which students were bothered about FW and why

Thinking about when you have to throw uneaten food items away, to what extent, if at all, does it bother you?	
	Pre-intervention (%)
A great deal	40.5
A fair amount	37.5
A little	19
Not very much	3
Not at all	0
Why does throwing away food bother you?	
It's a waste of my money	40.5
It's bad for the environment	22
It makes me feel guilty	72
It's dirty/makes the bin smell	9.5
It makes me feel that I haven't planned very well	22
I can't afford to throw away food	15.5
It makes me feel like I've wasted my time	9.5
It's a waste of good food	40.5
Food could be used by others	12.5
Don't know	6.5
How much effort do you make to minimise the amount of uneaten food you throw away?	
A great deal	31.5
A fair amount	40.5
A little	25
Not very much	3
None at all	0

While the surveys have touched on FW generation levels, causes of FW, and FW related behaviours and beliefs, the interviews and focus groups (discussed in the next section) should help improve understanding of how and why food is wasted, the interventions worked and students' beliefs and behaviours changed at the institution.

4.4.2. Interviews and focus groups

4.4.2.1. Reasons for food waste

Infrastructural factors were also the main reason for FW at the Indian University canteen (discussed in section 3.2.4.2.). With this being said, there were also behaviour-related 'Reasons for FW' concerning cultural differences and taste preferences.

The University has students from all over India, with cuisines and tastes varying greatly between different regions of India. The canteen typically cooked local Marathi food; therefore, students from other states usually wasted large quantities of food as they did not like the taste.

> Here in Mess C the food made is mostly Marathi cuisine, so if someone is from Delhi, they will probably not like the Marathi food [5].

4.4.2.2. Motivations to tackle food waste issues

Concerning 'motivations to tackle FW issues', the key motivation was social issues, while economic and environmental factors were also considered.

Social issues were considered the most important motivation for all of the catered students in the focus group at the Indian University. They were mostly concerned about the fact that so many people in India were going hungry, whilst so much food was wasted.

> In our country many people don't get to eat their daily food. I consider it a very big problem. We should reduce food waste as much as we can [5].

It could be argued that social issues are a higher priority for Indian students than UK students because wealth inequality, poverty and malnourishment are much greater and more visible in India than the UK, thus shaping their FW concerns (Suryanarayana and Silva, 2007).

Economics was not considered the most important factor for the Indian University catered students. They stated how they did consider economic issues with FW, but less on a personal level and more on a national and international level. This is likely because, while the UK University self-catered students pay for food that they waste, the catered Indian University students pay for their food in advance in an all you can eat basis, meaning personal FW does not directly relate to personal financial losses for them.

> If the food is being generated and being wasted it is a loss for the economy [5].

Meanwhile, environmental factors were not considered as such a significant concern for the Indian University students.

> The greenhouse gas emission factor is an issue but when you compare it to other emission sources such as transport and industry, it is not as important as the others [5].

4.4.2.3. Key opportunities to mitigate food waste issues

When considering key behavioural change related 'opportunities to mitigate FW issues', the key opportunities identified for reducing the amount of FW that is generated included FW related education and promoting the use of good practices, as well as student projects

focussing on both improving FW management and awareness was considered an opportunity to reduce FW.

Educating students and staff to follow general good practice in trying to minimise their FW was something that all of the participants at the Indian University considered as a key opportunity to reduce FW. The Indian University focus group and mess secretary emphasised that if students just take small amounts of each type of cuisine and repeatedly come back until they are full then FW could be dramatically reduced.

> In our meetings related to the mess, we always asked our members to take the food multiple times rather than taking it all at once and then wasting it if it is not to their liking [6].

Student projects were advocated for by the Indian University students as key opportunities to reduce FW generation and increase FW recycling. Focus group participants considered how there are many students at the institution with specific academic knowledge and expertise that could be used to help provide invaluable insights on how to improve FW management at the University.

> I think there should be more projects concerning all of the food waste factors such as economic, social and environmental [5].

4.4.2.4. Effect of behavioural change interventions on food waste generation and recycling

A number of FW behavioural change interventions were carried out to try to get students in India to reduce the amount of FW they generated. All of the students in the focus group noticed the interventions. It appeared that the interventions were considered to have a more significant impact among the participating Indian University catered students, when compared to the UK University participants. The students mentioned how some of the facts on the table cards made them really consider the impact of FW, while the FW signs made them feel guilty for wasting food, with the post-intervention surveys also indicating that the table cards had a particularly high impact on FW behaviours.

> The sign was very effective because I saw it when I was throwing away my food and I found it very disturbing to see [5].

4.4.3. Food waste reduction

While a 1-month baseline for FW generation at the Indian University canteen was gained, and the interventions were introduced, the Covid-19 pandemic forced the University to shut before the full post-intervention data for FW generation could be gained. Data for FW generation directly after the interventions were introduced was unattainable due to a Covid-19 related

University shutdown and citywide lockdown. Attempts were made to acquire the data once the lockdown was eased, and 10 months later it was finally possible to gain this data, however, the data showed the joint impacts of the FW interventions and Covid-19 related changes. The combined impacts of the interventions and Covid-19 changes led to a 50.2% reduction of per capita FW generation at the Indian University canteen (from 0.11826kg/capita/day to 0.058925kg/capita/day). These FW reductions will have led to highly significant environmental and economic benefits, as the environmental impacts and financial outlays associated with the FW of each student at the canteen will have roughly halved. It seems apparent that both the interventions changes associated with Covid-19 had a very significant impact on FW reduction.

4.5. China

4.5.1. Covid-19 limitations

It was not possible to carry out food waste reduction interventions due to Covid-19 entry restrictions in China. All of the research was carried out remotely for China due to these travel restrictions.

4.5.2. Survey

4.5.2.1. Catered

Causes of food waste and quantities generated

Regarding self-perceived FW generation, most catered students believed that they wasted ‘small amounts’, ‘hardly any’, or no FW at all (~67%) as shown in Table 4.11. This shows the majority of them did not consider themselves wasteful, while around a third of the students (33%) reported themselves to waste ‘some’, ‘a reasonable amount’, or ‘quite a lot’ of food.

When considering the main causes of FW for the Chinese catered students, the majority of students chose the food not tasting good (65.4%) as the main reason for FW, followed by taking too much food (19.2%) as shown in Table 4.11. Overall, this shows that the food not meeting taste requirements was the key cause of FW, followed by a lack of portion control, as was the case with Indian students.

Table 4.11. Catered Chinese students – Causes of FW and quantities generated

How much uneaten food – overall - would you say you throw away in general?	
	Pre-intervention (%)
Quite a lot	1.9
A reasonable amount	11.5
Some	19.2
A small amount	38.5
Hardly any	28.8
None	0
Which of these would you say are the main reasons why you throw away food?	
Food didn't taste good	65.4
Made too much food	0
Not enough time	1.9
Plans change in the week/can't plan	5.8
Took too much food	19.2
Food spoilt	3.80
Inedible herbs and spices	0
Don't know	3.8

Extent to which students were bothered by food waste and why

When considering the extent to which the Indian catered students were bothered by FW, the slight majority of those surveyed stated 'not very much, or 'a little' (~54%) as displayed in Table 5.12., while, a slight minority stated they were bothered 'a fair amount', or 'a great deal' (~46%), with no one stating that they weren't bothered at all. This shows students did, overall, have some concern about FW, but the majority did not see it as a major concern.

When asked why the participants were bothered about FW, the most common reason was that it was a waste of good food (63.5% of all those surveyed) as shown in Table 4.12. Following this, feelings of guilt was the biggest concern (51.9%), followed by environmental concerns. Economic concerns were only experienced by around 19% of those surveyed (15.4% selecting 'it's a waste of money' and 3.8% selecting 'I can't afford to throw away food'). Overall, the results signify that wasting food does make the majority of them feel guilty, while many were also concerned about social and economic issues related to FW. Overall, the results signify that the students were most bothered about social and ethical issues related to 'wasting good food' and harbouring general feelings of guilt, followed by environmental issues related to FW, with other FW-related concerns such as economic concerns, hygiene issues and wasting time being considered as less important.

Regarding the amount of effort Chinese catered students made to minimise the amount of FW they generated, the majority made either a great deal, or a fair amount of effort (~69%), with only 3.8% stating they made no effort at all, as displayed in Table 4.12. This shows that the majority of the students were consciously enacting FW minimisation strategies.

Table 4.12. Catered Chinese students – Extent to which students were bothered about FW and why

Thinking about when you have to throw uneaten food items away, to what extent, if at all, does it bother you?	
	Pre-intervention (%)
A great deal	21.2
A fair amount	25
A little	44.2
Not very much	9.6
Not at all	0
Why does throwing away food bother you?	
It's a waste of my money	15.4
It's bad for the environment	36.5
It makes me feel guilty	51.9
It's dirty/makes the bin smell	11.5
It makes me feel that I haven't planned very well	13.5
I can't afford to throw away food	3.8
It makes me feel like I've wasted my time	0
It's a waste of good food	63.5
Other	0
How much effort do you make to minimise the amount of uneaten food you throw away?	
A great deal	26.9
A fair amount	42.3
A little	13.5
Not very much	13.5
None at all	3.8

While the surveys have touched on FW generation levels, causes of FW, and FW related behaviours and beliefs, the interview and focus group (discussed in the next section) helps improve our understanding of how and why food is wasted, why the interventions worked, and how students' beliefs and behaviours changed at the institution.

4.5.3. Interviews and focus groups

Again, infrastructural factors were the key reason for FW at the Chinese University (see section 3.2.4.2.). With this being said, like India, there were also behaviour-related 'Reasons for FW' concerning cultural differences and taste preferences.

The University has students from all over China, with cuisines and tastes varying greatly between different regions in the country, and particularly between the north and the south. The canteen generally cooked typical Northern Chinese cuisine; therefore, students from other regions usually wasted large quantities of food, as they did not like the taste.

> The people in the southern area that cannot eat much food and when we come to the north area. Food in this canteen is so spicy and saucy [7].

4.5.3.2. Motivations to tackle food waste issues

Concerning 'Motivations to tackle FW issues', the key motivations were the impacts of FW on the environment, institutional and wider-ranging impacts on the economy, while more personal social issues were also considered.

The environmental factors that were reflected upon tended to centre around the impact of FW on climate change. This included the emissions throughout the lifecycle of the wasted food, from the production stage right through to the end disposal, or treatment of the waste. Additionally, there was a particular emphasis on the end disposal/treatment stage.

> If we have too much [food waste] there is a real cost from carbon emissions or energy to treat this waste. [7].

Economic impacts were also considered important. Bigger picture impacts were discussed including the economic losses related to wasting food, while again there was a particular emphasis to the economic costs of treating the FW.

> We need to treat the food waste, and we need to use a lot of energy and money to do this [7].

On an institutional level, economic savings through improved FW management was considered a major driver for tackling FW issues.

> Cost reduction is a key motivation [8].

On the other hand, personal economic issues were not considered at all important in China, with cheap food even being considered a barrier to FW reduction.

> We make food waste now, especially in China just because we have more money [7].

The Chinese catered students also considered personal social issues, albeit to a lesser extent. They were mostly concerned about the disappointment caterers may feel when the food they cook is wasted.

> When you waste food, the person that made this food will feel sad when they see it being wasted [7].

4.5.3.3. Key opportunities to mitigate food waste issues

When considering key behavioural change related 'Opportunities to mitigate FW issues', the key opportunities identified for reducing the amount of FW that is generated included encouraging the adoption of good FW minimisation practices.

> We could make a team to go to the canteen, because if there are three or even four more people, we could eat everything and we could have a different kind of dishes. [7].

With this being said, it was also mentioned that the social distancing Covid-19 precautions relating to health and safety in place in the canteen at the time would have made this impossible.

> Because it's a special COVID period, we have the social distancing in canteen, so it's impossible for us to do this right now [7].

Additionally, canteen staff already try to raise awareness about FW by allocating one member of staff to wait by the bins querying students on why they have wasted food, if they have wasted something. This is believed to be effective at reducing FW and can be seen as a key opportunity to minimise FW going forwards.

> Someone in the canteen stands in front of the food waste bin and always asks someone with a lot of food waste "why do you waste that kind of food?" And I think it's good behaviour to reduce food waste by [8].

4.5.3.4. Effect of behavioural change interventions on food waste generation

A number of FW behavioural change interventions were shown and explained to the participants during the focus group with an aim to understand how effective each intervention may have been and why, if implemented. The students were not particularly confident that the interventions would have had a major impact, as FW awareness in China is relatively high, and similar FW awareness campaigns have been present from school through to university.

> Reducing food waste is China's traditional behaviour, and everyone in China from the Secondary school, middle school, are always being asked to reduce food waste [7].

Furthermore, previously mentioned infrastructural issues related to the canteen not offering flexible portions, as well as the low cost of food, and subsequent low expense associated with wasting food meant the students doubted the interventions would have a large impact, in contrast to the UK and Indian Universities.

The Chinese students believed that the FW signs would have the least impact of the interventions, and prompting students to go back for more food would not help reduce FW, due to the inconvenience of returning for food.

> I think the signs would be the least effective, because there are so many signs in China [7].
>
> I have no chance to buy any more later because if you go to the canteen you will be waiting for about ten minutes. I don't want to do this, it's a waste of time [7].

When considering the potential impact of the posters, they believed that the prompt poster would not have a significant impact, but the feedback poster with statistics associated with FW and related impacts at the canteen could be effective. It was also highlighted that the text being in English, not Chinese, would make it more eye-catching.

> Definitely [it will have an impact], sure. It will draw people’s attention to waste problem. Especially with it being in English, it will draw people’s attention to these words [7].

With this being said, they thought the impact would wane over time if the feedback poster were not updated.

> In the beginning, very beginning, it could be helpful, but many days after, people will feel nothing about these words [7].

The students believed that the table cards would be the most effective intervention. This was mostly because, while many FW awareness campaigns are conducted in China, table cards are rarely used. This novelty would increase the impact when compared to the other interventions. In addition, the fact that table cards would be located on the tables in the eye-line of those eating, rather than on the wall, may mean they would command greater attention.

> We seldom use table cards. This would be a new method in China [7].
>
> The poster and this sign, are just on the wall, but the table cards are on the table where people take their food, so should be more effective [7].

4.5.4. Food waste reduction

Due to Covid-19 travel restrictions, it was not possible to conduct the FW reduction interventions at the Chinese canteen. For this reason, it is not possible to infer the levels of FW reduction these interventions would be able to create at this site and similar sites across China.

4.6. UK, Indian and Chinese comparison

4.6.1. Introduction

Through comparing the findings of the surveys, interviews and focus groups, for the UK, Indian and Chinese Universities, as well as the FW reduction interventions for the UK and Indian Universities, it is possible to see how and why FW related challenges, management strategies, opportunities, barriers and motivations to tackle FW issues differ between countries. This section explores the differences between the FW landscape and behavioural change in the Indian, UK and Chinese university settings.

4.6.2. Survey

Concerning how much self-perceived FW was generated in each country, UK students considered themselves to be less wasteful than Indian and Chinese students, with almost 60% of UK students stating they wasted ‘Hardly any’, or no waste at all, when compared to 25% for Indian students and 29% for Chinese students, as shown in Table 4.13. In addition, only around 6% of UK students stated that they wasted ‘quite a lot’, or ‘a reasonable amount’ of FW, compared to around 22% of Indian students, and 13% of Chinese students. This means that UK students believed themselves to be the least wasteful, while Indian students believed that they

were the most wasteful. With this being said, as it was self-perceived FW, not truly quantified FW, it may well be that the Indian students were the most aware of the food that they wasted, with UK students having the lowest levels of awareness.

Regarding why food is wasted in the different countries, food not tasting good was the key issue for Indian and Chinese students (selected by ~56% and ~65%); however, it was not a major issue for UK students (selected by ~16%). Time management issues were the main reasons for FW in the UK with roughly a combined 40% of students selecting that not having enough time, or plans changing in the week was the main reason for FW, compared to around 9% and 8% for Indian and Chinese students respectively. Lack of portion control concerning 'making too much food' and 'taking too much food' was considered a major issue by a large proportion of Indian students (~31%) and to a lesser extent Chinese students (~19%), but was not regarded by many UK students as a key issue (~9%). This shows that while the main causes for FW in India and China are taste preferences and portion control, time scheduling pressures were more impactful in the UK. Additionally, 34% of UK students stated that they did not know why they wasted food, when compared to around 9% and 4% by Indian and Chinese students respectively, indicating that FW awareness and consideration as to the causes of the FW is greater among Indian and Chinese students when compared to those in the UK.

Table 4.13. Comparing UK, Indian and Chinese catered students- the causes of FW and self-perceived generation.

How much uneaten food – overall - would you say you throw away in general?			
	UK (%)	**India (%)**	**China (%)**
Quite a lot	3.125	3.125	1.9
A reasonable amount	3.125	18.75	11.5
Some	9.375	12.5	19.2
A small amount	21.875	40.625	38.5
Hardly any	56.25	21.875	28.8
None	3.125	3.125	0
Which of these would you say are the main reasons why you throw away food? Please tick 1 box for each section			
	UK (%)	**India (%)**	**China (%)**
Food didn't taste good	16	56.25	65.4
Made too much food	9	21.875	0
Not enough time	13	6.25	1.9
Plans change in the week/can't plan	28	3.125	5.8
Took too much food	0	9.375	19.2
Food spoilt	0	9.375	3.80
Don't know	34	9.375	3.8

When looking at why throwing away food bothered the students, most significantly around 98% of UK students stated reported economic concerns (stating 'it's a waste of money', or 'I can't afford to throw away food'), when compared to 56% of Indian students, and only around

19% of Chinese students, as displayed in Table 4.14. Additionally, UK students were the most concerned about environmental issues (selected by 53%), with the Indian students showing the least concern for environmental impacts (22%), and Chinese students being somewhere in the middle of the two (~37%). On the other hand, more Indian students stated that wasting food made them feel guilty (72%) when compared to UK students (59.5%) and Chinese students (~52%), and more stated that the food could be used by others (12.5%), when compared to the UK (3%) and China (0%). Meanwhile, Chinese students were the most concerned about wasting good food (selected by 63.5%), slightly more than UK students (56.5%) were and notably more than Indian students (40.5%) were. This signals that UK students are more concerned about economic issues than Indian students are, and much more concerned than Chinese students are. UK students are also more concerned about environmental issues than Chinese and Indian students are. Chinese students are particularly bothered about wasting good food, while Indian students are particularly concerned with the social and ethical ramifications of FW.

Table 4.14. Comparing UK, Indian and Chinese catered students- Why students were bothered about FW

Thinking about when you have to throw uneaten food items away, to what extent, if at all, does it bother you?			
	UK (%)	**India (%)**	**China (%)**
A great deal	31.25	40.625	21.2
A fair amount	40.625	37.5	25
A little	9.375	18.75	44.2
Not very much	12.5	3.125	9.6
Not at all	0	0	0
Why does throwing away food bother you? (only answered by participants bothered by food waste)			
	UK (%)	**India (%)**	**China (%)**
It's a waste of my money	72	40.5	15.4
It's bad for the environment	53	22	36.5
It makes me feel guilty	59.5	72	51.9
It's dirty/makes the bin smell	12.5	9.5	11.5
It makes me feel that I haven't planned very well	25	22	13.5
I can't afford to throw away food	25	15.5	3.8
It makes me feel like I've wasted my time	15.5	9.5	0
It's a waste of good food	56.5	40.5	63.5
Food could be used by others	3	12.5	0
Don't know	0	6.5	0

In conclusion, through conducting the pre-intervention surveys at the UK university, Indian institute B, and the Chinese University, a great deal can be inferred that can help in understanding FW related attitudes and behaviours, and how these differ between UK, Indian and Chinese students.

Concerning the self-perceived FW generation of the students, it remains to be seen whether the self-reported FW differences relates to statistically significant, real differences in the amount of FW that is generated. UK students did report wasting less than Chinese students and substantially less than Indian students however, signalling a lower awareness, and/or

acceptance of the levels of FW they generate. For catered students in China and India, the primary reason for FW appears to be the food not tasting good, whereas in the UK, plans changing in the week was the greatest issue. This signals that the main room for improvement in reducing food waste in the Indian and Chinese University canteen could be to make changes in the food they serve. Portion control seems to be a significant issue in the Indian University, and to a lesser extent in the Chinese University, meaning they could benefit significantly from adopting FW awareness and education to encourage good practice in terms of portion control. On the other hand, the main scope for improvements within the UK University canteen could be in changing the system to make it more flexible and compatible with students' unpredictable schedules.

It seems clear that, overall, the students were bothered by FW; however, the Indian students clearly had the greatest concern, and the Chinese students were the least bothered. The reasons why they cared about the FW differed significantly however, with UK students being particularly bothered about the economic and environmental issues, Chinese students being the most bothered about wasting good food, and Indian students being more bothered about social issues. In addition, Chinese students were particularly unconcerned by economic issues relating to FW, when compared to the UK and Indian students.

While the surveys touched on the differences between FW generation levels, causes of FW, FW related behaviours and beliefs among UK, Indian and Chinese students, the interviews and focus groups (discussed in the next section) help to improve understanding of how and why food is wasted, why the interventions worked, and how students' beliefs and behaviours changed in the institutions.

4.6.3. Interviews and focus groups

Through conducting the semi-structured interviews and focus groups at the UK, Indian and Chinese Universities, a great deal can be inferred that can help in understanding what FW related issues there are at these universities, what the reasons are for these FW issues and what can be done to improve the situation. It seems apparent that there are key differences in drivers and motivations when comparing the Indian, UK, and Chinese Universities, as personal financial savings appears a greater driver at the UK University, climate change mitigation seems a much greater driver in the UK and Chinese University, whilst increasing food security was considered much more important at the Indian University. In addition, in China there was a particular lack of concern regarding the personal cost of wasting food, while there was a special concern for the impact of FW treatment. There are many FW related issues that all of the institutes have in common, such as difficulties in estimating how much food to produce in canteens. Moreover, some of the institutions have specific FW challenges typical of the

country that are not present in other studied Universities. At the Indian and Chinese Universities, there were significant issues relating to cultural taste preferences and FW, which are inherent of universities in India and China due the cultural diversity within these countries, but these characteristics are not very applicable to UK universities, as UK cuisine is less regionally diverse.

Awareness campaigns to increase FW awareness and subsequently reduce FW present substantial behavioural change opportunities for minimising FW at the Universities. The UK and Indian students proposed that these awareness campaigns could be student led, whereas the Chinese University considered a more staff driven approach. Moreover, informed menu choices based on student feedback was considered a key opportunity at all of the Universities, while having more flexible meal sizes was considered a major opportunity for FW reduction at the Chinese University.

The focus groups also helped with understanding how and why the FW interventions worked, to what extent they worked, and what limitations they had. Canteen interventions were perceived to be more effective at the Indian University than the UK University, with FW signs making students feel guilty wasting food and statistical information that was displayed, having a particularly significant impact. While it was not possible to carry out the interventions in China, after showing and explaining the interventions to the focus group it appeared that the interventions might have been the least effective in China out of the three countries, due to China already having a very visible existing national FW awareness campaign. With this being said the Chinese students also noted the value of having statistical information and believed that the use of English text on the materials would increase the impact of the interventions. Moreover, it was generally agreed across all of the Universities that the table cards had, or would have the greatest impact, followed by the feedback poster. FW recycling interventions such as the FW events appeared to be effective when the UK self-catered students were aware of them; however, publicising the events and communicating the messages appeared to be the key limitation, as many residents missed the emails and social media posts and were unaware that the FW events were occurring.

4.6.4. Food waste reduction interventions

As the post-intervention FW generation data at the Indian University canteen also included Covid-19 impacts, it is impossible to make a true comparison of the impact of the FW reduction interventions between the UK and India. With this being said, the interventions were found to be highly successful in reducing FW quantities in the UK University by reducing per capita FW by over 13%, while combined post-intervention and Covid-19 FW reduction in the Indian University

canteen was much higher at over 50%. There is uncertainty over how long these reductions may last however. The post-intervention FW attitudes and behaviours appeared to be better among Indian respondents than those in the UK were, and the Indian focus group seemed to find the FW reduction interventions more effective than the UK focus group did. As the behavioural change FW reduction interventions led to a 13.2% reduction in FW at the UK University canteen, it is likely that the behavioural change interventions led to at least 13.2% of the overall 50% per capita reduction found at the Indian University canteen. With this being said, it is probable that the Covid-related changes at the canteen had the biggest proportional impact on FW reduction at the Indian University canteen. As it was not possible to conduct the FW reduction interventions at the Chinese University, it is difficult to know what impact the FW interventions would have had. With this being said, the focus group responses indicate that the interventions may have had a less significant impact in China, than in the UK and India.

4.7. Discussion

It is clear from the results of the research that the interventions changed the behaviours of the students making them reduce their food waste and significantly increase FW recycling, which in turn, will have brought about a wide range of environmental, social and economic benefits. Based on the focus group responses, it is also believed that the interventions would have had some impact in China if they were conducted, but the scale and longevity of that impact remains to be seen. It was also found that FW related attitudes differed significantly among catered and self-catered students, as well as UK, Indian and Chinese catered students. Additionally, it is vital to compare and contrast with previous studies to see where the literature supports the research results, where the findings differ and what the reasons for the differences may be. It is important to then use this analysis to see how it could improve our understanding on enacting effective FW related behavioural change and what implications this could have on the wider context of improving institutional FW management, and the benefits these improvements could bring.

4.7.1. Exploring survey findings

4.7.1.1. Catered and self-catered student comparison

The surveys found that catered students believed they wasted less food, perhaps due to a greater visibility of the food wasted by self-catered students due to many segregating their FW. It is still unknown however which group generated more FW in reality and why, information that would be useful to know in order to better tackle FW issues, as a greater awareness of FW generated may positively affect FW related behaviour. Catered students were also more concerned about wasting good food, whereas self-catered students cared

more about wasting money. This could well be specific to this particular study site however, depending on payment systems for catered students and quality of food served at particular sites. While the pre-intervention surveys had a statistically significant sample size, as determined by a power calculation, it was still a relatively small sample size, especially considering the total size of the residence. Altogether only 62 (catered and self-catered students) of around 550 students (total number at residence) were surveyed, and this residence only made up around 550 of over 36,000 students across the University. Moreover, while the University could be considered broadly representative for a UK university, as detailed in Table 2.8, the UK has a diverse range of universities regarding geography, size and specialisms. Additionally, the studied university only makes up around 36,000 of the total 2.75 million University students in the UK (Statista, 2022). Comparing the FW-related behaviours and attitudes of catered and self-catered students in different universities of different sizes and different FW management systems throughout the UK with larger sample sizes could help validate the findings of this research, or any findings that may be institution-specific.

4.7.1.2. UK, Indian and Chinese student comparison

When comparing UK, Indian and Chinese students, the UK students were more concerned about the personal economic impacts of FW, the UK and Chinese students were more bothered about greater environmental impacts, while Indian students were more concerned about the social impacts of FW, in particular that the food could be used by others. Understanding what specific groups find most important and why interventions affect certain groups more than others may help in creating targeted approaches. These targeted approaches may be more effective in enacting positive behavioural change.

As comparing FW related attitudes between catered and self-catered, as well as UK, Indian and Chinese students is a novel topic area, there is a lack of literature to compare the findings with. All of the pre-intervention surveys had a statistically significant number of participants (31, as calculated during a power calculation). Additionally, numerous studies such as WRAP and the Women's institute (2008); and Hampshire County Council and Brook Lyndhurst (2010); as well as Whitehair et al. (2013); Luecke (2015); Schmidt (2016); and Visschers et al. (2020) have been carried out on FW generation behaviours in the catering sector, as well as FW recycling behaviours in self-catered residences respectively. These studies used very similar survey questions with similar outcomes as this study, concerning specific FW behaviours and attitudes, thus supporting the findings of this research.

Comparing FW-related attitudes between students in the UK, India and China was a novel topic area. This meant there was an absence of literature that could be used to compare the

findings. Literature comparing FW generation behaviours and attitudes in different countries was sourced however. Grainger et al. (2018) found that self-reported per-capita FW was higher among survey respondents in EU countries with lower levels of GDP. This mirrored the findings in this study, where the comparatively lower GDP countries of India and China had greater levels of self-reported FW than the country with the highest GDP, the UK, thus supporting the findings. Additionally, studies by Heng and House (2022), comparing FW behaviours in the UK, France, USA and Canada, as well as Jörissen et al. (2015), comparing FW behaviours in Germany and Italy, both identified notable differences in self-perceived FW and reasons for FW in the different countries assessed. This showed how FW-generation behaviours could differ significantly in different countries, as was found to be the case when comparing UK, Indian and Chinese students in this research.

All of the pre-intervention surveys had a statistically significant number of participants (≥31, as calculated during a power calculation), the post-intervention surveys however, did not have sufficient participation to make them statistically significant (<31). This means the post-intervention results should only be considered as anecdotal. Concerning the socio-demographics of the pre-intervention surveys, while the UK and Chinese university participants consisted of male and female students (as well as non-binary UK students), the Indian university sample consisted of male-only students. The implications of gender on FW-generation behaviours has been studied by Silvennoinen et al. (2015) as well as Koivupuro et al. (2012) with both studies finding that females had greater levels of self-reported FW generation than the males they surveyed. Conversely, the survey in the PhD found that the male-only Indian university sample recorded greater levels of self-reported FW than the mixed-gender UK and Chinese university samples. In addition, Cantaragiu (2019) found that females tended to have a greater concern than males about the social implications of FW, including impacts on equality; nevertheless, the surveys and focus groups in the PhD identified that the all-male Indian students were more bothered by the social implications of FW than the mixed-gender students in the UK and China. Additionally, Sudershan (2009) and Lyndhurst (2007) found that females were more bothered by FW, and felt guiltier about wasting food. On the other hand, the surveys in the thesis found a higher level of guilt attributed to wasting food, and greater general concern about FW among the male-only Indian students, when compared to the mixed-gender UK and Chinese students. It therefore seems apparent that gender influences are not able to explain the different FW-related behaviours and attitudes observed by the male-only Indian students, when compared to the mixed-gender UK and Chinese students, because, if the implications of cultural differences were excluded, all of the findings in this thesis would controvert the findings of previous studies. Therefore, the cultural

differences observed in the PhD may have been even more pronounced if the surveys and focus groups were conducted with participants exhibiting the same gender mixes (Sudershan et al., 2009).

Altogether, while the pre-intervention surveys had a statistically significant number of participants and the Universities were all considered broadly representative, as shown in Table 2.8, the sample only consists of small proportions of students eating at one of numerous canteens in one of many universities across the respective countries. Increasing sample sizes within universities, and expanding the number of institutions studied in the different countries, especially in the particularly regionally diverse India and China, would help ensure that all country specific differences are picked up, alongside those characteristics that are site specific.

4.7.2. Exploring interview and focus group findings

4.7.2.1. Reasons for food waste

The interviews and focus groups found that the key reasons for FW in catering were overfilling plates leading to plate scrapings and over producing food, leading to surplus food being produced. Goonan et al. (2014) also made the same findings when they carried out a similar FW related study on the catering sector in hospitals. Meanwhile, key causes of FW among self-catered residents were found to be a lack of food minimisation skills, as well as lack of suitable FW related facilities such as providing sufficient refrigeration and storage spaces. Romani et al. (2018) also made the same findings when they carried out FW themed interviews on households. This reaffirms that education provision in FW minimisation skills and the provision of suitable infrastructure are key to reducing FW, alongside other opportunities such as developing systems to estimate catered food generation levels and collaborating with FW charities that redistribute surplus food.

While focus groups and interviews tried to cover the diversity of students and FW mangers in the study sites, it is possible that they only covered some of the diversity within the specific canteen/residence in the specific University, as there was only one focus group and a maximum of three interviews per country. The focus group and interviews brought up interesting perspectives and insights on FW within these sites pertaining to both the universities and wider country scale issues. On the other hand, if these focus groups and interviews were replicated in different canteens in the studied universities, as well across other universities it may be possible to gain a broader, more comprehensive knowledge of the key opportunities and challenges to improving FW management in UK, Indian and Chinese Universities. It would also help ascertain how challenges and FW management strategy differs through institution-specific factors.

4.7.2.2. Barriers to food waste recycling

The key reasons why self-catered residents did not recycle their FW included a lack of awareness of the benefits, effort required to recycle, odour and safety concerns with segregating FW, as well as practical and infrastructural issues, financial factors and policy barriers from the residential agency and municipality responsible for FW management were considered. Refsgaard and Magnussen (2009) also made roughly the same findings when they carried out FW related focus groups on households. This shows that FW education, as well as FW recycling needs to be provided and made as easy as possible by residences and municipalities in order to improve FW management.

4.7.2.3. Impacts of interventions

Concerning the effect of informative interventions on FW related behaviours, significant improvements were found after the interventions, due to increased awareness of FW issues, and the benefits of trying to minimise personal FW contributions. This indicates that beyond changes to FW generation and recycling levels the interventions affected the FW-related attitudes and beliefs of the students. Although, as the post-intervention surveys did not have a statistically significant sample size, these findings are somewhat speculative. Luecke (2015) also found that similar interventions influenced FW beliefs and attitudes when they used similar interventions on catered university students. Concerning the comparison between UK, Indian and Chinese institutions, Indian students and canteen staff were more concerned about social issues with FW, due to a greater prominence of food insecurity in India (Iacovidou, 2012). On the other hand, UK and Chinese institutional stakeholders were more concerned about economic issues. In addition, UK staff had a particular concern about environmental issues, due to a greater awareness of environmental issues in the UK (Lorenzoni et al., 2007), and Chinese staff had a particular concern about upholding Chinese tradition regarding sustainable FW practices. There was also more self-reported FW resultant from culinary taste preferences and cultural diversity in India and China, when compared to the UK, due to India and China having greater levels of cultural and culinary diversity. While the comparisons between the UK, Indian and China cannot be supported in the literature, due to the novelty of the research, the findings are in-line with the survey responses. Adapting interventions based on country specific FW concerns could help improve their effectiveness. Additionally, a targeted approach making informed menu choices based on students' preferences could represent a particularly significant opportunity for FW reduction in Indian University canteens.

4.7.3. Exploring food waste reduction findings

4.7.3.1. Impacts of awareness campaign

The FW reduction interventions were effective in both the UK and Indian University canteens, and based on focus group responses at the Chinese University, they may have been effective at

the Chinese University. FW was reduced in the canteen by 13.2%, when compared to the pre-intervention baseline figure in the UK University canteen, and was likely to have contributed to at least an equal reduction in FW at the Indian canteen, given the survey and focus group responses. This FW reduction figure is broadly similar to that seen in similar studies with FW reductions of between 9% and 19%, when using educational and feedback prompts as interventions in university canteens (Ahmed et al., 2018; Whitehair et al., 2013; Manomaivibool et al., 2016). Additionally, Kallbekken and Saelen (2013) found that FW reduced in buffet restaurants by a comparable 20.5% when using salient sign interventions, thus supporting the findings of this study. Conversely, a study carried out by Ellison et al. (2019) found a decrease in FW of only 4% with similar interventions, showing that there may not always be a large drop in FW generation. In addition, as the FW quantities at the canteen were combined at source with the self-catered FW from the UK University residence, some changes in FW that were recorded may have resulted from fluctuations in the self-catered FW stream. With this being said, catered FW makes up the majority of the total FW stream at the residence (~71%) and there was a 11.4% reduction of total FW at the residence (including self-catered FW) post-intervention. Considering this, and the fact that the majority of studies found comparable outcomes using similar interventions, it can be inferred that the results of the study are reliable, and that a FW reduction of around 13% could be expected when carrying out the same interventions in other university canteens in the UK, and perhaps India and China. From this, it can be gleaned that such interventions are an effective method for reducing FW and its related impacts. The interventions were highly cost effective and would be very easy to replicate (Kallbekken and Saelen, 2013). With this being said, there is a lack of long-term studies showing the effect of using informative printed interventions on FW reduction over time, with beliefs that their impacts may wane over time (Arlt et al., 2011). Altogether, this research helped identify to what extent such interventions could reduce FW in a UK University and why, but could only suggest FW reduction levels that could be expected in similar UK, Indian and Chinese Universities. The interventions would need to be tested in a range of UK, Indian and Chinese Universities to be able to gain accurate figures on average FW reductions, as well as the range of FW reductions achievable.

4.7.3.2. Impacts of Covid-19 infrastructural changes

It is clear that the Covid-19 impacts (both Covid-19 related infrastructural changes and general impacts of Covid-19 on FW behaviours) contributed significantly to reducing FW at the Indian University canteen. The awareness campaign would likely have contributed to the 50% per capita FW reduction post-Covid and post-intervention, but the majority of the reduction was likely to have resulted from the Covid-19 impacts. Looking at the survey and focus group responses it is probable that the FW reduction interventions were at least as impactful at the Indian canteens as in the UK canteens. Assuming the interventions had an equal impact in both

countries, Covid-19 impacts will have been responsible for a per-capita FW reduction of over 35%. This is reportedly due to a move to table service, improved food demand estimation, a scaled down menu, and increased FW awareness after the emergence of the Covid-19 pandemic. While it is helpful to understand that Covid-19 related interventions can aid FW reduction in an Indian University, other universities may have taken different strategic decisions pertaining to Covid-19 and FW management which could have had vastly different implications on FW generation. This therefore shows that Covid-19 could lead to FW reduction in Indian Universities, but by no means shows that Covid-19 related changes would result in FW reductions in all Indian Universities.

4.7.3.3. Combined impacts of awareness campaign and Covid-19 infrastructural changes

While the combined effect of such specific changes on FW generation have not been assessed in the literature, there have been studies assessing the impact of similar changes which have witnessed significant reductions in FW generation in researched canteens. Papargyropoulou et al. (2019) found that canteens with served meals may generate less than half of the amount of FW per capita than self-service buffets, as servers can instigate effective portion control, thus supporting the theory that a switch to table service reduced FW at the Indian canteen. On the other hand, Matzembacher et al. (2020) found that self-service canteens generated less FW per-capita due to customers having more autonomy to pick a portion size proportionate to their appetite. Meanwhile, improved food demand estimation has been reported at the Indian canteen since Covid-19, due to the canteen being better able to know how many students to serve on a given day. Leverenz et al. (2020) reported that improved food demand estimation allowed for more suitable food production levels for hotel breakfast buffets, allowing for end of service food surpluses to reduce by almost two-thirds, thus showing that improved food estimation can bring about significant FW reductions, as is reported to have occurred post-Covid-19 at the Indian canteen. In addition, the refined and more standardised menu that was introduced in the Indian canteen post Covid-19 was reported to have led to less FW being generated at the canteen. Cohen et al. (2014) and Schwartz et al. (2015) found that standardising menus at school canteens in the US led to reductions in wastage of up to 28% for certain food items, showing that menu changes can bring about significant FW reductions.

Both the behavioural change interventions and Covid-19 related changes likely contributed to the 50% FW reduction observed at the Indian canteen; however, the combined impact of such specific changes on FW generation have not been assessed in the literature. Nevertheless, studies have been conducted assessing the impact of awareness campaigns and infrastructural changes on FW generation, showing similar FW reductions in similar settings. Visschers et al. (2020) found a similar awareness campaign to that used in this study improved FW attitudes,

but did not lead to reduced FW generation, whereas when smaller meal portions were made available in combination with the awareness campaign, plate scrapings were reduced by 20%. This shows that a combination of behavioural change interventions and infrastructural interventions (such as the one used in this study) can lead to significant FW reductions, with the infrastructural changes having the greater contribution to FW reduction.

Additionally, Malefors et al. (2021) compared the impact of an awareness-raising behavioural-change intervention with infrastructural interventions on FW generation at Swedish schools, finding that a behavioural-change intervention (similar to that used in the PhD) led to a 35% reduction in plate scrapings. Malefors et al. (2021) also provided feedback on daily FW generation at the canteen, allowing the students to report why they wasted the food, such as specific taste issues with certain meals. The intervention led to a 62% reduction in surplus leftover food, through the menu being refined, as well as a 37% reduction in plate waste through improving the FW behaviours of the students. The FW feedback poster used at the Indian canteen (as part of the awareness campaign), as well as the post-covid menu refinement and improved food demand estimation, are similar in nature to the changes introduced by Malefors et al. (2021), showing similar impacts on overall FW generation. The findings of this study, in alignment with those of Visschers et al. (2020) indicate that infrastructural changes (such as those introduced at the Indian canteen post-Covid-19) lead to a greater FW reduction in canteens than awareness campaigns (such as those introduced at the UK and Indian canteens).

Covid-19 was also reported to have brought an increased FW awareness and resultant reductions in FW generation at the Indian canteen. Studies by Burlea-Schiopoiu et al. (2021) and Principato et al. (2020) reported similar findings, thus supporting this theory. However, these studies only looked at attitude changes and did not assess specific FW reductions, thus it is difficult to quantify what impact Covid-19 related behavioural change might have had on FW generation at the Indian canteen.

Positive impacts were reported on FW attitudes resultant from Covid-19, and the majority of studies found comparable outcomes when canteens underwent similar infrastructural changes. It can be inferred therefore, that the Covid-19 related changes were likely responsible for the majority of the per-capita FW reduction observed at the Indian University canteen. It also indicates that there could be a real opportunity for combining awareness campaigns with infrastructural changes in canteens to bring about enhanced reductions in FW generation. It is also likely that the behavioural change interventions had a greater impact, due to complimentary Covid-19 related attitude changes concerning FW (Burlea-Schiopoiu et al., 2021; Principato et al., 2020). Furthermore, similar impacts may be possible when enacting comparable behavioural change and infrastructural changes post Covid-19 in other University

canteens in India. From this, it can be gleaned that such infrastructural changes are a highly effective method for reducing FW and its related impacts.

4.7.3.4. Additional food waste reduction opportunities

Additionally, other studies have shown that other FW reduction methods such as adopting trayless canteens (Aramark, 2008) and reduced portion and utensil sizes (Wansak and Van Ittersum, 2013; Kallbekken and Saelen, 2013) can be highly effective, and thus where possible the most effective approach may be to combine all of these interventions to bring about longer-lasting greater reductions in FW. In addition, redistributing surplus food can help reduce FW further, as it tackles the surplus food stream, while the other interventions mentioned target the reduction of plate scraping FW, and should be carried out where possible (Feeding India, 2020). As was discussed in the focus groups and interviews, surplus food from catering establishments can be reduced through using apps such as Too Good To Go, which reduces FW by offering discounts on uneaten food before the closure of canteens (Maganti, 2018). The final daily surplus can then be redistributed by FW charities (Feeding India, 2020). Self-catered surplus food can also be reduced with residence-specific food sharing schemes, as well as apps such as Olio, which allows users to share, or collect surplus foods from throughout the network (OLIO, 2018). Reducing FW in the catering and residential sectors is incredibly important, as these sectors are two of the largest sources of global FW (WRAP, 2017) and lead to particularly high GHGs per quantity of FW. This is due to upstream emissions resultant from agriculture, processing, storage and transport, equivalent to over 2 tonnes of CO_2eq per tonne of FW (EC, 2010). FW also contributes significantly towards food insecurity (WRAP, 2017).

4.7.4. Exploring food waste recycling findings

4.7.4.1. Impact of interventions

The FW recycling interventions in this study resulted in increases in FW segregation by between 70 and 100%. While this increase is highly promising, studies carrying out comparable interventions only found increased FW recycling of between 9% and 28% (Burn, 1991; Shearer et al., 2016). Moreover, as previously mentioned, the self-catered FW was combined at source with the catered FW from the University residence, meaning that some of the changes in FW that were recorded may have resulted from fluctuations in the catered FW stream. Additionally, with self-catered FW contributing to a smaller proportion of the total FW generated at the residence (~29%), the true impact of the interventions on self-catered students is less certain than that of the catered interventions. With this being said, the interventions contributed towards increases of between 20 and 30% for total FW generated at the residence (including catered FW). Additionally, the surveys and focus groups indicated that

the interventions had a significant effect on FW related awareness, attitudes and behaviours, thus supporting the findings. Overall, it can be inferred that a replication of such FW segregation increases (70-100% increases) resulting from these interventions may be unlikely in similar self-catered residences in the UK, as previous studies show smaller increases. However, smaller yet still significant impacts, such as 20-30% FW recycling increases in-line with previous studies could be expected. Additionally, as with the FW reduction interventions, the FW recycling interventions were cost effective (Burn, 1991). Overall, the research would need to be replicated and studied in multiple UK Universities to ascertain typical FW recycling increases that could be expected when introducing these interventions.

There is also a lack of long-term studies showing the effect of printed and oral information, email reminders and public pledges on FW recycling increases over time. It is possible that their impacts will wane over time (Arlt et al., 2011).

Moreover, practical, financial and political barriers, mentioned by residential managers in the interviews section, would likely be apparent in numerous universities, thus unless situations change and FW recycling is made compulsory and offered by all local municipalities in the UK, it may not be feasible for many similar residences in UK universities to offer FW recycling for self-catered students.

4.7.4.2. Additional food waste recycling opportunities

Furthermore, other studies have used different interventions such as making FW bins more visually pleasing and having FW volunteers by the bins (Li et al., 2017) as well as introducing incentives for recycling FW (Li et al., 2017) to great effect. When possible, combining all possible effective FW recycling interventions could bring about the most significant, sustained increases in FW recycling in residences. Improvements in FW recycling and treatment are incredibly important in bringing about profound benefits such as reducing GHGs attributed to FW, as well as increasing nutrient recycling, reducing air pollution and producing renewable energy (Vision 2020, 2013).

4.8. Conclusion

This research has helped add to the literature, making novel findings through identifying key differences in food waste behaviours between catered and self-catered students, as well as UK, Indian and Chinese students, alongside quantifying food waste reduction opportunities associated with the Covid-19 pandemic. The study also agreed with findings from other studies that educational and awareness raising interventions, as well as infrastructural interventions can help improve food waste related attitudes and change behaviours, resulting in reduced food waste and increased food waste recycling, which in turn results in wide-ranging benefits.

Regarding the objectives of the PhD, this chapter has helped gain experimental behavioural change data at the UK University, and Indian institute B, while, to a lesser extent, insights were gained in China also.

Objective 2a, assessing the effectiveness of food waste reduction interventions, has been achieved in the UK and China, with the food waste interventions leading to a food waste reduction of almost 15% in the UK and potentially in India. Focus group responses indicate that a similar impact may have been achieved in the Chinese canteen; however, food waste reduction levels may have been slightly lower given the scale of existing awareness campaigns in the country. Meanwhile the Covid-19 infrastructural changes may have contributed to a further food waste reduction of around 35% in the Indian canteen. This shows that the food waste reduction interventions were highly effective; however, the infrastructural interventions brought about by Covid-19 appeared to have a greater impact than the behavioural change interventions. A combination of behavioural and infrastructural interventions would therefore be advised for similar institutions trying to reduce food waste.

Objective 2b, assessing the effectiveness of food waste segregation interventions, has also been achieved with the food waste segregation interventions leading to increases in food waste segregation by between 70% and 100%. It is therefore recommended that food waste segregation campaigns at self-catered university residences should be combined with similar food waste segregation interventions in order to increase segregation rates.

Objective 2c, gaining insights into students' food waste related attitudes, how they differ between the different institutions and how attitudes are affected by the interventions, has also been achieved. It is clear that there were prominent reasons for food being wasted such as students taking too much food. Reasons for not recycling food waste were also identified including students being put off by the extra effort required to recycle. It is also clear that food waste attitudes differed substantially in the UK, India and China, with UK students primarily concerned about the economics and Indian students most bothered by social issues of food waste. Additionally UK and Chinese students were more concerned about environmental issues than Indian students were. Moreover, beyond FW reduction and recycling increases it appears that behavioural change interventions may improve students' FW generation attitudes and beliefs.

Altogether, food waste reduction interventions led to a 13.4% decrease in food waste in a UK University canteen, while combined interventions and Covid-19 impacts led to a 50% decrease in an Indian University canteen. Moreover, food waste recycling interventions led to a 70% increase in recycling of self-catered students at a UK residence. Assessing the economic and

environmental implications of the food waste segregation increases and food waste reductions could allow for a quantification of the benefits that could be achieved through these interventions.

CHAPTER 5: LIFE CYCLE ANALYSIS AND LIFE CYCLE COST

5.1. Introduction

Due to their unique business structure, universities require their own FW management systems, with varying environmental impacts associated with different strategies. However, there is no consensus on the best practices for FW management, while, different institutions create varying amounts and compositions of FW (Salemdeeb et al., 2017). In addition, there is a lack of understanding regarding the level of the cost and GHG reduction opportunities associated with FW reduction and recycling increases through behavioural change (Reynolds et al., 2019). Moreover, there is a lack of research on the GHG and cost competitiveness of novel pre-treatment technologies, such as food waste desiccation and HTC, or how differing costs and infrastructures in different countries effects optimal FW management strategies.

This chapter uses data on FW generation, composition and treatment from Chapter 3, as well as FW reduction and recycling levels from Chapter 4 to conduct an LCA and LCC to assess the GHG and economic impacts of incorporating different FW reduction, recycling and treatment options at the studied Universities when compared to their current business as usual strategy. This chapter will discuss the methods used (including the goal and scope of the assessments and the specific FW management scenarios), and then the GHG impacts, economic impacts, and cost per GHG mitigation associated with the different scenarios broken down into the respective countries of the UK, India and China, before exploring the specific risks and opportunities of the scenarios.

5.1.1. Specific objectives

The specific objectives of the chapter concerning FW management strategies at the UK, Indian and Chinese universities are the following:

1. Identify the main country-specific, site-specific and general factors leading to GHG mitigation from FW management in the UK, Indian, and Chinese Universities.
2. Identify the main country-specific, site-specific and general factors leading to cost savings from FW management in the UK, Indian, and Chinese Universities.
3. Understand the primary drivers affecting the combined GHG and economic performance of FW management strategies.

5.2. Methodology

5.2.1. Goal and scope

The GHG and economic assessments aimed to identify areas in which FW management systems could be improved at the studied institutes when compared to their business as usual practices, in order to optimise their FW management approaches. The scope of the study included upstream impacts associated with FW reduction, as well as comparing the following emission factors and costs with different FW treatment strategies: construction emissions and costs; transportation emissions; energy and heat use in processing FW; maintenance and staffing costs from running FW treatment systems; as well as biogenic atmospheric emissions. This was compared against the following mitigation factors: heat and energy generation, biofertilizer and soil amendment production; as well as animal feed production and FW collection savings where applicable. The functional unit of the system was 1 tonne of FW generated at the studied site as received. For the FW reduction scenario, the system boundary concerns all of the upstream processes from initial production of the food, through to end disposal which was assumed 1.98 tCO_2eq/tFW (EC, 2010). For the FW recycling scenario and all of the FW treatment scenarios, the system boundary includes all processes from the point in which the FW is generated through to end disposal. Scope and boundaries are displayed in figures 5.1 and 5.2 for the GHG and economic assessment respectively.

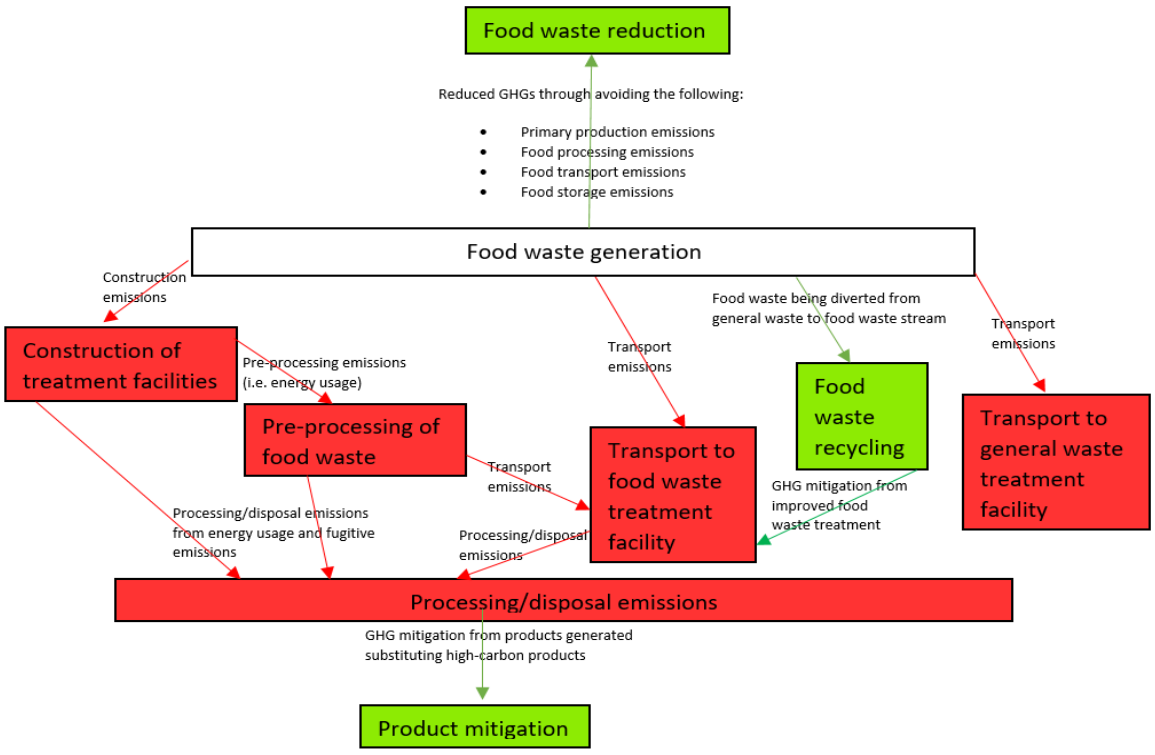


Figure 5.1.

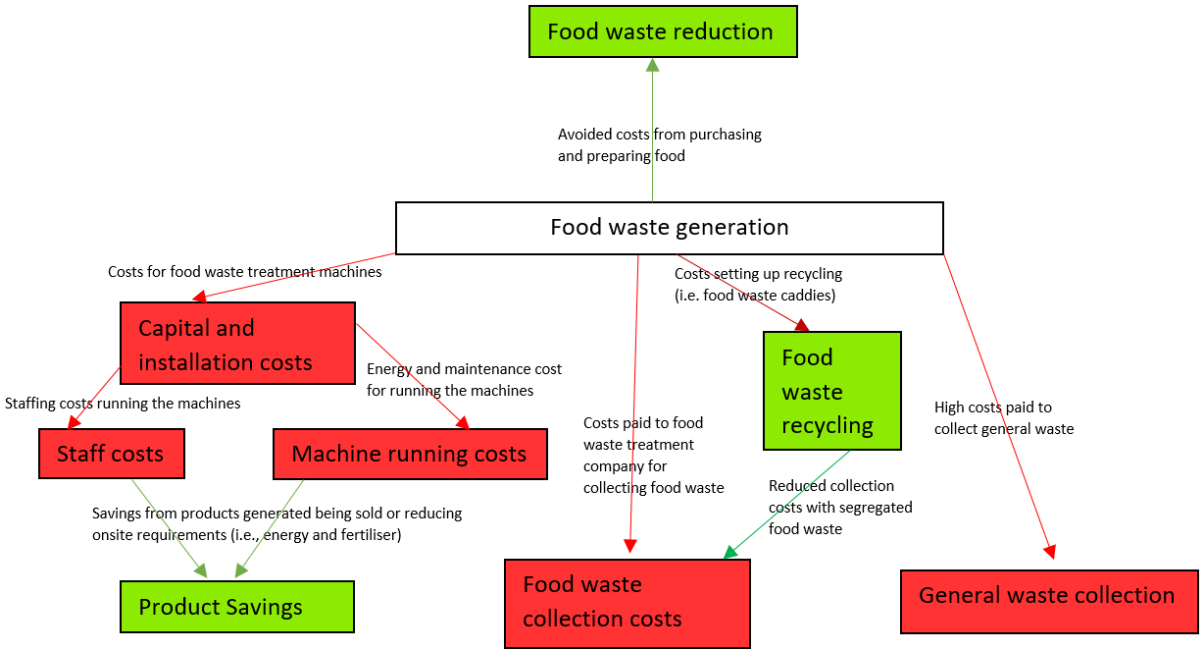


Figure 6.2.

5.2.2. Scenario Analysis

Scenarios were formed based on possible FW management options at the different Universities. This included a business as usual scenario, where the Universities continue the current FW management approach. It also included FW reduction and FW recycling scenarios, with achievable FW reductions and recycling increases as ascertained in Chapter 4. Further scenarios were formed based on onsite FW treatment scenarios, where Universities would purchase FW treatment equipment and treat all of their FW onsite. The scenario options are outlined in Table 5.1. and are explained in more detail below. All of the scenarios are based on a 20-year timeframe. It was assumed that the BAU strategy would be continued for 20 years and this was compared to the adoption and continuation of FW reduction and recycling scenarios for 20 years. It was also compared to the construction, purchasing, running and maintenance of the different onsite FW treatment plants associated with the different onsite FW treatment scenarios at each respective University. It was assumed that onsite FW treatment involved no transport emissions. BAU, scenarios 1, 2, and 5a have site and/or country specific differences, whereas all of the other scenarios are the same in all sites.

Table 5.1. Options and brief explanation

Scenario options			
Country	**UK University**	**India: Indian Institutes A and B**	**Chinese University**
BAU			
S1: FW reduction			
S2: FW segregation			
S3: AD			
S4: Composting			
S5: Desiccation			
a) Desiccation and BAU			
b) i. Desiccation and incineration (heat)			
ii. Desiccation and incineration (CHP)			
c) Desiccation and animal feed			
S6: HTC			
a) HTC and incineration			
b) i. HTC and soil amendment (heat)			
ii. HTC and soil amendment (CHP)			
S7: Landfilling			

5.2.2.1. Business as Usual (BAU)

UK

The University currently produces around 160 tonnes of FW per year which is sent offsite for AD with an average transport distance of 52km. Regarding economics, the current practice of FW collection and transportation to an AD facility costs the University £90 per tonne.

Most of the students at the UK University are self-catered with university residences previously not offering FW recycling. FW recycling is optional in the university residence that does offer FW recycling. Altogether, this means most of the University's FW gets collected as general waste. The UK University's general waste then goes to an RDF sorting plant, after sorting around 25% is utilised locally, while 75% is utilised in N. Europe with an average transportation of 739km by road and 210km by ferry, meanwhile general waste collection costs £173 per tonne.

India: Indian Institutes A and B

Indian institute A produces roughly 1,860 tonnes of FW per year. Currently around 0.5TPD of FW is anaerobically digested on site, with the products utilised onsite. A further 0.35TPD of raw FW from self-catered residences is composted on site along with green waste, with the compost being used in the soil amendment of green spaces around campus. The remaining 4.25TPD of FW generated on site is sent for landfilling offsite.

Indian institute B produces around 83 tonnes per year, with all of the FW generated being composted and utilised onsite.

China

The Chinese University has eight campuses. The Jinan Campus produces around 480 tonnes of FW per year and sends all of its FW to be anaerobically digested at a site around 33km away.

5.2.2.2. Scenario 1: Food waste reduction

Scenario 1 involved the addition of the FW reduction interventions and associated FW reductions discussed in the behavioural change chapter. In the UK, FW was reduced by 13.4%. In India, the pre-intervention FW generation data was gained pre Covid-19 whilst the post-intervention data also included Covid-19 impacts with an overall 50% reduction in per capita FW. The Indian FW reductions also included extra costs in the form of hiring extra serving staff, with the staff to customer ratio going from 15:1 to 10:1. It was not possible to conduct FW reduction interventions in China due to Covid restrictions, so the FW reduction scenario was not included. Regarding environmental impacts, it was assumed that per tonne of FW avoided 1.98 tonnes of CO_2eq was mitigated (EC, 2010). Regarding economics, the cost saved depended on the average cost spent purchasing each tonne of food wasted and the cost of FW disposal in each country.

5.2.2.3. Scenario 2: Food waste segregation

Scenario 2 involved the addition of the FW segregation interventions and associated FW segregation increases in the behavioural change chapter. As all students are catered in the Indian and Chinese Universities being studied, this scenario only applies to the UK University. Scenarios included recycling in one residence with 350 self-catered students with and without interventions, as well as recycling in all University residences (1857 self-catered students) with and without interventions. At the studied site, 350 self-catered students recycled around 2 tonnes of FW per year, while after the interventions mentioned in the behavioural change section FW recycling increased by around 70%, to an expected 3.5 tonnes per year. It was assumed that the same per-capita recycling rate would be possible at all sites, and the same impact from the interventions would be observed (70% increase in recycling rates). Recycled FW was anaerobically digested locally as opposed to being used as RDF further afield. GHGs associated with each treatment scenario were compared, with the difference in associated GHG emissions of each treatment (tCO_2eq/tFW) multiplied by the quantity of FW, while there was an economic saving of £83 per tonne of FW recycled (£90 per tonne FW collected, compared to £173 per tonne general waste collected).

5.2.2.4. Scenario 3: Anaerobic digestion

Scenario 3 comprised of onsite AD, involving the purchasing of an AD unit able to process all of the FW generated at each University, with the biogas being used for heat and energy (using a CHP boiler) and the digestate being used to substitute chemical fertiliser use onsite. Biomethane potential MP was calculated through conducting an experimental biomethane potential test on the UK University FW. The theoretical biomethane potential was also calculated based on the CHNS content of the FW (equation 5.1), using Boyle's equation (where C stands for carbon, H for hydrogen, O for oxygen, and N for nitrogen). The biodegradability index was then calculated by dividing the experiential biomethane potential (BMP_{ex}) by the theoretical biomethane potential (BMP_{th}) (equation 5.2) (Nielfa et al., 2015). For India and China, the theoretical biomethane potential was calculated and was then multiplied by the biodegradability index to gain realistic biomethane potential estimates for the different sites. A CHP boiler would be used to generate heat and energy, with parasitic loads, conversion efficiencies and biomethane assumptions based on data provided by the proposed AD supplier, as shown in Table 5.2. Regarding economics, the cost of buying, running and maintaining the machine was assessed through using supplier quotes, as well as energy and staffing costs from the literature.

$$BMPth = 22400 \times \frac{\left(\frac{C}{2}\right)+\left(\frac{H}{8}\right)-\left(\frac{O}{4}\right)-\left(\left(3\times N\right)\frac{3\times N}{8}\right)}{(12\times O)+H+(16\times O)+(N\times 9)} \quad (5.1)$$

$$Biodegradability\ Index = \frac{BMPexp}{BMPth} \quad (5.2)$$

5.2.2.5. Scenario 4: Composting

Scenario 4 comprised of onsite composting, involving the purchasing of composting machines able to process all FW generated at the studied sites with the compost being utilised on the campuses thus substituting peat-based compost currently being used on site. Regarding energy usage, it was assumed that either 2HP or 3HP shredders and 1.5 to 3.7kW composting machines would be used for processing between 2 and 5 tonnes of FW per day respectively according to supplier specifications. Additionally, it was assumed that the compost lost 56% of its original C content, as based on the literature (Hermann et al., 2011). Regarding atmospheric emissions, it was assumed that 0.00048% of N in the FW would form N_2O and 0.0011% of C would form CH_4 (Hermann et al., 2011). GHGs associated with atmospheric emissions of N_2O and CH_4 are shown in equations 5.3-5.6, where FW(dry) refers to the dry weight of the FW, C and N refer to the elemental fraction of C and N in the FW respectively (Hermann et al., 2011). Resultant CH_4 and N_20 emissions had a global warming potential of 28 and 298 times that of CO_2 respectively (IPCC, 2014). It was also assumed that the compost

would substitute peat and would result in 830.52kgCO_2eq/tcompost as based on the literature (Roy et al., 2020). Regarding economics, the cost of buying, running and maintaining the machine was assessed through using supplier quotes, as well as energy and staffing costs from the literature, with the compost produced being used onsite to avoid paying market cost for compost.

$$CH4\ (total) = FW(dry) \times C\ \times (0.0011) \quad (5.3)$$

$$\text{Global warming potential (landfill gas)} = 28\ \times\ \text{CH4 (total)} \quad (5.4)$$

$$\text{N2O (total)} = \text{FW(dry)} \times \text{N} \times (0.00048) \quad (5.5)$$

$$\text{Global warming potential (landfill gas)} = 298\ \times\ \text{CH4 (total)} \quad (5.6)$$

5.2.3. Scenario 5: Desiccation

Scenario 5 comprised of onsite desiccation of FW, involving the purchasing and installation of an onsite desiccation system at all of the studied Universities with the desiccated FW being treated/utilised in the following way:

a) Combined with BAU approach,
b) Incinerated onsite for energy generation,
c) Sold as animal feed, substituting conventional feed.

5.2.3.1. Scenario 5a: Desiccation with offsite anaerobic digestion

Scenario 5a involved onsite desiccation with a continuation of the BAU FW treatment approach (AD offsite in the UK University and the Chinese University, offsite landfilling and onsite AD and composting in Indian institute A, onsite composting in Indian institute B). It was assumed that desiccation removed all moisture content in the FW. This meant that much smaller quantities of FW needed to be collected and transported from the Universities that had offsite FW treatment (the UK University, Indian institute A and the Chinese University). This was calculated against the construction and energy GHG emissions, as well as the purchasing and running cost of the machines.

5.2.3.2. Scenario 5b: Desiccation with onsite incineration (both 5b i. and 5b ii.)

Scenario 5b involved desiccation with incineration of the desiccated FW onsite in a biomass boiler. Assessments were made for both 5b i., using a biomass boiler to generate heat to substitute natural gas, as well as 5b ii., using a CHP boiler to generate both heat and energy to substitute both natural gas and grid energy used onsite. It involved pelletizing machines and biomass boilers, as well as the desiccators. Energy generation was calculated on a dry ash free

basis using Friedl's equation (Friedl et al., 2005) (equation 5.7), with energy generation figures shown in Table 5.2.

$$HHV = 3.55Cx^2 - 232C - 2230H + 51.2 \times H + 51.2C \times H + 131N + 20600 \quad (5.7)$$

5.2.3.3. Scenario 5c: Desiccation with use as animal feed

Scenario 5c involved desiccation with the desiccated FW being sold as animal feed. This scenario is not currently allowed under UK legislation, but this scenario would be run under the assumption that it would be made possible, while it is currently possible in both India and China. It was be assumed that the animal feed would substitute commercial animal feed in the respective countries, offsetting related emissions and being sold at half the market rate (Albizzati et al., 2021) with all costings, savings, GHG emissions and mitigations detailed in Table 5.2.

5.2.4. Scenario 6: Hydrothermal Carbonisation

Scenario 6 comprised of onsite HTC, including the purchasing of a HTC unit capable of processing all FW generated onsite, producing HC and PW with the products being utilised in the following ways:

a) HTC with use of HC and PW for soil amendment and biofertiliser use
b) HTC with incineration of HC for energy generation and AD of PW for energy and biofertiliser generation

5.2.4.1. Scenario 6a: Hydrothermal carbonisation with soil amendment

Scenario 6a involves HTC with use of the HC and PW produced as a soil amendment product and biofertiliser respectively. The process conditions were chosen to optimise the solid and carbon yields, with a process temperature of 190°C and residence time of 20 minutes and using the natural moisture content of the FW. The HC would be used as a soil amendment product onsite substituting current peat usage (Roy et al., 2020), while the PW would be used as a biofertilizer substituting chemical fertilisers used onsite, with mitigation per tonne N varying in each country (Kongshang, 1998). Solid yields, HC yields, energy inputs, as well as levels of C and N retained in HC and PW were calculated using a model by Borbolla-Gaxiola et al., (2022) detailed in Table 5.2., while it was assumed the soil amendment and biofertiliser products could be used to avoid paying market cost for compost and synthetic fertilisers onsite.

5.2.4.2. Scenario 6b: Hydrothermal carbonisation with combustion

Scenario 6b involved HTC with combustion of HC and AD of PW. It encompasses the purchasing of biomass boilers, as well as anaerobic digesters large enough to process all FW in the

different Universities, as well as the HTC unit. The process conditions were chosen to optimise net energy generation, with a process temperature of 250°C, residence time of 20 minutes and using the natural moisture content of the FW. The PW from HTC and biogas from AD would be used to power the HTC process. The remaining HC would be combusted for both 6b i., using a biomass boiler to generate heat to substitute natural gas, as well as 6b ii., using a CHP boiler to generate both heat and energy to substitute both natural gas and grid energy used onsite. In addition, the digestate formed from AD would be used onsite to displace chemical fertilisers. Solid yields, HC yields and energy generation, from HC and AD of PW was calculated using a model from a member of my research group (Borbolla-Gaxiola et al., 2022) with energy inputs and outputs detailed in Table 5.2.

5.2.5. Scenario 7: Offsite landfilling

Scenario 7 involved all sites landfilling all of their FW with transport distances corresponding to distances between the Universities and local landfilling sites, and costs per tonne of FW being estimated from the literature for each country. Methane emissions were calculated for each FW type for the different regions using equation 5.8. This was done by multiplying the quantities of landfilled FW on a dry basis, by the carbon fraction of the FW, the dissimilation factor of biogenic carbon as landfill gas (LFG), the proportion of carbon in the FW that would be expected to turn into LFG, (0.64) and the proportion of LFG that would be expected to be methane (0.55), (Manfredi et al., 2009). The quantities of methane were then converted into CO_2 equivalent emissions by multiplying total methane emissions by the global warming potential of methane, (28 times more potent than CO_2) (equation 5.9) (IPCC, 2014).

$$\mathrm{CH4\ (total)} = \mathrm{FW(dry)} \times (0.55\ \times 0.64) \tag{5.8}$$

$$\text{Global warming potential (landfill gas)} = 28 \times \mathrm{CH4\ (total)} \tag{5.9}$$

Other emissions associated with landfilling each tonne of wet waste (as received) such as construction, excavation, and onsite diesel use were also included using the following figures: diesel fuel, synthetic liner, and gravel, altogether totalling 8.8 kg CO_2eq/tonne FW [56], as shown in equation (5.10). In the equation Global warming potential (other) is the total (non-methane) emissions from running the landfill site (associated with the landfilled FW), and FW(wet) is the total wet FW (as received). The overall calculation factoring in methane emissions and other landfilling emissions is shown in Equation (5.11), where Global warming potential (landfill gas) is the overall CO_2eq mitigation from landfill avoidance, Global warming potential (total) is the total CO_2eq mitigation from methane avoidance, and Global warming potential (other) is the total (non-methane) emissions from running the landfill site.

$$\text{Global warming potential (landfill gas)(other)} = FW(wet) \times 0.0088 \quad (5.10)$$

$$\text{Global warming potential (total)} = \text{Global warming potential (landfill gas)} + \text{Global warming potential (landfill gas) (other)} \quad (5.11)$$

5.2.6. Scenario exploration

The scenarios were further explored in order to understand what opportunities and risks may be associated with the different FW management scenarios at the different Universities.

Numerous scenario explorations involved all of the scenarios to some degree. There was a Covid scenario where, based on reported FW data, FW generation onsite roughly halved (due to students being off campus or taking away their food, while FW recycling at Halls of residences stopped (due to logistical issues of reduced numbers and health and safety implications. As a result, there was an increased GHG mitigation from reduced FW, increases in GHG emissions from reduced FW recycling as well as reductions in the impacts of the FW treatment scenarios, due to reduced FW being treated onsite.

The 2040 scenario was a further scenario exploration that affected all scenarios. It involved having projected 2040 grid energy mixes and associated carbon intensities at the Universities in each of the countries. This scenario exploration thus influenced all scenarios that used, or generated electricity, with energy becoming less carbon intensive over time, due to decarbonisation strategies. The grid energy carbon intensity is set to go from (0.17 to 0.06 $kgCO_2eq/kWh$) in the UK (IEA, 2020; Statista, 2022), (0.7 to 0.31 $kgCO_2eq/kWh$) in India (IEA, 2020; IEA, 2022b), and (0.58 to 0.27 $kgCO_2/kWh$) in China (IEA, 2020; Song et al., 2022). This means GHG emissions associated with energy usage and GHG mitigation associated with energy generation would reduce.

The green grid scenario exploration concerned all technologies that use energy to treat the FW, with it being proposed that all energy would come from a green grid, with no GHGs associated with energy usage. This, therefore, means all energy inputs would be mitigated, meaning scenarios with large energy inputs would have greater GHG mitigation associated.

5.2.7. Sensitivity analysis

The LCA and LCC also involved the evaluation of the sensitivity related to key assumptions of variables used in the assessment. For economics, impacts on total LCC from realistic variability in the following was assessed: FW reduction costs (removing additional staffing costs); capital and installation costs for purchasing machinery (+/- 20%); Annual costs associated with FW treatment (+/- 20%); annual savings from FW treatment (+/- 20%); heat and energy generation efficiency of machines (+/- 20%); exchange rates for local currencies against US dollar (+/-

20%). For GHGs, impacts on total lifecycle GHGs from realistic variability in the following was assessed: heat and energy generation efficiency of machines (+/- 20%); fugitive methane escaping from anaerobic digester with onsite AD, 15% of total methane escaping (Flesch et al., 2011). The sensitivity analysis was performed to evaluate the most relevant parameters that might affect the results.

5.2.8. Life cycle inventory and assumptions

The full life cycle inventory (LCI) is completely disclosed and presented in the Appendix B1 and B2, with the relevant literature sources shown alongside the figures. Figures were gained from a mixture of suppliers, experimental data, the literature, and the GaBi professional database. Assumptions were made based on data from suppliers, as well as the literature. The assessment was conducted on a combination of GaBi LCA software and Microsoft Excel.

5.2.9. GHG assessment

Emission factors included construction, pre-processing (where applicable) and processing emissions, atmospheric emissions (where applicable), and transport emissions (where applicable). It was assumed that emissions in CO_2 would be equal to the carbon sequestered in the production stage. On the other hand, emissions in the form of methane, as well as N_2O emissions were assessed according to their GWP in comparison to the equivalent amount of carbon being emitted as CO_2 as shown in Table 5.2. (British Standards Institution, 2011). Mitigation factors included GHGs mitigated from substituting products that the treatment technologies produce, as well as carbon sequestration from retaining carbon in the end-products, with the GHG mitigation figures for substituting grid energy in each country, natural gas, fertiliser, peat and animal feed each shown in Table 5.2. Moreover, FW reduction mitigation factors included mitigating upstream factors from primary production of food to end FW production totalling 2.07tCO_2eq/tFW as shown in Table 5.2. (EC, 2010). All data for emissions and mitigation factors was gained from the literature, experimental data, and GaBi professional database.

5.2.10. Economic assessment

Regarding the economic assessments, costings for different management options were gained from the literature, as well as quotes from potential suppliers (Appendix B3). Cost factors were calculated, including capital and installation costs (cost to purchase machines/infrastructure), annual costs (energy, staff and maintenance), with the annual savings also being calculated (reduced collection costs, FW avoidance, and savings/sales from products created, and any government subsidies). Economic calculations conducted included the life cycle cost (LCC), the total cost/saving of the scenario over the course of a 20-year life cycle (Goedkoop et al., 2013),

as well as the simple payback time of the initial investment. The discounted payback time was assessed for the top two performing scenarios for each country, as well as the longest simple payback time for each Institute. The economic assessment compared the scenarios with the BAU FW management strategy at the different universities. The exchange rates used were 1.25 GB Pound per US Dollar, 0.013 Indian Rupee per US Dollar, and 0.15 Chinese Yuan per US Dollar, with figures taken from 19/05/2022 (XE, 2022), although there have been strong fluctuations in exchange rates over the course of the research (XE, 2023).

5.2.11. Combined economic value of cost reduction and CO_2 mitigation

The LCA and LCC were combined to assess the joint economic value of cost savings and CO_2 reductions through improved FW management. The GHG mitigation of the FW management scenario (tCO_2eq/tFW) was multiplied by the social value of CO_2 mitigation, 60 USD per tonne of CO_2eq mitigated, as taken from the literature (Stiglitz et al., 2017). This was then added to the net economic cost of the FW management scenario (USD/tFW), when compared to BAU, to calculate the combined value of economic and CO_2eq savings in USD/tFW as shown in equation 5.12.

$$\text{Combined saving} = \left(\left(\frac{\text{Net GHG emissions}}{\text{tFW}}\right) \times 60\ USD\right) + \left(\frac{Net\ cost}{tFW}\right) \quad (5.12)$$

5.2.12. Assessment mechanisms

The environmental and economic assessments were carried out on Microsoft Excel. Components, figures and sources (literature, experimental and GaBi LCA database) for construction, transport, atmospheric and energy emissions, as well as product mitigation were calculated using formulas 5.1-5.11. All figures are detailed in Appendix B1. Net GHG impact per year (tCO_2eq) was calculated by subtracting the GHGs from product mitigation from the combined total of the energy emissions, transport emissions, atmospheric emissions, and a 20^{th} of the construction emissions. Figures were then compared to the BAU approach by subtracting the net BAU emissions. The net GHG impact per tonne FW (tCO_2eq) was gained by dividing the net GHG impact per year (tCO_2eq) by the number of tonnes of FW generated onsite every year. Furthermore, the net GHG impact over the lifecycle (tCO_2eq) was calculated by multiplying the Net GHG impact per year (tCO_2eq) by the number of years in the lifecycle (20).

For the economic assessment, components, figures and sources (and literature, actual costs paid, and supplier quotes) for capital and installation costs, annual costs, collection savings, and annual product/cost savings are detailed in Appendix B3 and were calculated using formulas 5.1, 5.2, and 5.7.

Payback time (yrs) was calculated by dividing the capital and installation cost for the scenario by the total of the annual product/cost savings, plus the collection savings (or the savings by avoiding the expenditure related to the BAU FW treatment strategy), minus the annual cost. The net lifecycle cost/savings were calculated in Excel by adding the annual cost to a 20^{th} of the capital and installation cost, and then subtracting the net annual product/cost savings (USD/yr) and net savings associated with avoiding the BAU FW treatment approach (mainly collection savings). The net cost impact per tonne FW (USD) was gained by dividing the net cost impact per year (USD/yr) by the number of tonnes of FW generated onsite every year. Furthermore, the Net cost impact over the lifecycle (USD) was calculated by multiplying the Net cost impact per year (USD) by the number of years in the lifecycle (20). Costs were converted between USD and local currencies in Excel using figures from the literature.

Table 5.2. Inputs figures used for scenarios

Technology		UK University	Indian institute A, India	Indian institute B, India	Chinese University	Sources
Energy content	HHV	21.29MJ/Kg	20.34 MJ/Kg*	20.34 MJ/Kg*	20.33MJ/kg*	Friedl et al., 2005
	HHV adjusted*	21.29MJ/Kg	21.34MJ/kg*	21.34MJ/kg*	21.32MJ/kg*	UK FW experimental data
AD figures	Experimental BMP (m3/T)	385.72	-	-	-	UK FW experimental data
	Theoretical BMP (m3/T)	579.16	556.17	556.17	551.03	Nielfa et al., 2015 (Boyle's equation)
	Biodegradability index	0.67	0.67	0.67	0.67	
	Adjusted BMP (mlCH4/gVS)	370.41	366.98	366.98	370.41	
	Methane generated (m3CH4/tonne FW)	86.30	82.57	82.57	86.30	
	Parasitic load heat/energy (% of heat/energy generated)	19/20	19/20	19/20	19/20	Supplier quotes
HTC energy/soil amendment figures	Energy input (KWh/T)	160.11/276.39	159.89/270.82	159.89/270.82	159.2/255.73	Borbolla-Gaxiola et al., 2022
	Energy yield %	0.81/0.67	0.82/0.69	0.82/0.69	0.82/0.71	
	Solid yield %	54.42/67.26	54.73/64.33	54.73/64.33	54.6/63.39	
	Carbon yield %	79.2/84.13	79.06/80.88	79.06/80.88	78.84/79.88	
	Nitrogen yield %	60	60	60	60	Ekpo et al., 2016
Desiccation figures	Energy input (KWh/T)	1.4	1.4	2	1.4	Supplier technical specifications with appropriate machines
	Mass reduction (%)	70	75	75	74	Assume 100% moisture reduction
Composting figures	Energy requirements (KWh/T)	0.08	0.08	0.05	0.08	Supplier quotes
Incineration	Energy requirements (KWh/T)	160	160	160	160	Mondello et al., 2017
Pelletizer	Energy requirements (KWh/T)	30	30	30	30	Fantozzi and Buratti, 2010

5.3. UK

Figures on GHG lifecycle emissions, LCC, and cost per GHG mitigation were generated for the different FW management scenarios at the UK University, with the scenarios being compared to the respective GHG emissions and costs associated with the BAU approach at the University.

5.3.1. GHG assessment

Regarding GHG emissions at the UK University, Table 5.3. and Figure 5.3. clearly show that the current BAU strategy results in significant GHG mitigations due to product mitigations. The majority of other FW treatment strategies (S4-7) had lower levels of GHG mitigation attributed to them. The only FW treatment scenarios that had a greater net mitigation than the BAU were AD onsite (S3) (due to reduced transport emissions), desiccation with heat/energy production S5b (i. & ii.), as well as desiccation and animal feed production (S5c). Desiccation and animal feed production had the greatest GHG mitigation of all scenarios due to it having a particularly high GHG mitigation from product substitution. Both behavioural change scenarios of FW reduction (S1) and FW recycling (S2) brought about net reductions in GHG emissions, as any reduction is additional to BAU GHG mitigation due to the scenarios not influencing the current FW treatment strategy. S1 brought about a significant GHG reduction of over 700 tCO_2eq over the lifecycle, which was the second greatest mitigation of all the scenarios when compared to the BAU approach. This was because FW reduction leads to the avoidance of significant upstream emissions from producing the food. Notably, landfilling (S7) provided the greatest net GHG emissions, totalling over 6000 tCO_2eq over the lifecycle. This was mostly due to its high atmospheric emissions.

Table 5.3. UK University GHG mitigation figures from FW management strategies

Scenario	BAU	S1	S2	S3	S4	S5				S6			S7
						a	b		c	a	b		
							i.	ii.			i.	ii.	
Construction emissions (tCO_{2eq}/yr)	2.31	-	-	2.3	2.2	4.6	3.3	3.3	2.3	40.8	44.1	44.1	28.2
Transport emissions (tCO_{2eq}/yr)	0.90	-	-	0	0	0.27	0	0	0	0	0	0	0.31
Atmospheric emissions (tCO_{2eq}/yr)	0	-	-	0	0.85	0	0	0	0	0	0	0	299.94
Energy emissions (tCO_{2eq}/yr)	0	-	-	0	0.002	13.45	13.52	13.52	13.45	7.43	0.07	0.07	0
GHG from product Mitigation (tCO_{2eq}/yr)	25.1	-	-	25.1	15.89	25.17	43.17	40.89	64.83	32.05	18.88	17.98	0
Net GHG impact per tonne FW (tCO_{2eq}/yr)	**-0.15**	**--0.23**	**-0.015**	**-0.16**	**-0.09**	-0.07	-0.18	-0.17	-0.32	**-0.12**	**-0.087**	**-0.08**	**1.88**
Net GHG impact per year (tCO_{2eq}/yr)	**-24.1**	**-36.12**	**-2.42**	**-25.05**	**-14.92**	-11.22	-29.49	-41.77	-51.27	**-19.82**	**-13.86**	**-12.95**	**301.35**
Net GHG impact over lifecycle (tCO_{2eq}/yr)	**-482.9**	**-722.30**	**-48.46**	**-501.02**	**-298.47**	-224.41	-589.82	-835.44	-1025.45	**-396.47**	**-277.13**	**-258.97**	**6026.98**

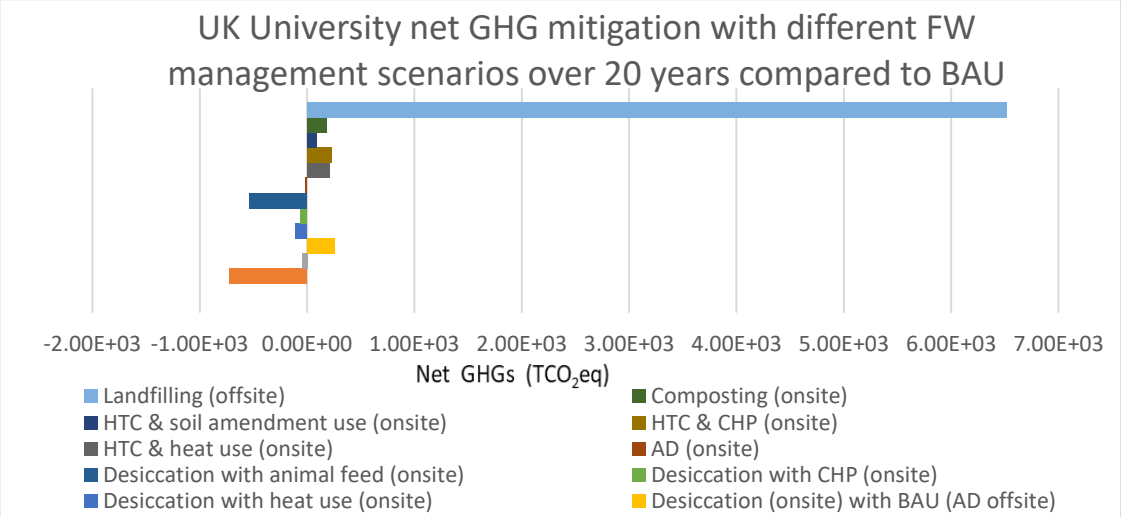


Figure 7.3.

5.3.2. Economics

Regarding economic impacts at the UK University, it is clear that the current BAU strategy results in significant expenditure over the lifecycle, as presented in Table 5.4. and Figure 5.4. All of the scenarios apart from desiccation and BAU (S5a), and HTC and soil amendment (S6a) resulted in net savings over the lifecycle. Desiccation and BAU did not result in net savings, due to high annual costs, resulting from high energy bills, outweighing FW collection savings. HTC

and soil amendment does not result in net savings because of its high capital and installation cost, high annual costs (due to large staff requirement and energy inputs), as well as not having particularly high product savings. In particular, the scenarios involving heat generation performed well because of the current high price of natural gas (EIA, 2022). Specifically, desiccation with heat generation (S5bi.) was the best performing scenario due to it having particularly high product mitigation savings and low initial and annual costs. AD (S3) and HTC with heat generation (S6bi.) also resulted in very large, but substantially lower lifecycle savings caused by them, having notably higher initial and annual costs than desiccation and heat due to the requirement of more complex, expensive equipment with considerably greater staff requirements. In addition, scenarios involving heat generation (S5bi. & S6bi) led to greater net savings than those involving CHP (S5bii. & S6bii), as the cost of natural gas was considerably higher than the cost of electricity at the time of assessment. Furthermore, the behavioural change scenarios of FW reduction (S1) and FW recycling (S2) brought significant net savings over the lifecycle caused by a combination of low initial and annual costs and large annual savings, in particular for FW reduction due to the avoidance of purchasing large quantities of expensive food. Additionally, because these scenarios (S1 & S2) did not influence the current FW treatment strategy, these could be combined with a specific FW treatment scenario (S3-6) to bring about further lifecycle savings.

Table 5.4. UK University economic figures from FW management strategies

Scenario	**BAU**	**S1**	**S2**	**S3**	**S4**	**S5**				**S6**		
						a	**b**		**c**	**a**	**b**	
							i.	ii.			i.	ii.
Initial cost (GBP)	0	0	304.2	141703.6	21323.6	37515	41373	41373	37515	122413.7	216298.9	216298.9
Annual costs (GBP/yr)	14400	510	318.3	10873.6	9452.4	14317.6	14512.0	14512.0	14317.6	126110.1	110916.1	110916.1
Annual product/cost savings (GBP/yr)	0	191647.7	0	542956.6	13020.7	0	1676330.5	1316009.9	5065.5	3362.4	664396.2	524844.8
Collection savings (GBP/yr)	0	0	1211.5	14400	14400	10123.2	14400	14400	14400	14400	14400	14400
Simple payback time (yrs)	N/A	0.0	0.0	0.3	1.2		0.0	0.0	7.3		0.4	0.5
Net lifecycle cost/savings (GBP)	288000	-3822753.6	-17558.1	-10788160.4	-338042.5	121403.1	-33482996.7	-26276584.9	-65443.1	2292742	-11141304.6	-8350276.6

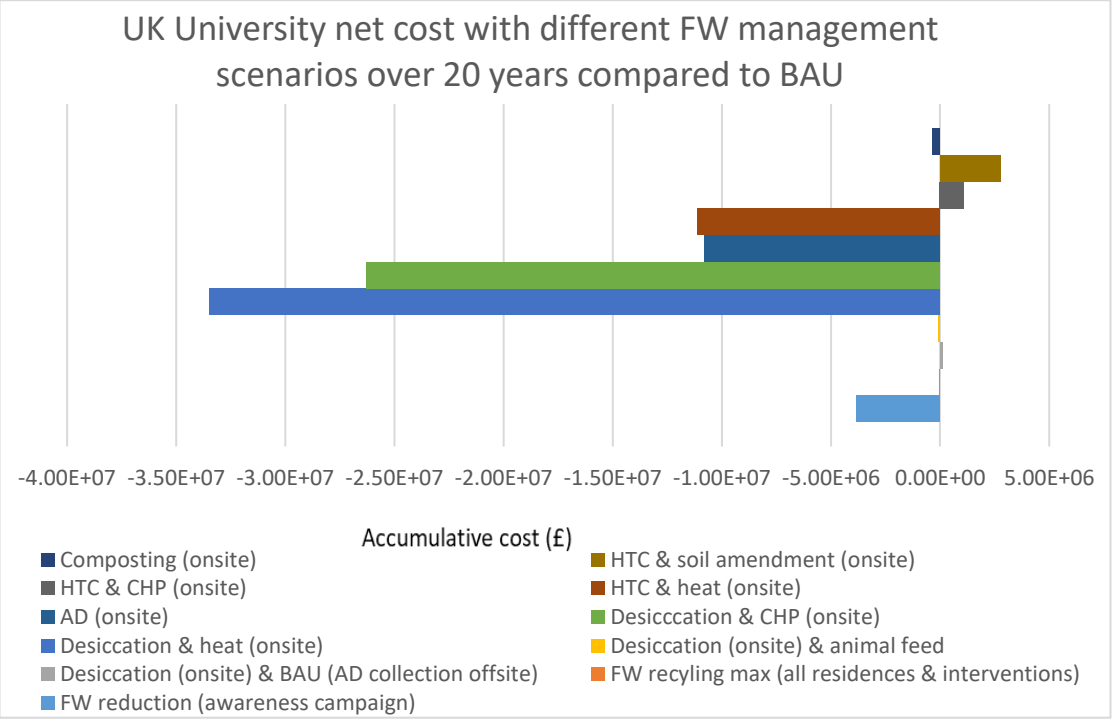


Figure 5.4.

5.2.3. Cost per tonne of CO_2 mitigated

There are a number of scenarios that provide both net GHG reductions and cost savings over the lifecycle, as shown in Figure 5.5. Desiccation with heat generation provides the greatest cost savings over the lifecycle, while also having the third greatest GHG mitigation out of all of the scenarios (only behind desiccation with animal feed and FW reduction). Both desiccation and HTC with heat generation have a greater GHG reduction and cost saving than their respective scenarios with CHP generation, due to energy being comparatively cheap and having low carbon intensity in the UK. Desiccation with animal feed production produces the greatest GHG mitigation of all scenarios, but a much lower cost saving than desiccation with heat generation. FW reduction had the second greatest GHG mitigation of all of the scenarios and still resulted in significant cost reductions over the lifecycle (fifth best mitigation). Meanwhile, FW recycling brought about comparatively small, GHG reductions and cost savings. As these behavioural change scenarios can be combined with the FW treatment options, the best way to maximise GHG mitigation and cost savings at the UK University would be to adopt FW desiccation with heat generation, in combination with the FW reduction, and FW recycling scenarios.

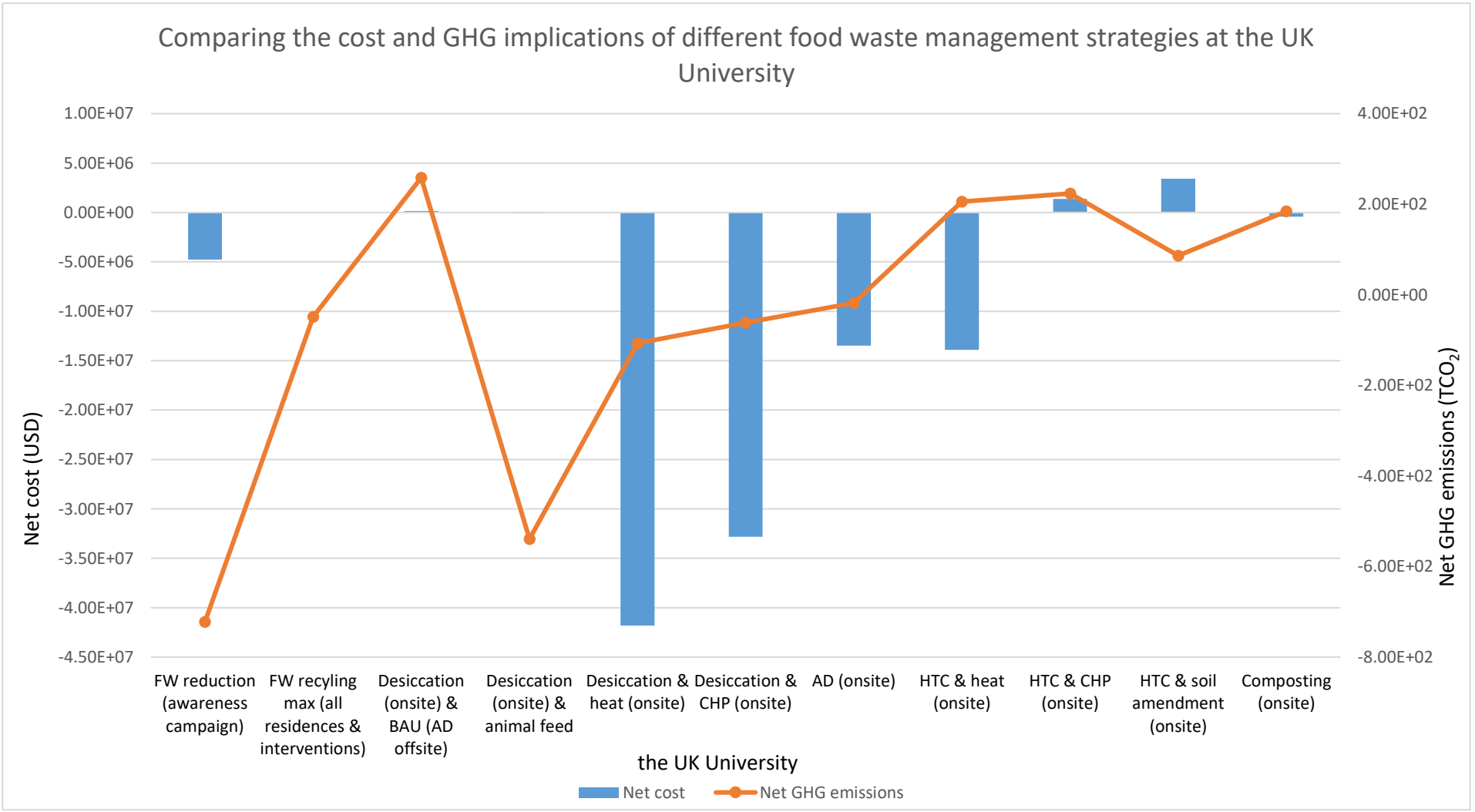

Comparing the cost and GHG implications of different food waste management strategies at the UK University
1.00E+07
5.00E+06
0.00E+00
-5.00E+06
-1.00E+07
-1.50E+07
-2.00E+07
-2.50E+07
-3.00E+07
-3.50E+07
-4.00E+07
-4.50E+07
Net cost (USD)
4.00E+02
2.00E+02
0.00E+00
-2.00E+02
-4.00E+02
-6.00E+02
-8.00E+02
Net GHG emissions (TCO2)
FW reduction (awareness campaign)
FW recyling max (all residences & interventions)
Desiccation (onsite) & BAU (AD offsite)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desiccation & CHP (onsite)
AD (onsite)
HTC & heat (onsite)
HTC & CHP (onsite)
HTC & soil amendment (onsite)
Composting (onsite)
the UK University
Net cost
Net GHG emissions

Figure 5.5.

5.4. Indian Institutions

The impacts of the same scenarios on GHG emissions and economic impacts were assessed at the two Indian institutes. Scenario 2 was not applicable, due to all Indian students being catered, with catered FW already being recycled. There were some common features, including general cost factors such as machine and staff costs, product costs, and GHG factors including grid energy intensity. On the other hand, factors such as the vastly differing economic competitiveness and environmental sustainability of the BAU strategies meant there were key differences between the findings of the two Indian institutions.

5.4.1. Indian institute A

5.4.1.1. GHG assessment

Considering the impacts of the FW management scenarios on GHG emissions at Indian institute A, Table 5.5. and Figure 5.6. show that the current BAU strategy results in large net GHG emissions, primarily due to the atmospheric emissions associated with the University landfilling the majority of its FW. Only landfilling (S7), and desiccation with BAU (S5a) had greater net GHG emissions over the lifecycle. Landfilling had greater GHGs associated because some of Indian institute A's FW is treated more sustainably with AD and composting onsite, while desiccation with BAU had the same GHGs associated from landfilling, while energy emissions from desiccation had greater GHGs associated with it than the transport emissions avoided with the scenario. Conversely, many FW treatment scenarios had lower GHGs associated with them than the BAU strategy. The FW treatment scenario that had the greatest GHG mitigation was onsite AD (S3), followed by HTC and CHP (S6bii.) caused by high product mitigation from energy generation in India and low processing emissions from AD and HTC with CHP. In addition, due to the high carbon intensity of Indian grid energy, the CHP scenarios of desiccation with CHP production (S5bii.), as well as HTC with CHP production (S6bii.) performed notably better than the respective scenarios (S5bi. & S6bi.) caused by Indian grid energy being much more carbon intensive than the natural gas substituted by the heat generated. Additionally, the desiccation scenarios (S5a-c), as well as the HTC and soil amendment (S6c) scenario performed poorly, due to particularly high energy emissions associated with India's particularly carbon intense grid energy. Altogether, the scenario with the GHG greatest mitigation potential (almost four times greater than any other scenario) was FW reduction (S1) due to the great GHG mitigation potential of FW avoidance, as well as the large proportion of FW that could be avoided at the Indian Universities, as outlined in Chapters 3 and 4. The greatest GHG mitigation at Indian institute A would come from introducing the

FW reduction scenario (S1), in combination with onsite AD (S3), resulting in a total lifecycle mitigation of over 56,000 tonnes of CO_2eq.

Table 5.5. Indian institute A GHG mitigation figures from FW management strategies

Scenario	**BAU**	**S1**	**S2**	**S3**	**S4**	**S5**				**S6**			**S7**
						a	**b**		**c**	**a**	**b**		
							i.	ii.			i.	ii.	
Construction emissions (tCO_{2eq}/yr)	273.02	-	-	26.5	26.1	105.76	48.21	48.21	37.5	40.8	78.01	78.01	327.71
Transport emissions (tCO_{2eq}/yr)	3.09	-	-	0	0	0.77	0	0	0	0	0	0	3.71
Atmospheric emissions (tCO_{2eq}/yr)	2374.97	-	-	0	8	2374.97	0	0	0	0	0	0	2850.07
Energy emissions (tCO_{2eq}/yr)	0.01	-	-	0	0.1	658.4	660.87	660.87	658.4	356.61	2.47	2.47	0
GHG from product Mitigation (tCO_{2eq}/yr)	66.84	-	-	561.88	151	66.84	403.87	595.3	635.11	301.85	232.48	331.08	0
Net GHG impact per tonne FW (tCO_{2eq}/yr)	**1.25**	**-1.21**	**-**	**-0.30**	**-0.08**	1.6	0.14	0.04	0.01	**0.032**	**-0.12**	**-0.17**	**1.54**
Net GHG impact per year (tCO_{2eq}/yr)	**2321.78**	**-2248.92**	**-**	**-560.56**	**-141.59**	29729.59	257.37	67.99	25.17	**59.56**	**-223.36**	**-321.96**	**2866.46**
Net GHG impact over lifecycle (tCO_{2eq}/yr)	**46435.67**	**-44978.47**	**-**	**-11211.17**	**-2831.79**	59451.78	5147.41	1359.74	503.34	**1191.24**	**-4467.11**	**-6439.2**	**57329.12**

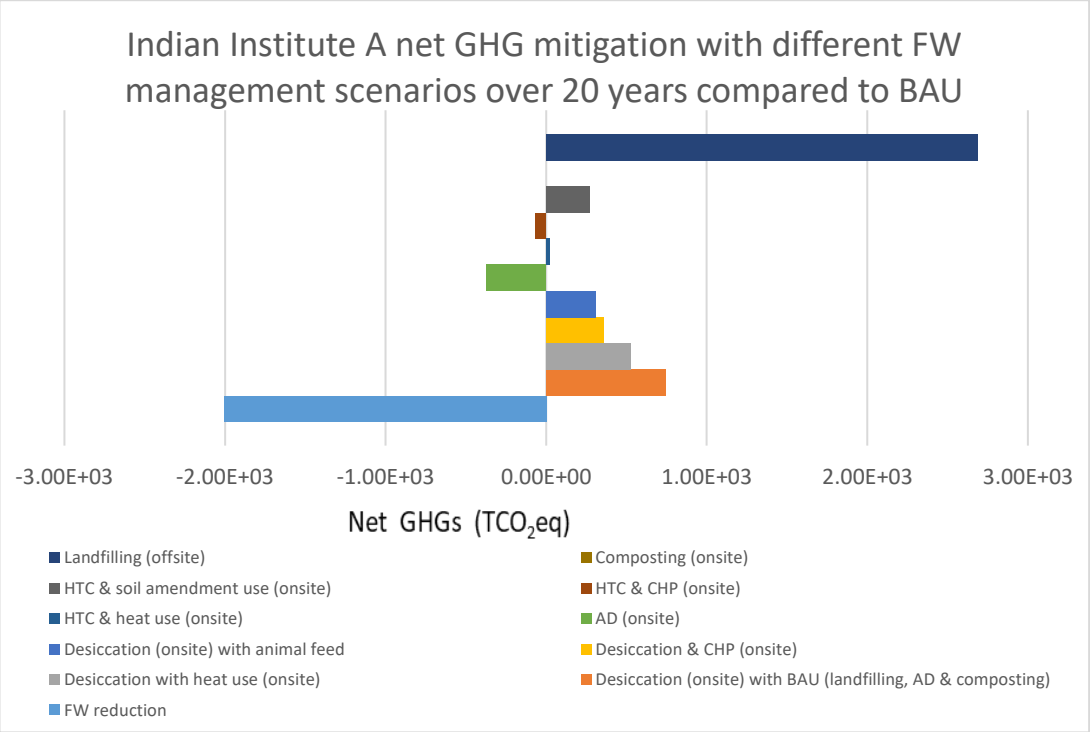


Figure 5.6.

5.3.1.2. Economics

It is clear that the current BAU strategy at Indian Institute A results in a relatively large expenditure over the lifecycle as shown in Table 5.6. and Figure 5.7. With this being said, the FW reduction scenario (S1), all of the desiccation scenarios (S5a-c) and the HTC and soil amendment scenario (S6a) resulted in net increased costs over the lifecycle, with FW reduction having the greatest costs associated, due to the extremely high costs of the extra staffing requirements. In addition, the desiccation scenarios did not result in net savings, due to high capital and installation costs and particularly high annual costs, due to large electricity demands, while HTC and soil amendment also did not result in net savings because of its high initial and annual costs, without having particularly high product savings. Onsite AD (S3) brought about the greatest savings due to its particularly high annual savings, followed by composting (S4) due to its low annual costs and annual savings being enhanced by subsidies offered for city-derived compost in the country (CPHEEO, 2016). Due to electricity prices being higher than natural gas prices in India at the time of the assessment, scenarios involving heat generation (S5bi. & S6bi) led to comparatively lower net savings than those involving CHP (S5bii. & S6bii).

Table 5.6. Indian institute A economic figures from FW management strategies

Scenario	BAU	S1	S2	S3	S4	S5				S6		
						a	b		c	a	b	
							i.	ii.			i.	ii.
Initial cost (RPS)	0	0	-	644458.71	2096003	14485609.6	14819999.8	14819999.8	14485609.6	10768457.6	17728039.8	17728039.8
Annual costs (RPS/yr)	20146892 1.1	64120948 83	-	8376102.1	2097771.9	12178749.8	12,216,732	12,216,732 8	12178749.8	5121981.2	1890602.4	1890602.4
Annual product/cost savings (RPS/yr)	838453.9	10781841 69	-	8376102.1	7728974.4	-	3342848.7	7352279.3	12178749.8	1159238.5	1788084.2	3853351.6
Collection savings (RPS/yr)				1706375.0	1706375.0	1536150	1706375.0	1706375.0	1706375.0	1706375.0	1706375.0	1706375.0
Simple payback time (yrs)	-	0	-	0.8	1.9						17.2	5.7
Net lifecycle cost/savings (RPS)	39403270.3	1.06678E+9	-	-170504693.8	-122553282.3	22733760 2.8	17007610 1.6	8988 7491	13068891 0.2	67389120.3	-28557844.3	-44161134.4

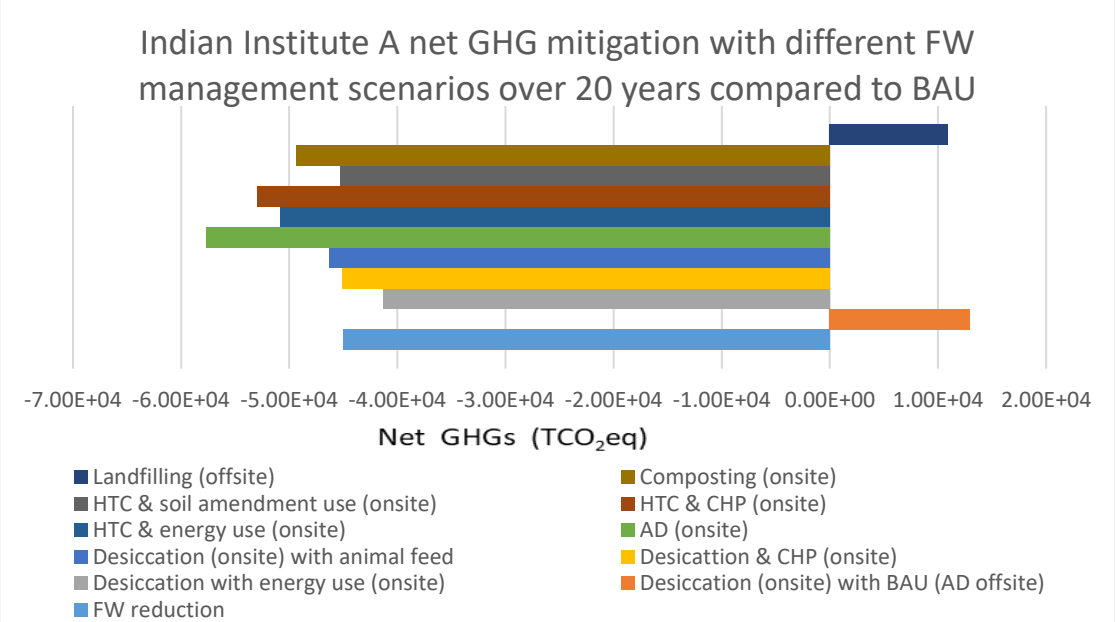


Figure 5.7.

5.4.1.3. Cost per tonne of CO_2 mitigated

When considering the cost per tonne of CO_2eq mitigated for the different mitigation strategies, while most scenarios provided GHG savings, most scenarios also resulted in net increases in costs over the lifecycle as shown in Figure 5.8. While FW reduction (S1) results in the greatest GHG saving, it also has the greatest costs associated with it. Additionally, all desiccation scenarios (S5a-c), as well as HTC and soil amendment (S6a) resulted in GHG savings, but a net cost over the lifecycle. On the other hand, a number of scenarios offered both net GHG and cost reductions over the lifecycle. Onsite AD (S3) had the greatest cost saving over the lifecycle and GHG mitigation of all scenarios, while HTC with CHP (S6bii.), as well as composting onsite (S3) both brought about notable GHG and cost savings. The best option for combined GHG and economic savings therefore is the adoption of onsite AD.

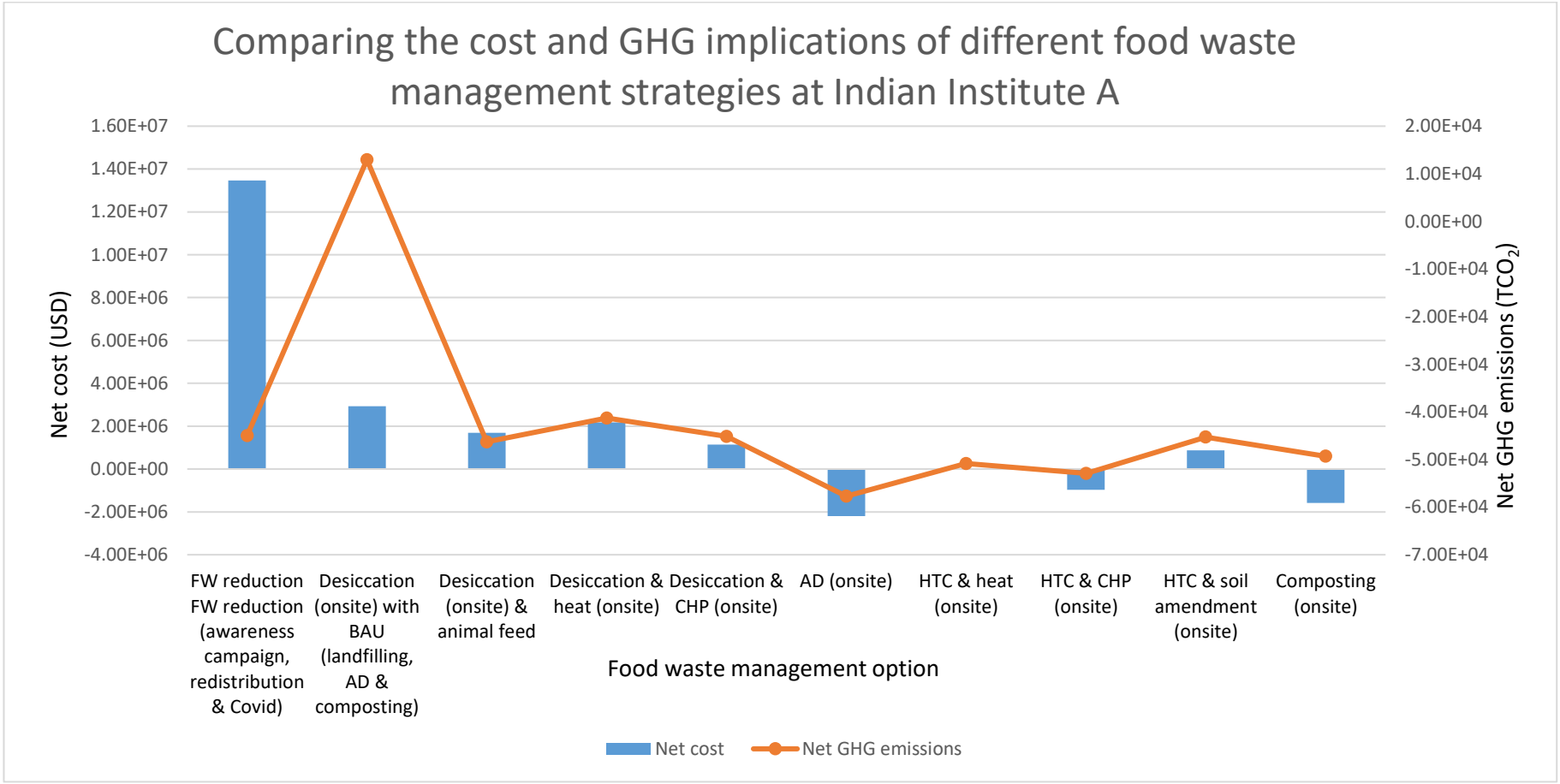

Comparing the cost and GHG implications of different food waste management strategies at Indian Institute A
1.60E+07
1.40E+07
1.20E+07
1.00E+07
8.00E+06
6.00E+06
4.00E+06
2.00E+06
0.00E+00
-2.00E+06
-4.00E+06
Net cost (USD)
2.00E+04
1.00E+04
0.00E+00
-1.00E+04
-2.00E+04
-3.00E+04
-4.00E+04
-5.00E+04
-6.00E+04
-7.00E+04
Net GHG emissions (TCO2)
FW reduction (awareness campaign, redistribution & Covid)
FW reduction
Desiccation (onsite) with BAU (landfilling, AD & composting)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desiccation & CHP (onsite)
AD (onsite)
HTC & heat (onsite)
HTC & CHP (onsite)
HTC & soil amendment (onsite)
Composting (onsite)
Food waste management option
Net cost
Net GHG emissions

Figure 5.8.

5.4.2. Indian institute B

5.4.2.1. GHG assessment

When analysing the impacts of the FW management scenarios on GHG emissions at Indian institute B, Table 5.7. and Figure 5.9. show that the current BAU strategy of composting onsite (also S4) is relatively sustainable, in that it results in net GHG mitigation. With this being said, only five scenarios resulted in a net increase in emissions. Unsurprisingly, landfilling (S7) was the worst performing scenario, while all desiccation scenarios (S5a-c), as well as the HTC with soil amendment scenario (S6a) led to net increases in GHG emissions, due to the high energy input emissions not making up for increased GHG product mitigation and reduced atmospheric emissions. Additionally, desiccation with BAU led to a net increase in emissions because all FW is treated onsite and thus the desiccation did not lead to reduced transport emissions to make up for the associated construction emissions and energy usage. As with Indian institute A, onsite AD (S3) had the greatest GHG mitigation potential of the FW treatment scenarios; however, the FW reduction scenario (S1) had the greatest GHG mitigation associated with it (almost four times greater than any other scenario). This was because Indian institute B has a much lower mitigation potential from FW treatment scenarios, as its BAU strategy (composting) is much more sustainable than that of Indian institute A (mostly landfilling). Altogether, for the greatest GHG mitigation, Indian institute B should adopt onsite AD (S3), as well as the FW reduction strategy.

Table 5.7. Indian institute B GHG mitigation figures from FW management strategies

Scenario	**BAU**	**S1**	**S 2**	**S3**	**S4**		**S5**			**S6**			**S7**
						a	**b**		**c**	**a**	**b**		
							i.	ii.			i.	ii.	
Construction emissions (tCO_{2eq}/yr)	0	-	-	1.18	0	2.32	2.798	2.8	2.32	40.8	42.46	42.46	14.61
Transport emissions (tCO_{2eq} /yr)	0.36	-	-	0	0	0	0	0	0	0	0	0	0.16
Atmospheric emissions (tCO_{2eq}/yr)	0.00	-	-	0	0.36	0.36	0	0	0	0	0	0	127.04
Energy emissions (tCO_{2eq}/yr)	6.73	-	-	0	0.00	0.11	36.98	37.09	37.09	36.98	0.11	0.11	0
GHG from product Mitigation (tCO_{2eq}/yr)	6.73	-	-	24.99	6.73	6.73	6.73	18	26.54	28.31	10.34	14.74	0
Net GHG impact per tonne FW (tCO_{2eq}/yr)	-0.08	-0.99	-	-0.3	-0.08	-0.07	0.371	0.23	0.13	0.11	**-0.06**	**-0.11**	1.54
Net GHG impact per year (tCO_{2eq}/yr)	-6.37	-100.25	-	-24.93	-6.37	-6.15	30.72	19.23	10.69	8.78	**-5.35**	**-9.4**	127.77
Net GHG impact over lifecycle (tCO_{2eq}/yr)	-127.42	-2004.95	-	-498.7	-127.42	-122.95	614.42	384.53	213.87	175.7	**-107.1**	**-187.91**	2555.49

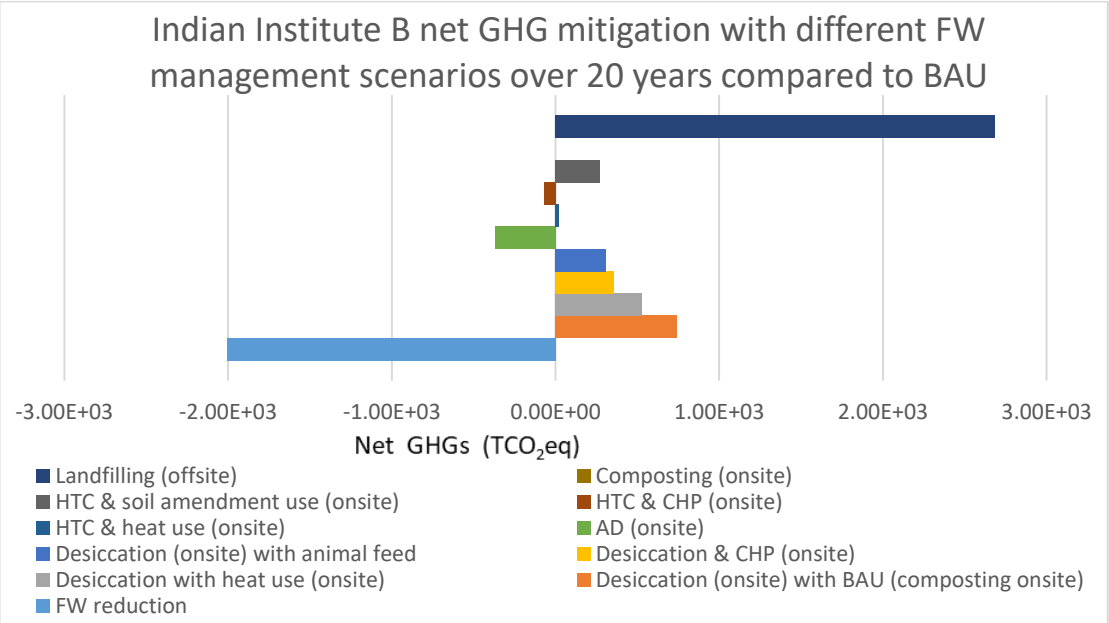


Figure 5.9.

5.4.2.2. Economics

It is clear that Indian institute B has a highly cost effective BAU strategy of composting onsite, as shown in Table 5.8. and Figure 5.10. All of the scenarios would bring about net lifecycle costs because the capital and installation costs of composting are already covered (as the composting is already established onsite), while composting had relatively low annual costs, and relatively high product sales associated with it. With this being said, AD (S3) had the

lowest net lifecycle expense of the different scenarios, while HTC and soil amendment (S6a) had the greatest costs of the FW treatment scenarios. Overall, FW reduction (S1) had the greatest cost by a significant margin, due to prohibitively high staff costs outweighing savings from FW reduction. It is apparent, therefore, that the most cost-effective strategy would be to retain the BAU strategy.

Table 5.8. Indian institute B economic figures from FW management strategies

Scenario	**BAU**	**S1**	**S2**	**S3**	**S4**	**S5**				**S6**		
						a	**b**		**c**	**a**	**b**	
							i.	ii.			i.	ii.
Initial cost (RPS)	0.0	0.0	-	1506091.2	0.0	1316873.6	1484273.2	1484273.2	1316873.6	10768457.6	12304728.6	12304728.6
Annual costs (RPS/yr)	78294.1	1473069207.4	-	143281.7	78341.4	719002.7	729240.6	729240.6	719002.7	1814513.1	1341047.9	1341047.9
Annual product/cost savings (RPS/yr)	344524.7	22014614.6	-	373370.8	344524.2	-1441.9	149013.3	327733.1	233439.1	51673.9	79705.2	171765.9
Collection savings (RPS/yr)	-	-	-	-	-	-	-	-	-	-	-	-
Payback time (yrs)	-	0.0	-		0.0							
Net lifecycle cost/savings (RPS)	-5324613.0	2902109176 3.0	-	2228920.3	-5324613.0	15696927.4	18413500.0	14839038.3	16352790.3	51349853.7	42856194.5	41014982.8

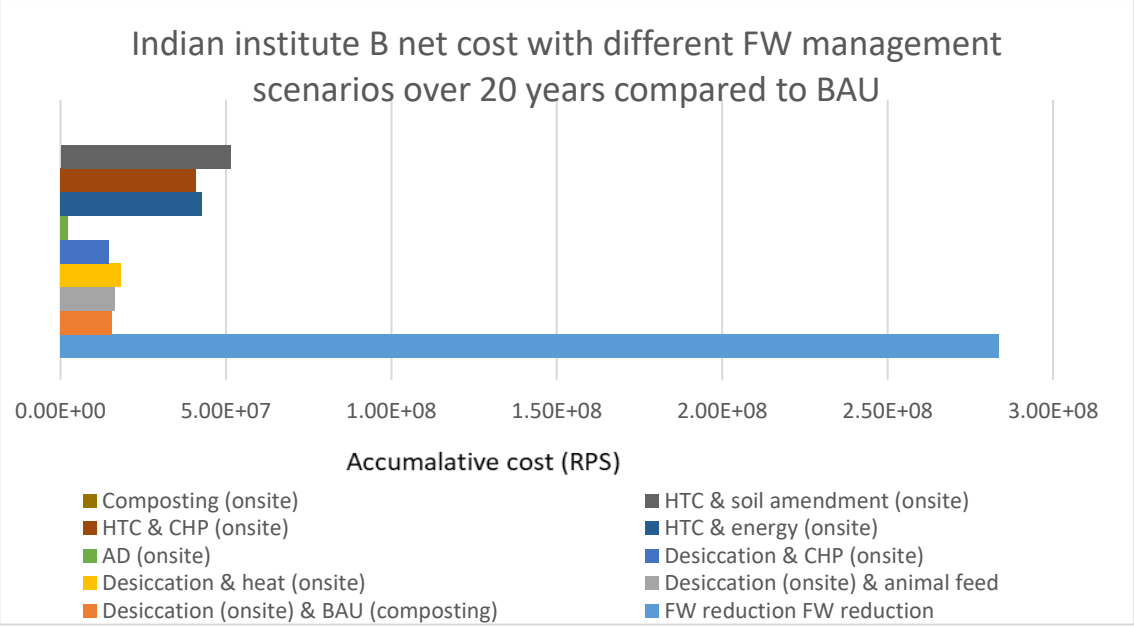


Figure 5.10.

5.4.2.3. Cost per tonne of CO_2 mitigated

There are no scenarios that would bring about combined GHG and economic savings at Indian Institute B over the lifecycle, as shown in Figure 5.10. With this being said, some of the scenarios would bring about GHG savings while presenting relatively modest lifecycle costs. AD

(S3) is the scenario with the lowest net cost and brings about the greatest GHG savings besides the FW reduction scenario. As there are no scenarios that bring about GHG mitigation without incurring net costs, the optimal scenario could be either to retain the BAU strategy, or to adopt AD onsite to bring about a relatively cheap GHG mitigation.

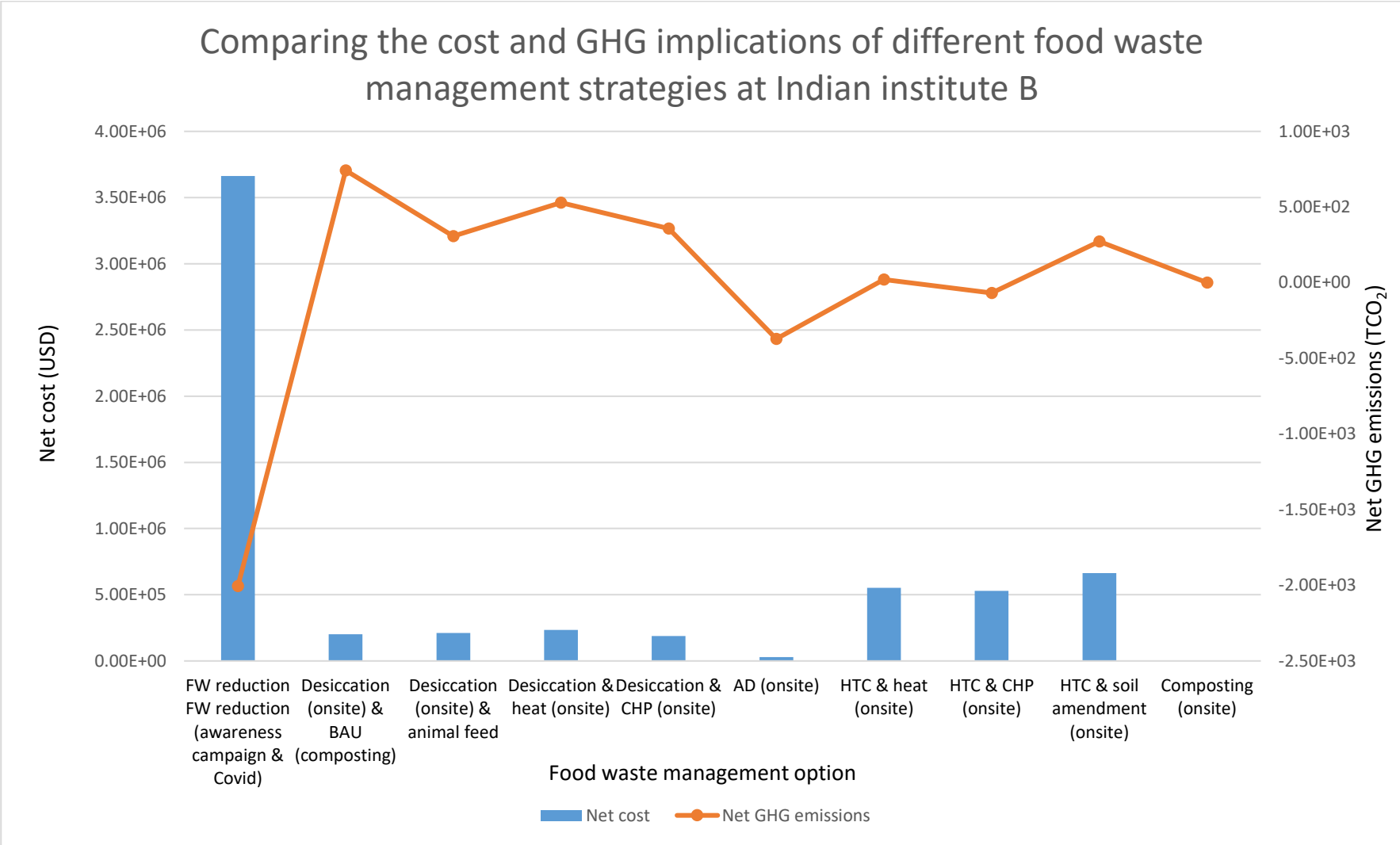

Comparing the cost and GHG implications of different food waste management strategies at Indian institute B
Net cost (USD)
4.00E+06
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
Net GHG emissions (TCO2)
1.00E+03
5.00E+02
0.00E+00
-5.00E+02
-1.00E+03
-1.50E+03
-2.00E+03
-2.50E+03
FW reduction
FW reduction (awareness campaign & Covid)
Desiccation (onsite) & BAU (composting)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desiccation & CHP (onsite)
AD (onsite)
HTC & heat (onsite)
HTC & CHP (onsite)
HTC & soil amendment (onsite)
Composting (onsite)
Food waste management option
Net cost
Net GHG emissions

Figure 5.10.

5.5. China

The impacts of the same scenarios on GHG emissions and economic impacts were assessed at the Chinese University; however, as with the Indian institutions, Scenario 2 was not applicable due to all Chinese students being catered, while Scenario 1 was not included, due to Covid-19 restrictions making it not possible to conduct the necessary interventions.

5.5.1. GHG assessment

When analysing the impacts of the FW scenarios on GHG emissions at the Chinese University, Table 5.9. and Figure 5.11. clearly show that the current BAU strategy results in significant GHG mitigations resultant from high product mitigations, similar to the UK University, with the two institutions having fundamentally the same BAU approach. Of all the scenarios, only AD onsite (S3) had a greater net mitigation than the BAU approach, due to reduced transport emissions. The AD scenarios performed particularly well due to them having low processing emissions and a high GHG product mitigation associated with them. HTC with CHP (S6bii.) was the best performing scenario not to involve AD, due to low processing emissions and high GHG product mitigation. As with India, CHP scenarios performed better than straight heat generation because of an enhanced product mitigation with the relatively carbon intense Chinese grid energy (albeit less carbon intense than in India). Notably, landfilling (S7) provided the greatest net GHG emissions, totalling almost 14,000 tCO_2eq over the lifecycle, mostly caused by its high atmospheric emissions. In addition, the desiccation scenarios (S5a-c), as well as HTC and soil amendment had performed significantly less well than the AD scenarios, primarily due to the high energy emissions from processing the FW required with these scenarios.

Table 5.9. Chinese University GHG mitigation figures from FW management strategies

Scenario	BAU	S1	S2	S3	S4	S5				S6			S7
						a	b		c	a	b		
							i.	ii.			i.	ii.	
Construction emissions (tCO_{2eq}/yr)	6.23	-	-	6.23	6.14	15.6	11.89	11.89	9.37	40.8	49.55	49.55	77.09
Transport emissions (tCO_{2eq}/yr)	1.56	-	-	0	0	0.34	0	0	0	0	0	0	0.74
Atmospheric emissions (tCO_{2eq}/yr)	0	-	-	0	1.91	0	0	0	0	0	0	0	687.58
Energy emissions (tCO_{2eq}/yr)	0	-	-	0	0.02	127.02	127.3	127.3	127.02	64.97	0.28	0.28	0
GHG from product Mitigation (tCO_{2eq}/yr)	120.54	-	-	120.54	36.43	120.54	92.28	124.55	145.21	73.62	56.97	74.26	0
Net GHG impact per tonne FW (tCO_{2eq}/yr)	-0.27	-	-	-0.27	-0.08	0.017	0.08	-0.01	-0.04	-0.01	**-0.12**	**-0.16**	1.58
Net GHG impact per year (tCO_{2eq}/yr)	-118.67	-	-	-120.23	-34.19	7.6	35.62	3.344	-17.73	-3.86	**-51.46**	**-71.5**	691.44
Net GHG impact over lifecycle (tCO_{2eq}/yr)	-2373.34	-	-	-2404.54	-683.78	152.02	712.34	66.88	-354.52	-77.21	**-1029.13**	**-1429.94**	13828.77

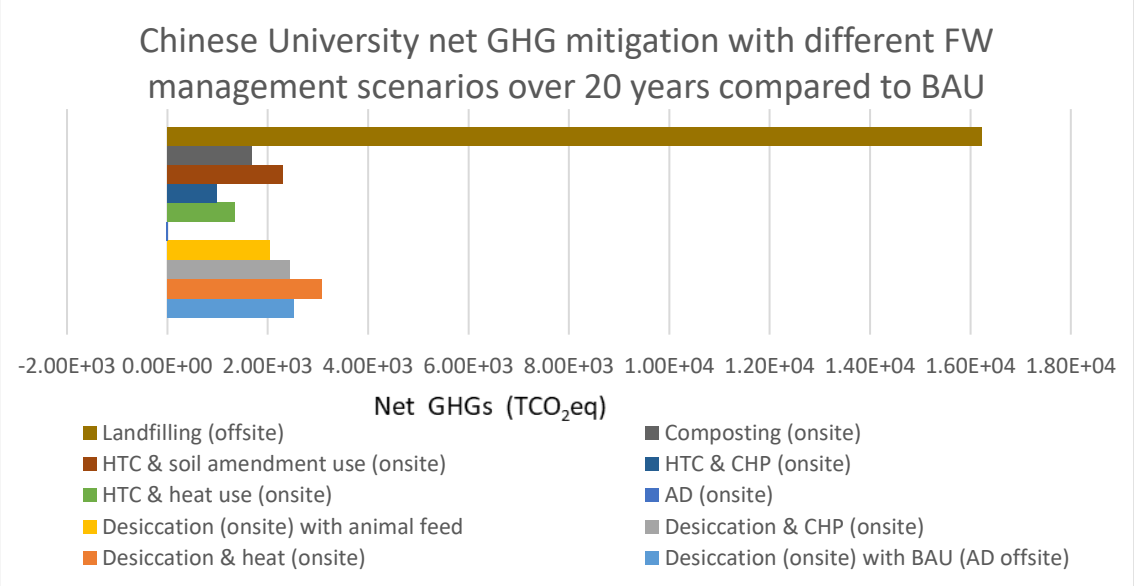


Figure 5.11.

5.5.2. Economics

With regards to economic impacts at the Chinese University, it is clear that the current BAU strategy results in significant expenditure over the lifecycle, as shown in Table 5.10. and Figure

5.12. All of the scenarios apart from the HTC scenarios (S6a, S6bi. and S6bii.), as well as desiccation with a continuation of BAU (S5a) resulted in net savings over the lifecycle. The HTC scenarios performed poorly because of prohibitively high capital and installation costs, while also having large annual costs associated. In particular, HTC and soils amendment (S6a) performed the worst because of comparatively lower product sales than the other HTC scenarios. Desiccation with BAU also performed poorly due to high annual costs (particularly energy costs) outweighing avoided FW collection cost. All of the other scenarios (S3, S4, S5bi., S5bii. and S5c) resulted in net savings over the lifecycle, with composting bringing about the greatest savings due to high product sales, with compost being relatively expensive (compared to products from other technologies) in China. AD (S3), as well as the desiccation scenarios (S5a-c), have lower net cost savings because they have lower general annual product cost savings despite having lower capital and installation costs. Additionally, CHP scenarios (Sbii. and S6bii.) brought about greater cost savings than the heat production scenarios (S5bi. and S6bi.), due to energy costs being greater than comparative heat costs (natural gas).

Table 5.10. Chinese University economic figures from FW management strategies

Scenario	**BAU**	**S1**	**S2**	**S3**	**S4**	**S5**				**S6**		
						a	**b**		**c**	**a**	**b**	
							i.	ii.			i.	ii.
Initial cost (RMB)	0.0	-	-	247822.2	457698.0	308162.2	322862.4	322862.4	308162.2	854063.3	1112223.4	11122 23.4
Annual costs (RMB/yr)	983310.0	-	-	27896.1	64474.6	143940.3	143940.3	143940.3	143940.3	306640.7	222978.9	222978.9
Annual product/cost savings (RMB/yr)	-	-	-	160410.7	305923.5	-	153635.2	170751.1	49851.6	61002.2	84828.8	44423.4
Collection savings (RMB/yr)	-	-	-	109500.0	109500.3	82891.7	109500.3	109500.3	109500.3	109500.3	109500.3	109500.3
Simple payback time (yrs)	-	-	-	1.0	1.3		2.7	2.4	20			
Net lifecycle cost/savings (RMB)	2190000.0	-	-	-2040009.1	-6561272.0	1529138.0	-2061039.5	-2403357.8	-65.8	3576833.5	1685224.5	24933 33.8

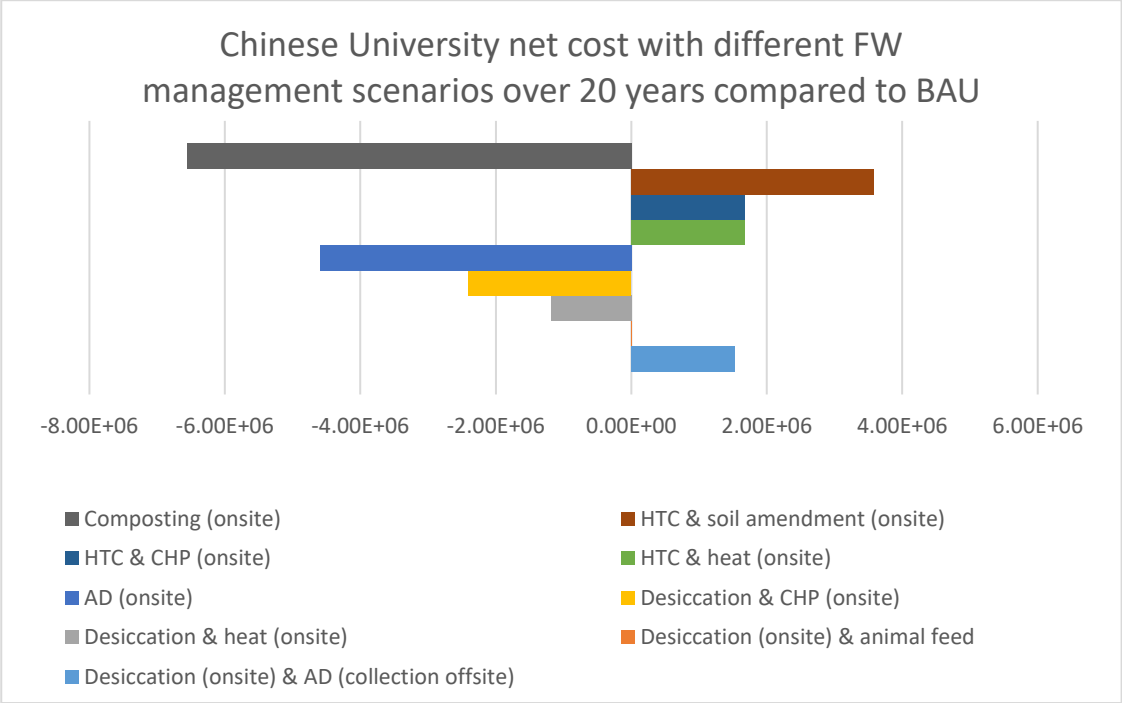


Figure 5.12.

5.5.3. Cost per tonne of CO_2 mitigated

When analysing the cost per tonne of CO_2eq mitigated for the different FW management strategies, Figure 5.13. shows only AD (S3) provides both GHG and cost savings, with it being the only scenario to provide GHG savings when compared to BAU, while also providing the second greatest cost saving, behind composting. Composting brought the greatest cost saving, but resulted in a net increase of GHG emissions when compared to the BAU strategy. Furthermore, HTC with soil amendment performed the worst regarding both net cost and GHG emissions, leading to a significant increase in both over the lifecycle. Overall, it is clear that AD onsite is the scenario that the Chinese University should adopt if it were to change its FW management approach.

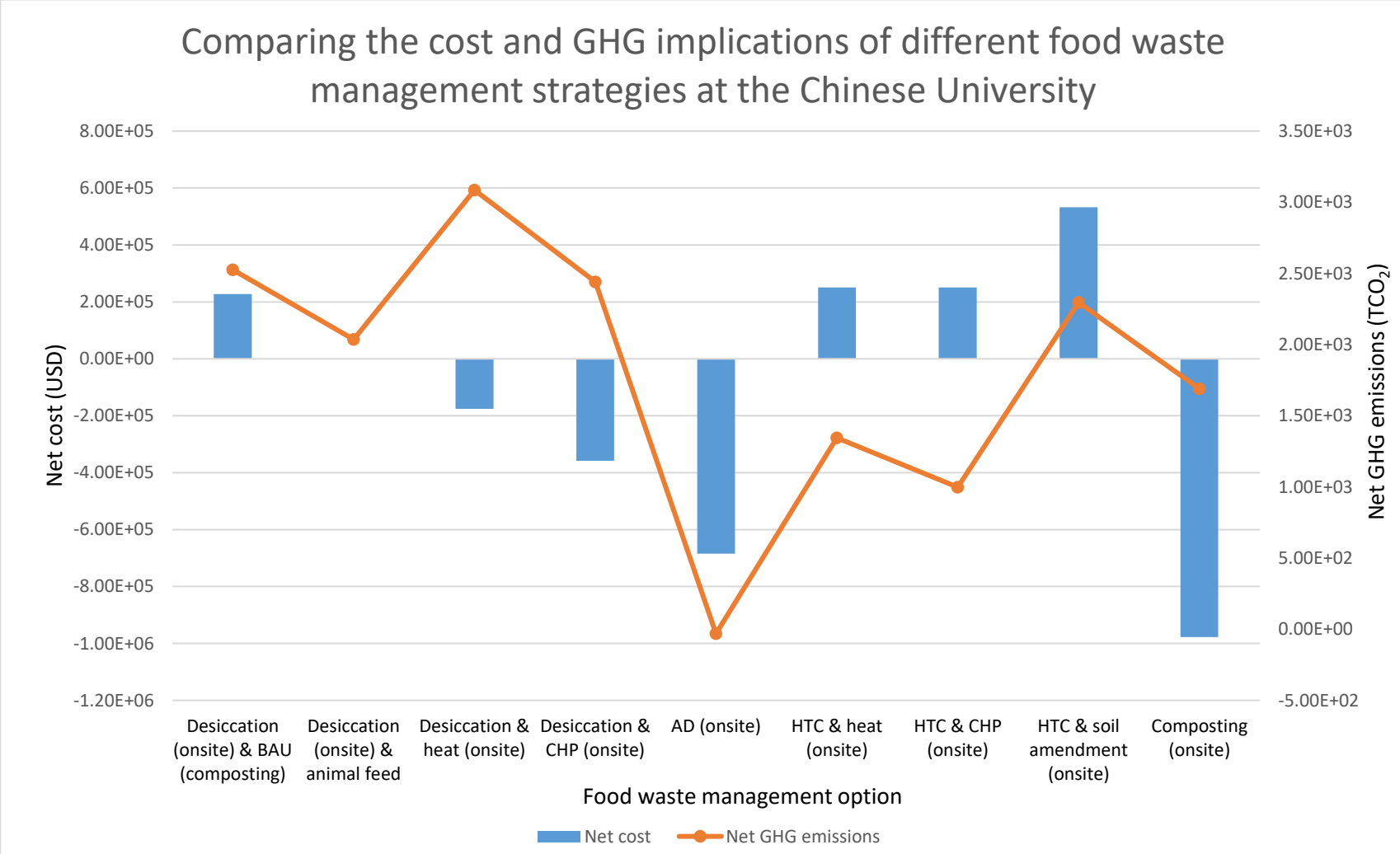

Comparing the cost and GHG implications of different food waste management strategies at the Chinese University
8.00E+05
6.00E+05
4.00E+05
2.00E+05
0.00E+00
-2.00E+05
-4.00E+05
-6.00E+05
-8.00E+05
-1.00E+06
-1.20E+06
Net cost (USD)
3.50E+03
3.00E+03
2.50E+03
2.00E+03
1.50E+03
1.00E+03
5.00E+02
0.00E+00
-5.00E+02
Net GHG emissions (TCO2)
Desiccation (onsite) & BAU (composting)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desiccation & CHP (onsite)
AD (onsite)
HTC & heat (onsite)
HTC & CHP (onsite)
HTC & soil amendment (onsite)
Composting (onsite)
Food waste management option
Net cost
Net GHG emissions

Figure 5.13.

5.6. Country comparison

When comparing the GHG mitigation, cost implications and cost per mitigation of each of the different FW management scenarios at the different Universities, there are some clear differences and similarities among the Universities with certain universities showing significantly greater opportunities than that of others assessed.

5.6.1. GHG assessment

Regarding GHG emissions Figure 5.14. illustrates that there were differences between the different Universities because of varying BAU strategies, as well as country-specific factors such as the carbon intensity of grid energy. Desiccation and animal feed production brought about the greatest mitigation of all of the FW treatment scenarios at the UK University; however, onsite AD brought about the greatest mitigation at the other universities. Desiccation with animal feed generation performed much better at the UK University caused by lower energy input emissions. Meanwhile AD performed much better in the Indian and Chinese Universities caused by a greater GHG mitigation from the energy generated, due to India and China having much greater GHGs associated with grid energy than in the UK. On the other hand, landfilling brought about the greatest increase in GHG emissions of all scenarios due to its high atmospheric emissions and having no GHG mitigation from products. With this being said, Indian institute A had significantly greater GHG mitigations/reduced GHG increases associated with all scenarios compared to other universities caused by it having a less sustainable BAU FW treatment strategy (primarily landfilling) than the other Universities. On the other hand, the Chinese University and the UK University had the lowest GHG mitigation/greatest GHG increases associated with them, due to them having the most sustainable BAU strategies in place (AD offsite). However, despite the two Universities having effectively the same BAU treatment strategy (AD offsite), the Chinese University has an enhanced GHG mitigation from the BAU strategy because the energy generated in this scenario offsets more carbon intense energy (as grid energy is more carbon intense in China than the UK). This means the Chinese University has a lower GHG mitigation/greater increase in GHG emissions than the UK University, when compared to the BAU strategy, from FW treatment scenarios that do not include energy generation. Again, due to varying carbon intensities of grid energy, the AD and CHP scenarios performed best in India and much better in China than the UK because India has the greatest grid carbon intensity and the UK has the lowest among the studied countries. Consequently, CHP scenarios performed better than heat generation (natural gas substitution) scenarios at the Indian and Chinese Universities, but not at the UK University. Furthermore, for FW reduction, GHG mitigation was greatest in Indian

institute A, because the institute had the greatest proportion of FW being reduced due to the inclusion of surplus food redistribution. Meanwhile the UK University had a significantly lower GHG mitigation, due to Covid-19 and infrastructural reductions not being included (according to the FW scenarios discussed in Chapter 4), whilst this scenario was not assessed for the Chinese University. Additionally, due to country-specific FW infrastructures (see Chapter 3), FW recycling and the related opportunities were only considered at the UK University.

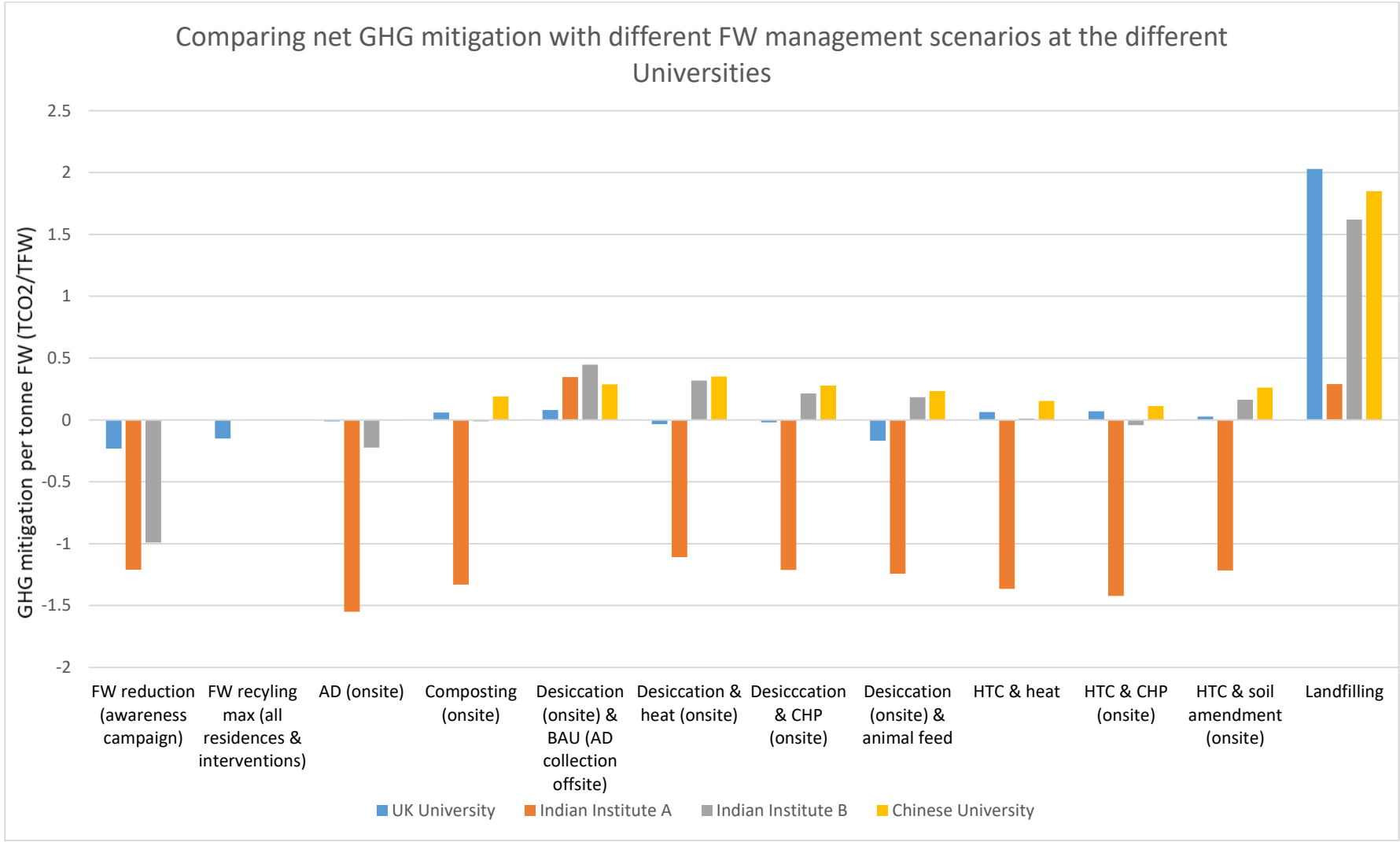

Comparing net GHG mitigation with different FW management scenarios at the different Universities
GHG mitigation per tonne FW (TCO2/TFW)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
FW reduction (awareness campaign)
FW recyling max (all residences & interventions)
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
Desiccation (onsite) & animal feed
HTC & heat
HTC & CHP (onsite)
HTC & soil amendment (onsite)
Landfilling
UK University
Indian Institute A
Indian Institute B
Chinese University

Figure 5.14.

5.6.2. Economics

When comparing the impacts of the scenarios on costs at the different Universities, Figure 5.15. shows there were significant differences due to varying BAU strategies, as well as country-specific factors such as costs of FW collection, purchasing machines, energy costs, and the value of products generated. Altogether, it is clear that the greatest costs came from the FW reduction, with the net costs being so high for the Indian Universities that the other scenarios for all universities appeared insignificant in comparison. This was due to extra staffing costs significantly outweighing FW-related savings. The net expenditure on this scenario at Indian institute B per tonne of FW generated at the University was significantly higher than at Indian institute A. This was mostly because the costs incurred in this scenario related to extra staff requirements, with staffing requirements being based on student numbers. Indian institute A generates considerably more FW per capita however, meaning that Indian institute A has the same costs related to FW reduction, but much greater savings than Indian institute B. This was based on the assumption that there would be the same proportion of FW reduction (~50%), thus there would be a greater quantity of FW avoided per additional staff member at Indian institute A, and thus enhanced savings. A further contributing factor was that Indian institute A currently works with a charity to redistribute surplus food, which means that there is a reduction in FW and associated costs, without any additional costs incurred (as the FW charity offers this service for free). Conversely, FW reduction led to net cost savings at the UK University, as there were no significant expenses associated, as no extra staffing was required (see Chapter 4).

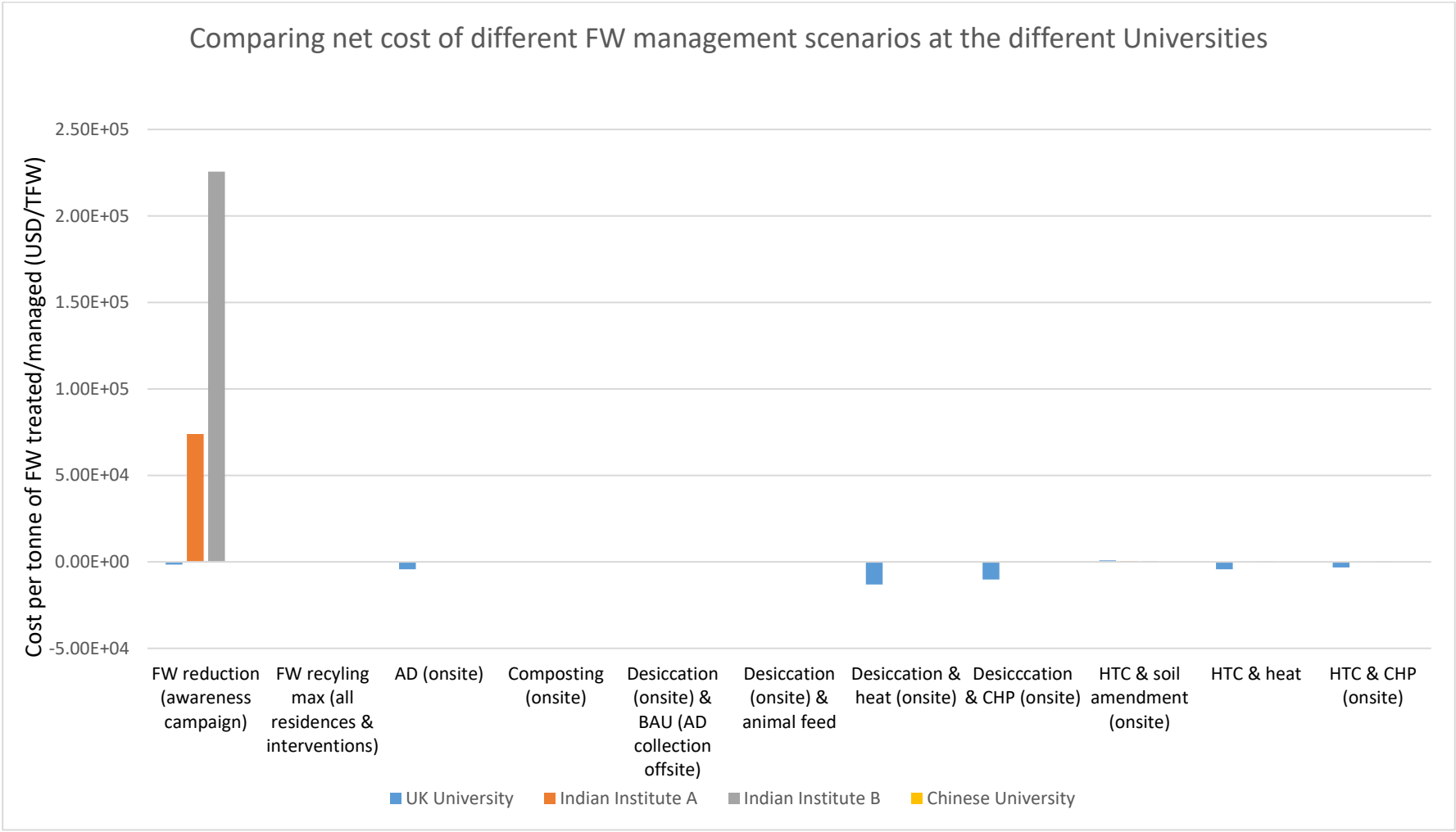

Comparing net cost of different FW management scenarios at the different Universities
Cost per tonne of FW treated/managed (USD/TFW)
2.50E+05
2.00E+05
1.50E+05
1.00E+05
5.00E+04
0.00E+00
-5.00E+04
FW reduction (awareness campaign)
FW recyling max (all residences & interventions)
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
HTC & soil amendment (onsite)
HTC & heat
HTC & CHP (onsite)
UK University
Indian Institute A
Indian Institute B
Chinese University

Figure 5.15.

Looking specifically at the FW treatment scenarios, it is clear that all of the greatest cost reductions (per tonne of FW treated) concerned FW treatment strategies at the UK University, as shown in Figure 5.16. This was primarily because both FW collection, as well as product costs (heat and energy) are much higher in the UK when compared to India and China (World Data, 2021). On the other hand, as spending power and what could be purchased with these savings is much lower in the UK than in India and China, it is possible that these perceived enhanced economic opportunities in the UK are not as great as the results suggest (World Data, 2021). The greatest cost saving mitigation of all the scenarios at all of the studied Universities was desiccation with heat generation, followed by desiccation with CHP at the UK University, due to the low costs associated and particularly large savings from substituting natural gas, and, to a lesser extent, energy in the UK. HTC and heat generation, AD and HTC with CHP also brought about noteworthy cost savings at the UK University. On the other hand, HTC with soil amendment brought about LCC increases at all Universities, while the other HTC scenarios also led to notable net cost increases at Indian institute B.

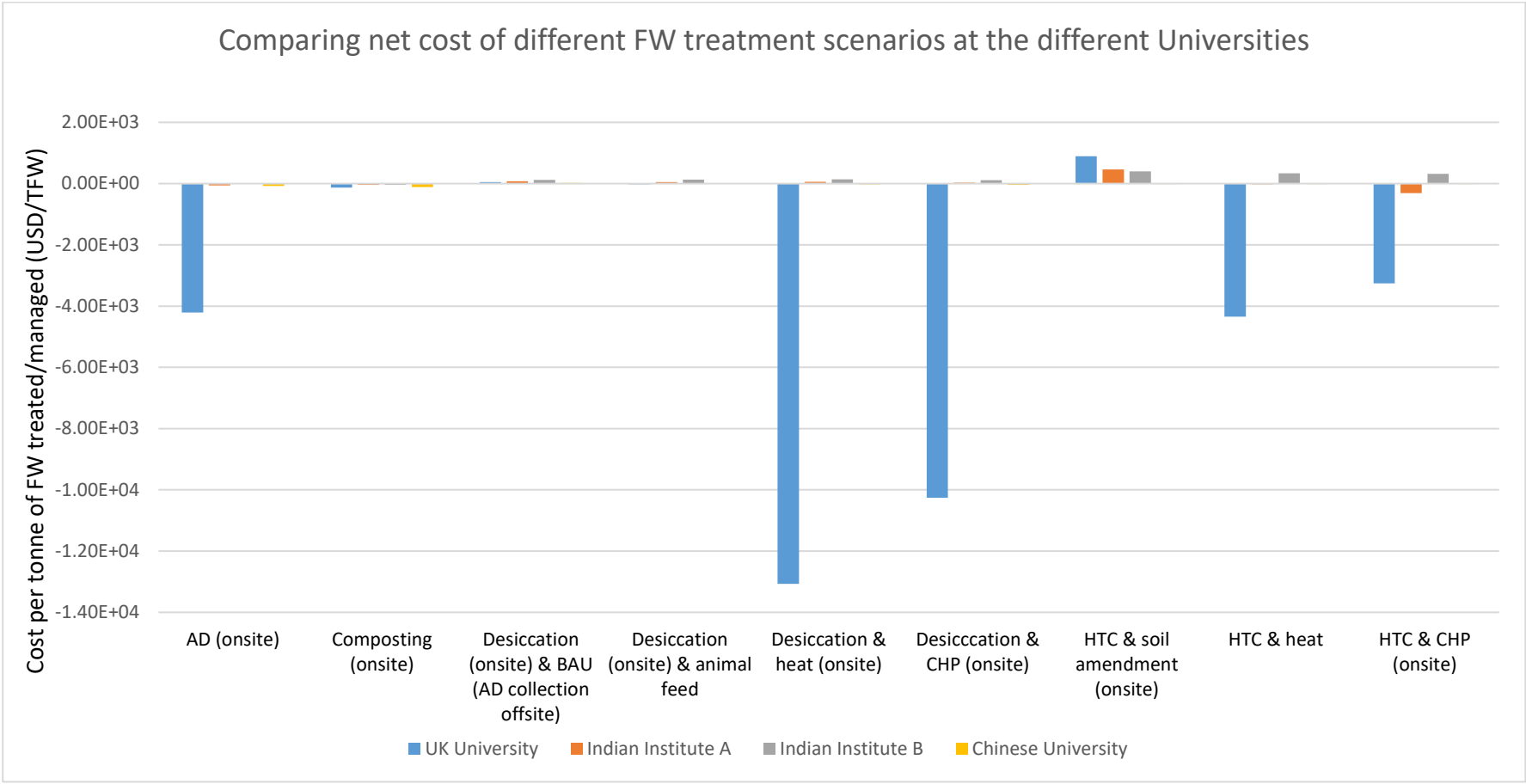

Comparing net cost of different FW treatment scenarios at the different Universities
Cost per tonne of FW treated/managed (USD/TFW)
2.00E+03
0.00E+00
-2.00E+03
-4.00E+03
-6.00E+03
-8.00E+03
-1.00E+04
-1.20E+04
-1.40E+04
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
HTC & soil amendment (onsite)
HTC & heat
HTC & CHP (onsite)
UK University
Indian Institute A
Indian Institute B
Chinese University

Figure 5.16.

5.6.3. Combined GHG and economic savings

When analysing the combined benefits of the economic savings and social value of CO_2 reduction from the different FW management strategies, it is apparent that levels of opportunities for cost-effective GHG mitigation vary considerably at the different Universities, as illustrated by Figure 5.17. The highest combined net cost came from FW reduction in the Indian universities, as the increased LCC for implementing this scenario far outstripped the social value of the GHG mitigation. The LCC for the FW reduction scenario in the Indian Universities was so high that all other scenarios in all studied universities were rendered comparatively insignificant. Conversely, FW reduction in the UK University led to combined savings.

Regarding the scenarios that brought about net combined savings from valuing both cost reductions and social benefits from GHG mitigation over the lifecycle, it is clear that opportunities varied considerably at the different Universities, as shown in Figure 5.18. The UK University had the greatest opportunities, as it had scenarios with both substantial LCC savings and GHG reductions. With this being said, there were still notable savings at Indian institute A, mostly because the current BAU strategy is less environmentally sustainable than at the other Universities, thus presenting greater GHG mitigation opportunities, and associated cost savings from valuing the social cost of GHG mitigation, when compared to the other studied Universities. Of all the scenarios at all of the Universities, desiccation with heat generation at the UK University offered the greatest combined GHG and cost savings, while desiccation with CHP at the UK University also brought about significant combined savings. This was due to low costs, large cost savings as well as GHG mitigation, especially from the natural gas substitution associated with the desiccation with heat generation scenario. Overall, when costing GHG savings at 60 USD (CEICTM, 2020), the bulk of the combined savings from the best performing scenarios (UK heat and energy generating scenarios) came from LCC savings. To illustrate this, the UK desiccation with combustion for heat generation scenario was assessed to have a combined value saving of 13,067 USD/tFW, of which 13,066 USD/tFW, or 99.99% of the savings came from reduced economic costs. With this being said, the addition of the social value of CO_2 did make an impact for scenarios that involved marginal net costs, but substantial GHG reductions. A clear example of this was the desiccation and combustion with CHP scenario at Indian institute A going from a net expense (32USD/tFW) to a net saving (-42USD/tFW).

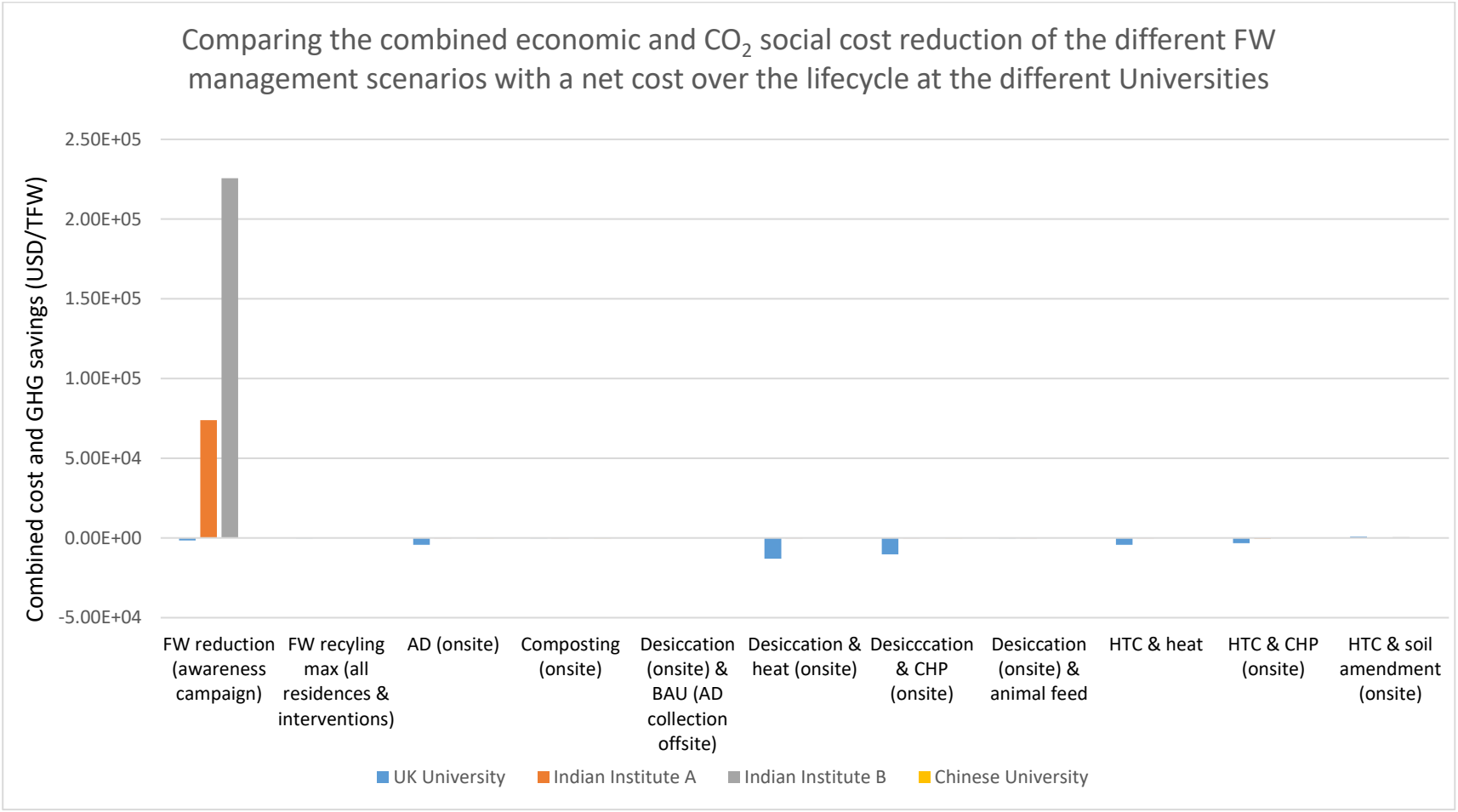

Comparing the combined economic and CO_2 social cost reduction of the different FW management scenarios with a net cost over the lifecycle at the different Universities
Combined cost and GHG savings (USD/TFW)
2.50E+05
2.00E+05
1.50E+05
1.00E+05
5.00E+04
0.00E+00
-5.00E+04
FW reduction (awareness campaign)
FW recyling max (all residences & interventions)
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
Desiccation (onsite) & animal feed
HTC & heat
HTC & CHP (onsite)
HTC & soil amendment (onsite)
UK University
Indian Institute A
Indian Institute B
Chinese University

Figure 5.17.

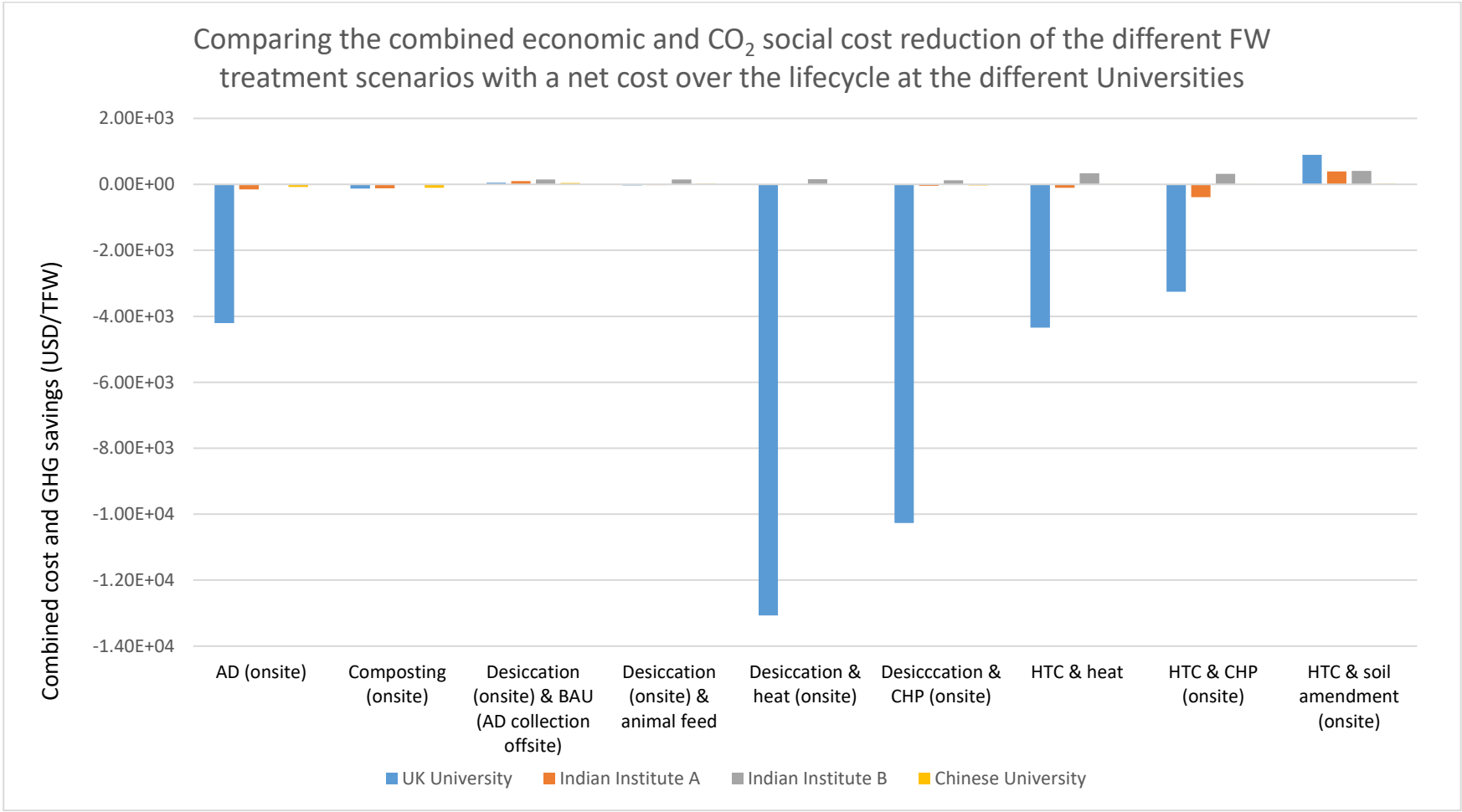

Comparing the combined economic and CO_2 social cost reduction of the different FW treatment scenarios with a net cost over the lifecycle at the different Universities
Combined cost and GHG savings (USD/TFW)
2.00E+03
0.00E+00
-2.00E+03
-4.00E+03
-6.00E+03
-8.00E+03
-1.00E+04
-1.20E+04
-1.40E+04
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation (onsite) & animal feed
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
HTC & heat
HTC & CHP (onsite)
HTC & soil amendment (onsite)
UK University
Indian Institute A
Indian Institute B
Chinese University

Figure 5.18.

5.7. Scenario exploration

As explained in the methodology, scenarios were explored further to see how changes that may be possible or may arise would impact the GHG and economic credentials of different scenarios. The 2040, green grid and Covid scenario explorations all affect all of the FW management scenarios. An additional scenario exploration affected only the HTC scenarios, with tailor-made HTC units being capacity-built to process only the levels of FW generated onsite.

5.7.1. UK

At the UK University, these scenario explorations led to considerable changes in the GHG impacts of the different FW management strategies, as shown in Figure 5.19. The 2040 scenario brought reduction in GHG mitigation for all scenarios involving energy generation, thus BAU, AD, as well as HTC and CHP all had decreased GHG mitigation. This scenario also brought about increases in GHG mitigation for all scenarios that used grid energy to process the FW, with desiccation and heat generation, as well as HTC and soil amendment showing the greatest GHG reduction (due to them having the greatest net energy inputs, and not generating energy). Additionally, composting and desiccation with BAU increased their net GHG mitigation due to reduced energy usage, and desiccation with CHP increased its GHG mitigation with reduced GHGs from energy inputs outweighing reduced GHG mitigation from energy generated. Furthermore, the green grid scenario brought about GHG reductions in all scenarios using energy for processing (all desiccation scenarios, composting, as well as HTC and soil amendment). All desiccation scenarios, as well as HTC with soil amendment had very significant increases in net GHG mitigation due to their high GHG emissions from energy inputs being mitigated. Desiccation with heat generation, and desiccation with CHP became the second and third best FW treatment scenarios, behind desiccation with animal feed generation, while HTC with soil amendment became the fourth best performing scenario, ahead of onsite AD. Moreover, desiccation with BAU overtook the BAU scenario, due to reduced transport emissions and no energy emissions resulting from the green grid. Additionally, net GHG mitigation for all HTC scenarios further increased by having tailor-made HTC units, due to construction emissions being 27 times smaller with the HTC units being specifically designed to only process the quantities of FW generated onsite. Moreover, the Covid scenario brought about a substantial increase in GHG mitigation from FW reduction (much greater than any other scenario, under any other scenario exploration). Conversely, the Covid scenario led to a halving of the GHG mitigation for all of the FW treatment technologies, as well as the FW recycling scenario due to a halving of FW generation onsite.

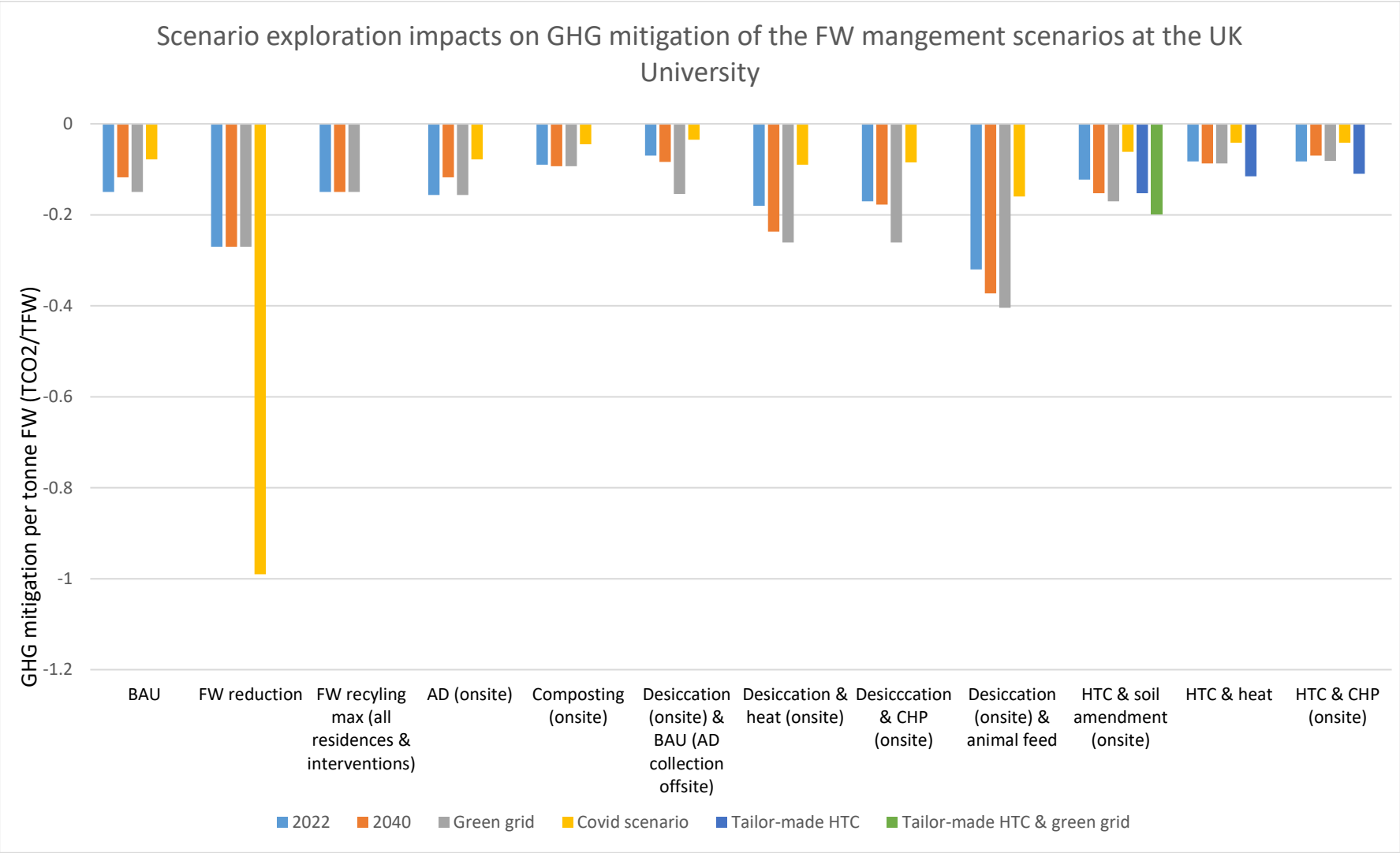

Scenario exploration impacts on GHG mitigation of the FW mangement scenarios at the UK University
GHG mitigation per tonne FW (TCO2/TFW)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
BAU
FW reduction
FW recyling max (all residences & interventions)
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
Desiccation (onsite) & animal feed
HTC & soil amendment (onsite)
HTC & heat
HTC & CHP (onsite)
2022
2040
Green grid
Covid scenario
Tailor-made HTC
Tailor-made HTC & green grid

Figure 5.19.

5.7.2. India

5.7.2.1. Indian institute A

At Indian institute A, these scenario explorations led to considerable changes in the GHG impacts of the different FW management strategies, as shown in Figure 5.20. As with the UK University, the 2040 scenario brought a reduction in GHG mitigation for all scenarios involving energy generation, with the AD, and HTC with CHP scenarios having decreased GHG mitigation. The 2040 scenario exploration also brought about GHG reductions in all scenarios with large energy inputs required. In particular, the desiccation scenarios, and HTC and soil amendment showed significant GHG reductions (due to them having particularly high energy inputs), with desiccation with heat, desiccation with CHP, desiccation with animal feed, and HTC with soil amendment production all going from having a net GHG emission to a net GHG mitigation associated. The green grid scenario brought about even greater GHG reductions for all scenarios with energy inputs, without reducing GHG mitigation associated with energy generating scenarios. All desiccation scenarios, as well as HTC and soil amendment again had particularly substantial increases in GHG mitigation/decreases in GHG emissions. Specifically, desiccation with animal feed became the best performing FW treatment scenario, overtaking the AD, composting, HTC with heat, and HTC with CHP scenarios, while desiccation with CHP became the third best performing FW treatment scenario, only behind desiccation with animal feed, and AD. Moreover, HTC with soil amendment went from being the worst performing scenario behind BAU and desiccation, and BAU, to performing better than composting, as well as HTC and heat generation. The tailor-made HTC scenario brought about further improvements in the performance of HTC with soil amendment, as well as other HTC technologies due to construction emissions more than halving. On the other hand, improvements were much less substantial at Indian institute A than at the other universities. This was because the institute generates substantially more FW than the other universities and the HTC unit assessed in the other scenarios/scenario explorations was much more suitable for Indian institute A (2.35 times too large) when compared to other institutes (27 times too large for the UK University). Overall, the 2040 and green grid scenarios had a much greater impact at Indian institute A when compared to the UK University, because Indian grid energy is much more carbon intense than in the UK. Furthermore, as with the UK University, the Covid scenario brought about a significant increase in GHG mitigation from FW reduction (much greater than any other scenario, under any other scenario exploration), while also leading to a halving of the GHG mitigation of all of the FW treatment technologies. On the other hand, the BAU scenario, all desiccation scenarios, and HTC and soil amendment scenario have net

emissions, so the GHG emissions halved under this scenario, thus reducing overall GHG emissions compared to the 2022 scenario.

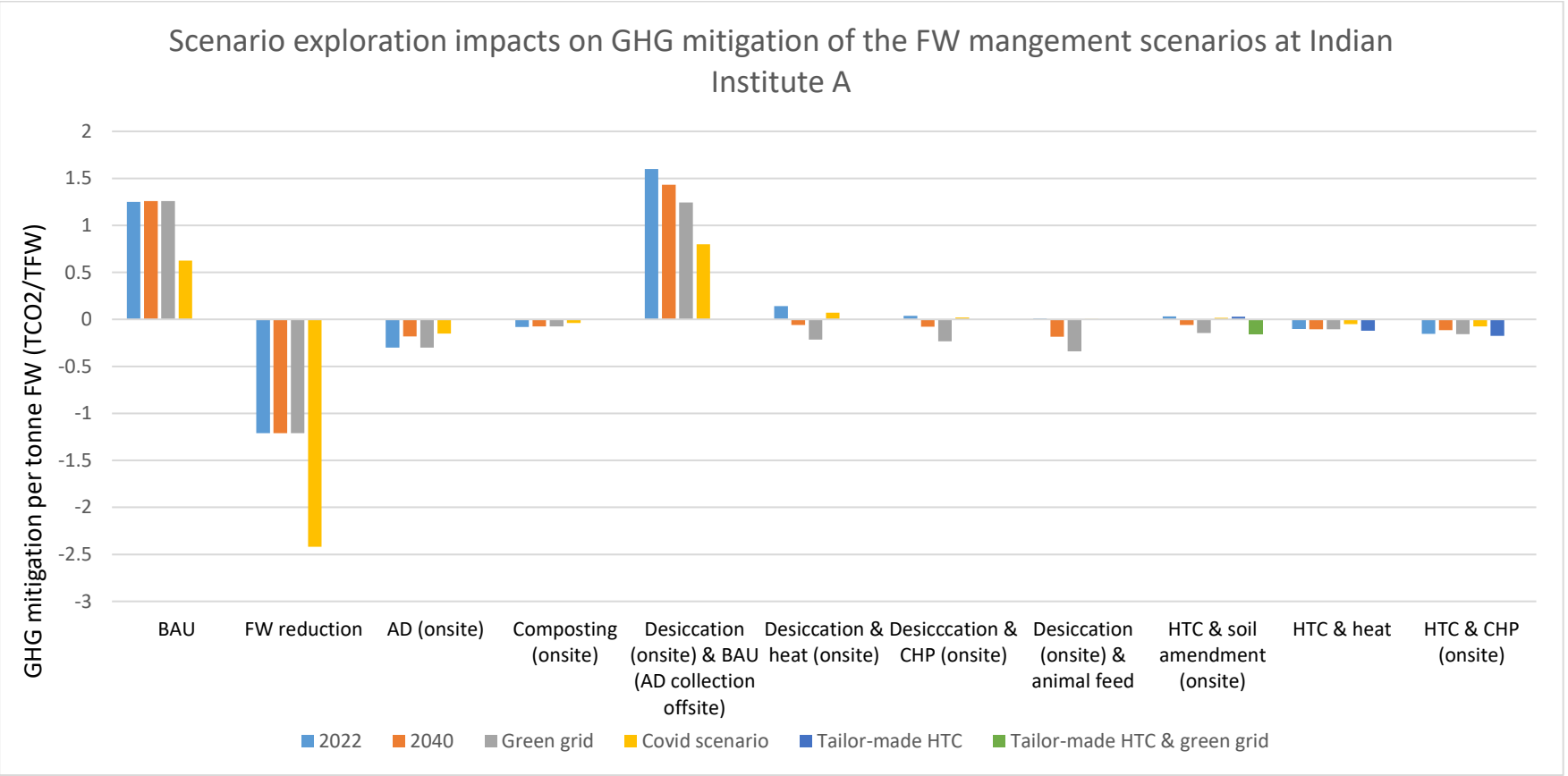

Scenario exploration impacts on GHG mitigation of the FW mangement scenarios at Indian Institute A
GHG mitigation per tonne FW (TCO2/TFW)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
BAU
FW reduction
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation & heat (onsite)
Desiccation & CHP (onsite)
Desiccation (onsite) & animal feed
HTC & soil amendment (onsite)
HTC & heat
HTC & CHP (onsite)
2022
2040
Green grid
Covid scenario
Tailor-made HTC
Tailor-made HTC & green grid

Figure 5.20.

5.7.2.2. Indian institute B

The impacts of the scenarios at Indian institute B were effectively the same as at Indian institute A due to there being the same scale of impacts from reductions in grid energy intensity. Figure 5.21. shows that the most notable change concerned the desiccation with heat, desiccation with CHP, and desiccation with animal feed, as well as the HTC with soil amendment scenarios, all of which performed less well than the BAU approach in 2022, but led to a net reduction in GHGs when compared to the BAU with the green grid scenario. Moreover, the performance of HTC and soil amendment as well as the other HTC scenarios, improved considerably with the tailor-made HTC scenario exploration, as the original unit size was over 50 times larger than required at Indian institute B, thus construction emissions were reduced by over 50 times. Impacts from the Covid scenario were also effectively the same as Indian institute A, besides it negatively impacting the BAU scenario, because the BAU scenario results in net mitigation at Indian institute B when compared to a net GHG emission at Indian institute A.

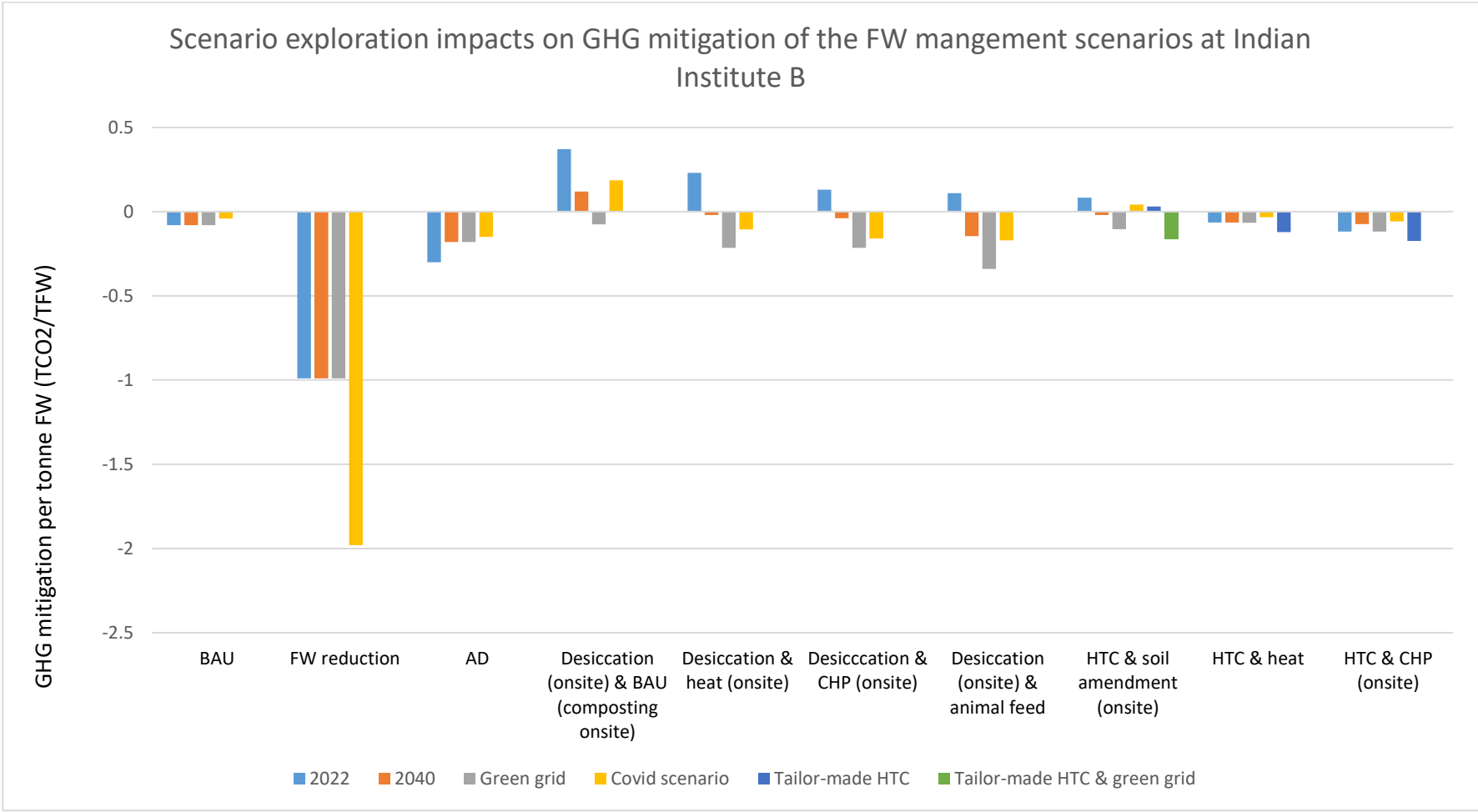

Scenario exploration impacts on GHG mitigation of the FW mangement scenarios at Indian Institute B
GHG mitigation per tonne FW (TCO2/TFW)
0.5
0
-0.5
-1
-1.5
-2
-2.5
BAU
FW reduction
AD
Desiccation (onsite) & BAU (composting onsite)
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
Desiccation (onsite) & animal feed
HTC & soil amendment (onsite)
HTC & heat
HTC & CHP (onsite)
2022
2040
Green grid
Covid scenario
Tailor-made HTC
Tailor-made HTC & green grid

Figure 5.21.

When analysing the impacts of the scenarios at the Chinese University, the impacts are very similar to that of Indian institute B. Figure 5.22. shows the 2040 and green grid scenarios had the same impact as in the Indian and UK Universities; however, as Chinese grid energy is somewhere between the carbon intensity of the UK and India, impacts related to GHGs were more intense than in the UK, but less intense than in India. Additionally, impacts on the BAU were very similar to the UK University (due to both Universities currently having FW anaerobically digested offsite), with 2040 and Covid scenarios reducing GHG mitigation and the green grid scenario having no impact. In addition, the tailor-made HTC scenario exploration made the HTC scenarios more competitive by reducing construction emissions to a tenth of their normal level. The FW reduction scenario was not considered at the Chinese University in the 2022, 2040 and green grid scenario explorations due to a lack of data; however, FW roughly halved due to Covid, leading to the greatest GHG mitigation of all scenarios, under all scenario explorations.

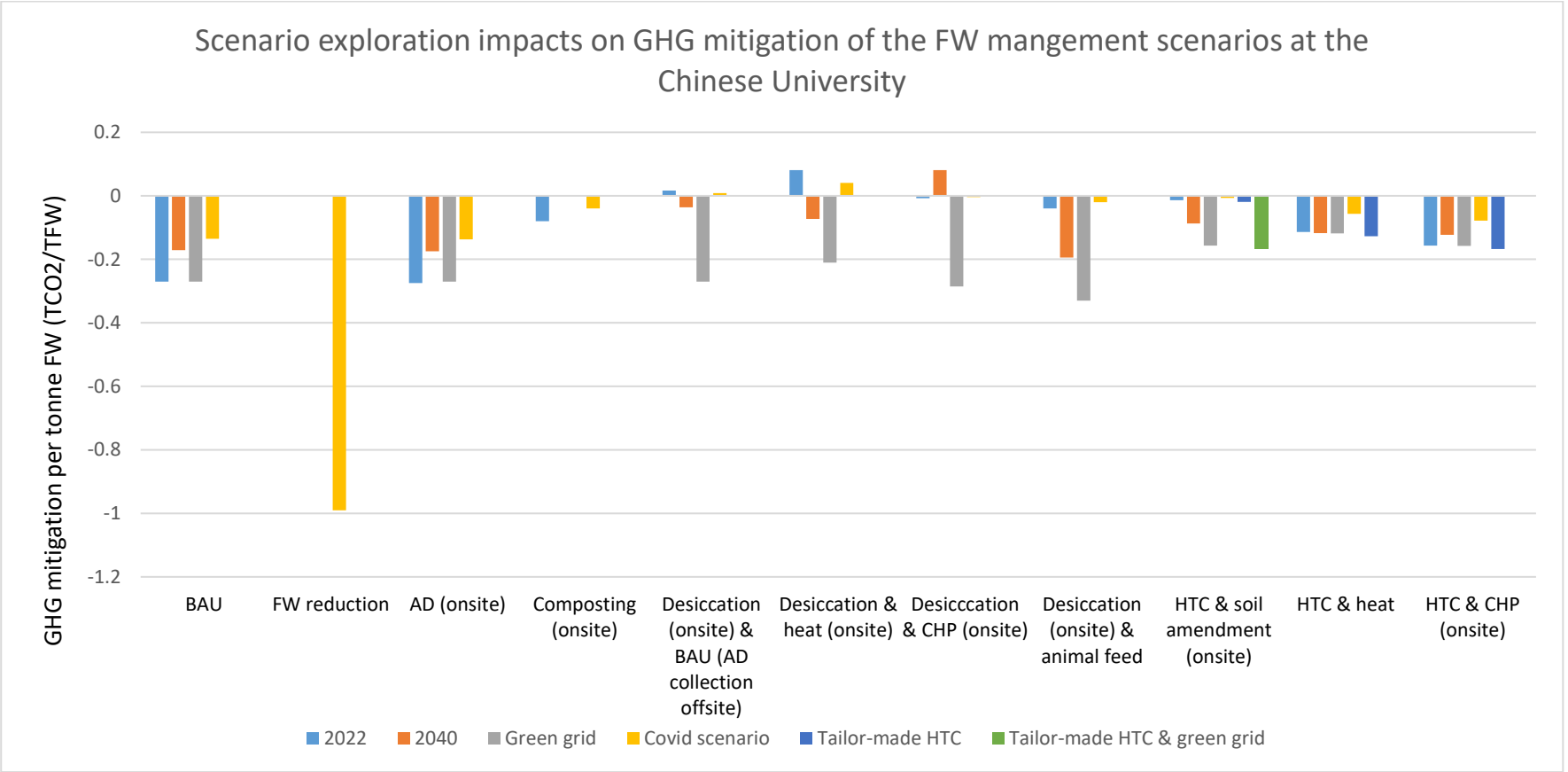

Scenario exploration impacts on GHG mitigation of the FW mangement scenarios at the Chinese University
GHG mitigation per tonne FW (TCO2/TFW)
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
BAU
FW reduction
AD (onsite)
Composting (onsite)
Desiccation (onsite) & BAU (AD collection offsite)
Desiccation & heat (onsite)
Desicccation & CHP (onsite)
Desiccation (onsite) & animal feed
HTC & soil amendment (onsite)
HTC & heat
HTC & CHP (onsite)
2022
2040
Green grid
Covid scenario
Tailor-made HTC
Tailor-made HTC & green grid

Figure 5.22.

5.8. Sensitivity analysis

The sensitivity related to key assumptions of variables used in the LCA and LCC was assessed for GHG and economic impacts.

5.8.1 GHG assessment

Table 5.11 shows how sensitivity factors affect total lifecycle GHG mitigation (tCO2eq impact for total FW at the institution) for all of the assessed institutions for all relevant FW management scenarios. Reference values show assessed lifecycle impacts, with positive figures denoting increases in GHGs, negative figures showing GHG mitigation, and +/- denoting both positive and negative variability in lifecycle GHGs.

If 15% of methane were to escape from anaerobic digesters as fugitive emissions, then AD would perform substantially less well. In addition, if technical efficiency regarding heat and energy generation were to drop by 20%, then GHG mitigation from AD would drop further still. If ran sub-optimally, AD may provide substantially less GHG mitigation than assessed in the main results section. Overall, heat and energy generation efficiency of AD and the novel technologies of HTC and desiccation is relatively uncertain and could be very influential on GHG mitigation potentials from associated FW treatment technologies.

Table 5.11. GHG sensitivity analysis

Sensitivity factor						
Scenario	**Institute**	**Unit**	**Reference value**	**Efficiency (+/-)**	**Fugitive methane (+)**	**Fugitive + efficiency (-)**
AD	UK	tCO2eq	-5.01E+02	1.01E+02	1.10E+02	1.95E+02
	India A	tCO2eq	-1.12E+04	2.25E+03	2.01E+03	3.92E+03
	India B	tCO2eq	-4.99E+02	1.00E+02	8.94E+01	1.74E+02
	China	tCO2eq	-2.40E+03	4.82E+02	4.34E+02	8.44E+02
Desiccation heat	UK	tCO2eq	-5.90E+02	1.73E+02		
	India A	tCO2eq	5.19E+03	1.62E+03		
	India B	tCO2eq	1.29E+04	1.25E+04		
	China	tCO2eq	1.14E+04	1.10E+04		
Desiccation CHP	UK	tCO2eq	-5.44E+02	1.64E+02		
	India A	tCO2eq	1.36E+03	2.38E+03		
	India B	tCO2eq	2.14E+02	1.06E+02		
	China	tCO2eq	6.69E+01	4.98E+02		
HTC heat	UK	tCO2eq	-2.77E+02	7.55E+01		
	India A	tCO2eq	-4.47E+03	9.30E+02		
	India B	tCO2eq	-1.07E+02	4.14E+01		
	China	tCO2eq	-1.03E+03	2.28E+02		
HTC CHP	UK	tCO2eq	-3.51E+02	7.19E+01		
	India A	tCO2eq	-6.49E+03	1.32E+03		
	India B	tCO2eq	-2.90E+02	5.89E+01		
	China	tCO2eq	-1.46E+03	2.97E+02		

5.8.1 Economic assessment

Tables 5.12-5.13 show how sensitivity factors affect total lifecycle costs (cost impact for total FW at the institution in US dollars) for all of the assessed institutions for all relevant FW management scenarios. Reference values show assessed LCC impacts, with positive figures denoting increases in costs, negative figures showing cost reductions, and +/- denoting both positive and negative variability in cost impacts.

In all countries, changes in the savings associated with products generated from FW treatment technologies, as well as efficiency of heat and energy generation (for relevant technologies) had the substantial impacts on costs, especially in the UK. On the other hand, changes in initial and annual costs had relatively modest impacts. Changing exchange rates also had substantial impacts on the LCC; however, exchange rates would influence all scenarios equally and would have little impact on the perceived economic competitiveness of a scenario unless it relied heavily on importing or exporting machinery or products. Specifically concerning the Indian Universities, the FW scenarios would go from being economically unviable to becoming highly cost effective if extra staffing costs associated with the FW reduction scenario could be avoided by implementing all of the Covid-19 related changes apart from a switch to table service.

Table 5.12. UK University economics sensitivity analysis

UK: Sensitivity Factor								
Scenario	**Unit**	**Reference value**	**Initial cost (+/-)**	**Annual cost (+/-)**	**Savings (+/-)**	**Efficiency (+/-)**	**Savings & efficiency (+/-)**	**Exchange rate (=/-)**
AD	USD	-1.50E+07	0.00E+00	6.05E+04	3.02E+06	3.02E+06	6.04E+06	3.00E+06
Composting	USD	-4.70E+05	5.93E+03	5.26E+04	7.24E+04			9.40E+04
Desiccation BAU	USD	1.69E+05	1.04E+04	0.00E+00	3.23E+04			3.38E+04
Desiccation heat	USD	-4.65E+07	1.15E+04	8.07E+04	9.32E+06	9.32E+06	1.86E+07	9.31E+06
Desiccation CHP	USD	-3.65E+07	1.15E+04	8.07E+04	7.32E+06	7.32E+06	1.46E+07	7.30E+06
Desiccation feed	USD	-9.10E+04	1.04E+04	7.96E+04	2.82E+04			1.82E+04
HTC soil	USD	3.19E+07	3.50E+05	7.01E+06	1.87E+05			6.37E+06
HTC heat	USD	-1.58E+07	3.50E+04	-5.73E+05	3.69E+06	3.69E+06	7.39E+06	3.17E+06
HTC CHP	USD	-1.20E+07	3.50E+04	5.73E+05	2.92E+06	2.92E+06	5.84E+06	2.39E+06

Table 5.13. Indian University economics sensitivity analysis

India: Sensitivity factor											
Scenario	**Institute**	**Unit**	**Reference value**	**FW reduction 1 (+/-)**	**FW reduction 2 (+/-)**	**Initial cost (+/-)**	**Annual cost (+/-)**	**Savings (+/-)**	**Efficiency (+/-)**	**Savings & efficiency (+/-)**	**Exchange rate (=/-)**
FW reduction	India A	USD	1.42E+07	-3.07E+08	-9.16E+07						2.84E+06
	India B	USD	3.86E+06	-9.84E+06	-5.44E+06						7.72E+05
AD	India A	USD	-2.32E+06			0.00E+00	3.50E+04	-2.22E+05	-2.22E+05	9.11E+05	-4.64E+05
	India B	USD	3.03E+04			0.00E+00	7.79E+03	-1.04E+04	-1.04E+04	4.06E+04	6.06E+03
Composting	India A	USD	-1.67E+06			3.45E+04	1.14E+05	-4.20E+05			-3.33E+05
	India B	USD	1.42E+01			0.00E+00	4.26E+03	1.26E-11			2.84E+00
Desiccation BAU	India A	USD	3.09E+06			3.94E+04	0.00E+00	-2.05E+05			6.18E+05
	India B	USD	2.13E+05			3.58E+03	0.00E+00	-2.08E+04			4.27E+04
Desiccation heat	India A	USD	2.31E+06			4.03E+04	6.65E+05	1.82E+05	1.82E+05	3.64E+05	4.62E+05
	India B	USD	2.50E+05			4.04E+03	3.96E+04	8.10E+03	8.10E+03	1.62E+04	5.01E+04
Desiccation CHP	India A	USD	2.02E+05			4.03E+04	6.65E+05	4.00E+05	4.00E+05	8.00E+05	4.03E+04
	India B	USD	-3.72E+05			4.04E+03	3.96E+04	1.78E+04	1.78E+04	3.56E+04	-7.44E+04
Desiccation feed	India A	USD	2.22E+05			3.94E+04	6.62E+05	-2.85E+05			4.45E+04
	India B	USD	-1.02E+01			3.58E+03	3.91E+04	-1.27E+04			-2.04E+00
HTC soil	India A	USD	6.98E+06			2.93E+05	2.78E+06	-6.30E+05			1.40E+06
	India B	USD	5.54E+06			2.93E+05	9.87E+05	-2.81E+04			1.11E+06
HTC heat	India A	USD	5.25E+05			2.93E+04	-6.81E+04	-9.72E+04	-9.72E+04	1.94E+05	1.05E+05
	India B	USD	1.35E+05			2.93E+04	-6.55E+04	-4.33E+03	-4.33E+03	8.67E+03	2.70E+04
HTC CHP	India A	USD	5.00E+05			2.93E+04	6.81E+04	-2.10E+05	-2.10E+05	4.19E+05	9.99E+04
	India B	USD	2.60E+05			2.93E+04	6.55E+04	-9.34E+03	-9.34E+03	1.87E+04	5.21E+04

Table 5.14. Chinese University economics sensitivity analysis

China: Sensitivity factor								
Scenario	**Unit**	**Reference value**	**Initial cost (+/-)**	**Annual cost (+/-)**	**Savings (+/-)**	**Efficiency (+/-)**	**Savings & efficiency (+/-)**	**Exchange rate (=/-)**
AD	USD	-3.16E+05	0.00E+00	1.73E+04	-1.04E+04	-1.04E+04	4.06E+04	-6.32E+04
Composting	USD	-1.02E+06	1.42E+04	3.99E+04	-1.89E+05			-2.03E+05
Desiccation BAU	USD	2.37E+05	9.54E+03	0.00E+00	2.27E+04			4.73E+04
Desiccation heat	USD	-3.19E+05	1.00E+04	8.91E+04	9.51E+04	9.51E+04	1.90E+05	-6.38E+04
Desiccation CHP	USD	-3.72E+05	1.00E+04	8.91E+04	1.06E+05	1.06E+05	2.11E+05	-7.44E+04
Desiccation feed	USD	-1.02E+01	9.54E+03	8.91E+04	-3.09E+04			-2.04E+00
HTC soil	USD	5.54E+06	2.64E+05	1.90E+06	-3.78E+05			1.11E+06
HTC heat	USD	1.35E+05	2.64E+04	-1.21E+05	-5.25E+04	-5.25E+04	1.05E+05	2.70E+04
HTC CHP	USD	2.60E+05	2.64E+04	1.21E+05	-2.75E+04	-2.75E+04	5.50E+04	5.21E+04

5.9. Impact of discount rate

A discount rate of 5% was used to assess the impact of discount rate on payback time for the best two performing scenarios, as well as the scenario with the longest simple payback time for each University. The impact of discount rate was not assessed at Indian Institute B, as no scenarios paid back initial investment at the institute. Implementation of the discount rate made no difference to ordering, regarding the best performing economic option at each University and it made very little difference to payback times for the best performing scenarios. The discount rate did have a substantial impact on the payback time for the less well performing scenarios. It more than doubled the payback time for the worst performing scenario in the UK University, and meant that the worst performing scenarios in Indian Institute A and the Chinese University never paid back their initial investment. With this being said, it would be unlikely that the Universities would consider these scenarios, as they perform substantially less well than the best performing options even before considering the discount rate.

Table 5.15. Impact of discount rate on payback time

	Best scenario (shortest payback time)	**2nd scenario (2nd shortest payback time)**	**Worst scenario (longest payback time)**
UK University			
Scenario	Desiccation & heat	Desiccation & CHP	Desiccation and animal feed
Simple payback time (yrs)	0.0	0.0	7.3
Discounted payback time (yrs)	0.0	0.0	15.9
Indian Institute A			
Scenario	AD	Composting	HTC & heat generation
Simple payback time (yrs)	0.8	1.9	17.2
Discounted payback time (yrs)	0.8	2.1	Never pays back
Chinese University			
Scenario	AD	Composting	Desiccation and animal feed
Simple payback time (yrs)	1.0	1.3	20
Discounted payback time (yrs)	1.1	1.4	Never pays back

5.10. Discussion

5.10.1. Key findings from food waste reduction and recycling costs and GHGs

When comparing the results to other studies, it appears that there are a lot of similarities and differences. It was clear that the impacts of FW reduction were much greater than that of FW recycling when considering GHG and cost impacts. Various studies have looked at the GHG impact of FW reduction and found that post-consumer (household and food service) FW reduction led to between 1.5kgCO_2eq/kgFW (ETC/SCP, 2009) and 4.2 kgCO_2eq/kgFW (Sander, 2008). On the other hand, a study by WRAP found that FW treatment in the UK only accounted for an average of 0.45kgCO_2eq/kgFW. Moreover, a study by Davison et al. (2022) found that the greatest GHG mitigation opportunities in FW treatment come from landfill avoidance, but benefits from substituting FW treatment technologies such as incineration for more

sustainable technologies such as AD and HTC, are much more limited in their impact. As general waste at the UK University was incinerated and not landfilled, the comparatively limited impact FW recycling and diversion to AD had, when compared to FW reduction at the University, directly mirrors the findings of the aforementioned studies. Regarding economic impacts on FW management, as with GHG mitigation, FW reduction had substantially greater FW savings associated with it, which is supported by the literature and resource assessment chapter. FW recycling only saves £83 per tonne in the UK University due to FW collection costs being cheaper than those for general waste, while FW reduction saves £90 per tonne in avoided FW collection costs, as well as over £10,000 per tonne avoiding the costs associated with purchasing and preparing the food that is wasted (WRAP, 2013). This would therefore mean that FW recycling would have to be at a scale more than 120 times greater than for FW reduction to have the same gross economic savings in the UK University (the only studied University with self-catered students and the FW recycling scenario).

5.10.2. Key factors affecting contrasting cost and GHGs of scenarios in different countries

Concerning GHG mitigation from FW treatment scenarios in the different countries, the findings differed significantly due to the carbon intensity of grid energy being much higher in India and China, when compared to the UK. This meant that in India and China, net energy generating countries had an enhanced GHG mitigation, while net energy using scenarios had a reduced net GHG mitigation, due to its comparatively low carbon intensity. As a result, in the UK the scenario with the greatest GHG mitigation was desiccation with animal feed production, due to it having the greatest product GHG mitigation, with a study by Takata et al. (2012) also finding that dry animal feed generation performed better than AD. On the other hand, in the Indian and Chinese Universities, AD and composting performed better than desiccation with animal feed generation, due to the high energy input emissions from the energy intensive desiccation machines when the energy was derived from the high-carbon Indian and Chinese grid energy. Salamdeeb et al. (2017) and Kim et al. (2011) also found AD and composting to perform better than dry animal feed production due to high energy input emissions form food drying. Davison et al. (2022) looked at GHG mitigation potentials from HTC and energy in the EU (with low grid carbon intensity), as well as India, and China (with high grid carbon intensity). They found that GHG mitigation from HTC with energy generation was much higher in the countries with higher grid carbon intensity (India and China), thus supporting the findings of this study.

Costs of heat and energy were substantially higher in the UK, than in India and China, due to a combination of the current conflict in Ukraine (Benton et al., 2022), as well as heavy subsidies

from the Indian and Chinese governments for energy and heating (Dansie et al., 2010). The differences in these costs meant that net heat and energy generating scenarios had substantially greater savings attributed to them in the UK, particularly for heat generating scenarios, with desiccation with heat generation having by far the greatest LCC savings. Additionally, the UK had higher FW collection costs (112 USD/tonne) than China (37 USD/tonne) and India (14 USD/tonne), which contributed towards the UK having much greater cost savings per tonne of FW for the best performing scenarios. This is expected to some extent, as living costs are generally much higher in the UK than China and India, with the UK having the 17th highest purchasing power index in the world (59.7), while China had the 38th (26.7), and India had the 101st (10.7) (World Data, 2021). With this being said, Figure 5.23. shows that percentage reductions from the best performing scenarios (heat and energy generating scenarios), in cost per tonne for treating FW, were significantly greater for the UK University when compared to the Universities in the other countries. Moreover, cost savings had a much greater influence on the combined economic savings and social benefits from CO_2 reduction, and thus the savings were greatest with the heat and energy generating scenarios in the UK University for the reasons discussed above.

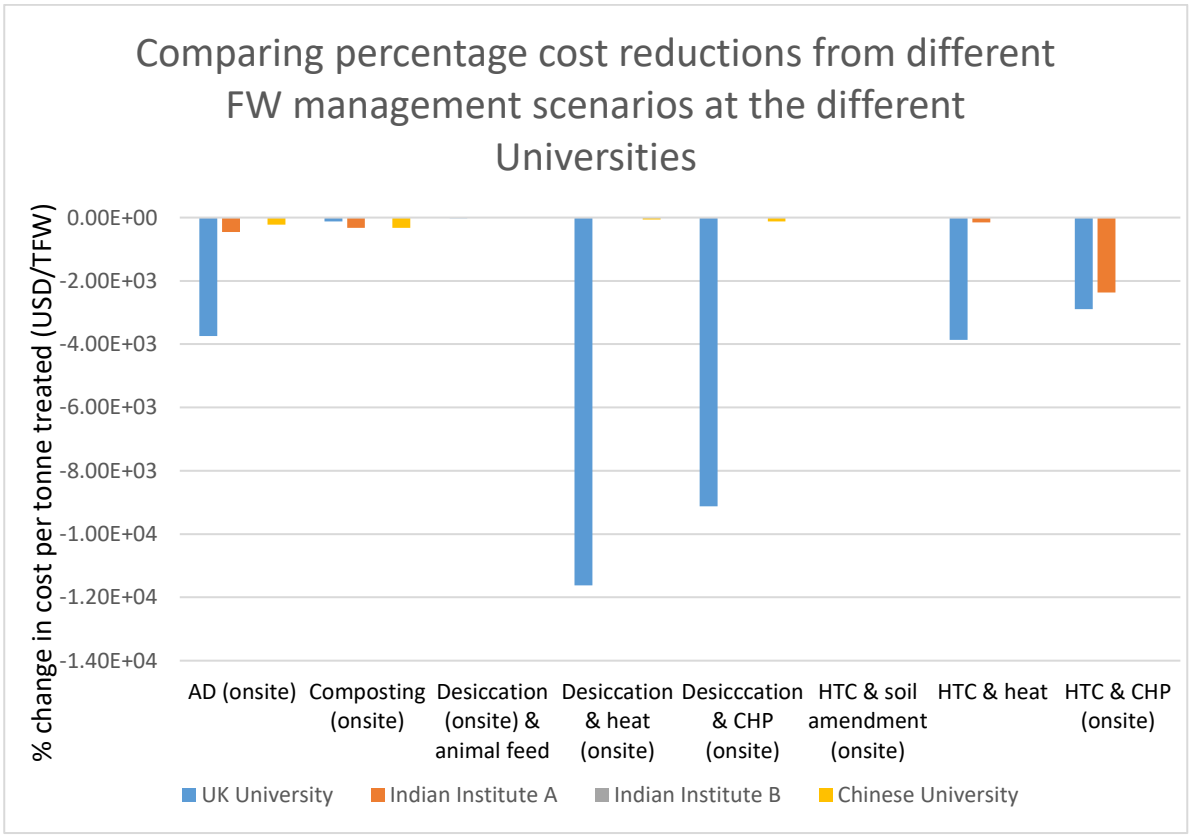


Figure 5.23.

5.10.3. Key site-specific factors affecting contrasting GHGs and costs of scenarios

In addition to those country-specific factors discussed, site-specific factors, particularly the current BAU FW treatment approaches, had major implications on the LCA and LCC of the different scenarios. Both the UK and Chinese Universities had a BAU approach (AD offsite) that performed well in the LCA, but poorly in the LCC. Both sites, therefore, had numerous scenarios that could lead to reduced costs, but had comparatively few scenarios that could lead to GHG reductions. In India, there was a stark contrast in the environmental and economic performances of the BAU FW treatment strategies at the different universities, with Indian institute A's strategy of mostly landfilling FW offsite performing poorly in both the LCA and LCC, while Indian institute B's strategy of onsite composting performed well in both the LCA and LCC. Consequently, most scenarios at Indian institute A brought about both economic and GHG savings, whereas most scenarios at Indian institute B brought about both increased costs and GHGs.

5.10.4. Key implications from scenario explorations

The scenario explorations had substantial impacts on GHG mitigation from different FW management scenarios. Concerning scenario exploration impacts on GHG emissions, the Covid-19 FW reduction scenario had the greatest GHG mitigation of all of the scenario explorations, due to a halving of FW being associated with it. The Covid-19 scenario was based on data shown in Chapter 4, with FW roughly halving at all studied Universities according to official data and observations from key FW managers. With this being said, the Covid scenario shows FW being halved at all universities, as was recorded in the data and observations; however, it is probable that FW among the university students did not reduce by half, but in fact the FW was just displaced elsewhere. When the universities were effectively closed at the height of the lockdowns in the different countries, it is likely that the students generated similar levels of waste in their households (Strotmann et al., 2022). Moreover, an increase in takeaways occurred alongside a reduction of dining in at canteens, especially in China. In China, FW disposed in canteens halved, but half of the customers moved to eating takeaways, thus it could be assumed that FW levels remained similar, but half of the canteen derived FW began to be deposited in general waste bins outside the campus. Not only would this mean that there was no GHG mitigation from FW reduction (as FW was not reduced in reality), there would have been a net increase in FW-related GHGs, as FW was displaced from AD bound FW bins, towards landfill, or incineration-bound general waste bins.

The 2040 and green grid scenarios had significant impacts on the GHGs associated with the FW treatment technologies. Specifically, the 2040 scenario considered reduced carbon intensities of grid energy in the different countries (in line with current policy and trends), leading to a

significant reduction in energy input emissions, but also the GHG mitigation from any energy generated from relevant scenarios. This led to improvements in net energy consuming technologies, such as desiccation with heat, or animal feed generation, as well as HTC with soil amendment. Conversely, it led to decreases in GHG mitigation from net energy generating scenarios, such as AD, as well as HTC with CHP. Furthermore, the green grid scenario, led to a total mitigation of energy input emissions, while not impacting on the GHG mitigation from energy generating scenarios, thus significantly improving the net GHG mitigation from FW treatment scenarios that required high energy input emissions, such as all desiccation scenarios, as well as HTC with soil amendment. With this being said, the 2040 scenario was based on current projections of grid energy intensity, as based on decarbonisation targets in the UK, India, and China. These targets may be subject to changes depending on shifting political pressures in the national and international landscape, as well as unforeseen technological and logistical opportunities and challenges in decarbonising energy, meaning that by 2040 the carbon intensity of grid energy may be significantly higher or lower than those figures used in the analysis in reality. Moreover, the green grid scenario may not be available for all sites in the different countries, and its adoption would be entirely dependent upon the will of the studied Universities to decarbonise in this way, and for the switch to a green grid to be technologically and economically viable. For these reasons, the opportunities that these scenarios offer are hypothetical at this stage and may not be realistic in reality for all sites.

5.10.5. Further considerations implicating the viability of the food waste management scenarios

While the GHG and cost implications of the scenarios are outlined and supported by the literature and previous thesis chapters, there are numerous practical considerations, uncertainties, as well as unassessed costs and benefits associated with the scenarios that are worthy of discussion.

5.10.5.1. Practical considerations for the food waste management scenarios

There are a number of practical considerations not covered by the assessments made in the results section, which have implications on the desirability of different FW scenarios for the different Universities.

Impact of current trends on heat and energy market

There is a pressure to source sustainable, cost effective heat and energy in UK, China and India to try to decarbonise the heat and energy sectors to meet decarbonisation targets (Davison, 2022). The requirement for clean affordable energy has been exacerbated by rising oil and natural gas prices caused, in part, by the conflict in Ukraine and sanctions on Russian fossil

fuels (Benton et al., 2022). Pressures in the heat and energy sector are much more acute in the UK, when compared to India and China, with price increases and the desire for domestically derived energy sources most pertinent in the UK (Mbah and Wasum, 2022). Current trends in the heat and energy sectors mean that heat and energy generating scenarios such as AD, as well as desiccation and HTC with heat and energy generation, are becoming increasingly economically beneficial and politically desirable, especially in the UK (UK government, 2022). Desiccation with either heat, or CHP production is the most cost effective of the FW treatment scenarios in the UK University and is cost effective in the Chinese University, but developments in the heat and energy sector are likely to make the scenarios even more economically competitive.

Impact of current trends on food industry

While heat and energy have seen the biggest price increases, current trends including the Ukraine conflict and resultant grain blockades and natural gas price rises are leading to increases in both fertiliser and food costs (Mbah and Wasum, 2022). These price increases mean that the food reduction, desiccation with animal feed, and biofertiliser generating scenarios (AD and HTC with soil amendment) are all becoming more cost effective (Benton et al., 2022). Furthermore, for the economic assessment, inflation was not considered, as it was assumed that all costs would rise at a rate proportional to the increase in spending power in the studied countries. Contrarily, current high inflation rates associated with the rising prices of commodities means that savings associated with product sales and other cost savings are likely to rise significantly faster than the rate of spending power increases, or savings interest in a bank account (Mbah and Wasum, 2022). This, therefore, means that net lifecycle savings from the different FW scenarios would likely be greater than that shown in the economic assessments.

Uncertainties and barriers associated with food waste desiccation

There are also certain scenario–specific uncertainties and barriers not considered in the analysis of the results that may have implications on the viability of the different FW management scenarios. Although desiccation and animal feed generation was assessed to be the scenario with the greatest potential for GHG mitigation at the UK University, while also being cost effective at the UK University, it is not currently legally possible to process canteen, or household derived FW to create products for the consumption of animals in the UK (DEFRA, 2014). A combination of the emergence of FW desiccation machines, as well as BREXIT allowing the UK to diverge from EU policies (also not permitting the use of FW for animal feed production), could lead the UK to change its legislation; however, there is currently no indication that this will happen (DEFRA, 2011; FSA, 2018; Salamdeeb et al., 2017). Additionally, China is trying to move away from using FW as animal feed; although, this is mostly due to

sanitary concerns that may be allayed by the thermal processing and pathogen removal provided by the desiccation process (Dhar, 2016).

Desiccation with combustion (for either heat, or CHP generation) had the best economic performance at the UK University, while also providing significant GHG mitigation; however, this was based on a purely theoretical assessment of the heat and energy generation potential of the feedstock. In reality, little research has been conducted as to how the dried FW material would perform as a fuel (Dhar, 2016). There would be some uncertainty over the fuel storage properties, bulk density, whether FW contents and acidity levels may damage the boiler, whether it would be easy to pelletize, what the thermal efficiency levels would be like, as well as what the energy density would be like when pelletized. It is possible, dried FW may not be suitable as a fuel, or may need to be blended with other feedstock such as lignocellusic feedstock to improve fuel quality. The sensitivity analysis showed that changes in heat and energy generation efficiency would substantially influence associated GHG and cost savings. While desiccation with combustion appears an incredibly promising FW treatment option, in actuality, more research needs to be conducted to assess its technological viability.

Uncertainties associated with hydrothermal carbonization

There are some uncertainties related to the HTC and soil amendment scenario also. It was assumed that the PW generated would be of a good enough quality to apply it directly to the soil as a biofertiliser. In reality, while it may contain large quantities of nitrogen, as well as phosphorous that would aid plant growth, it would also likely contain contaminants such as heavy metals that may cause harm to the plants (Puccini et al., 2018). An assumption was also made that the HC formed could be used as a peat-based soil amendment substitute, providing the carbon and nutrients needed to improve soil health, while sequestering carbon in a similar way to organic waste-derived compost. Similarly, not much is known about how effective the HC would be as a soil amendment product, whether it may have contaminants, whether the nutrients would be bioavailable, how long the carbon would be stored for, and generally whether its use would promote healthy soil (Busch and Glaser, 2015). Studies by Puccini et al. (2018), Busch and Glaser (2015), and Hitzl et al. (2018) have shown that HC can be utilised effectively for the purpose of soil amendment, has similar qualities to biochar, and can be used to substitute peat. With this being said, they found that post treatments such as composting or pyrolysis may be required to reduce the phytotoxicity of the HC to make it suitable for direct soil application. If post treatment were required, this would likely have negative impacts on the environmental and economic performance of the technology, which would require further studying (Puccini et al., 2018).

Uncertainties associated with food waste reduction

There are also some uncertainties about the FW reduction scenarios. Based on the results of chapter 5, it was assumed that awareness campaign-related FW reductions at the UK University could be sustained if implemented annually. In reality, the impact of the FW reduction materials may wane over time and the materials might have to be refreshed more regularly than every year, or even a more varied range of interventions may be required to sustain the FW reductions witnessed (Quested et al., 2013). In addition, in India a substantial reduction in FW was possible due to a mixture of infrastructural and printed awareness-based interventions; however, the FW reduction scenario had prohibitively high costs due to the extra staffing requirements. It may be possible, in actuality, to implement the awareness campaign materials, as well as the infrastructural interventions that did not involve extra staffing (refined menus, FW awareness raising staff, and improved food demand estimation), to achieve a large proportion of the FW reduction achieved. This would not incur the prohibitively high costs associated with implementing table service however (Papargyropoulou et al. 2019; Kallbekken and Saelen, 2013). This would have the potential to bring about both significant GHG reductions and net cost savings, as shown in the sensitivity analysis.

5.10.5.2. Other factors related to food waste management strategies

There are additional factors that affect how beneficial a FW management option is, including social benefits such as increasing food security, other environmental benefits such as nutrient recycling, or general practical factors such as ease of implementing the FW management strategy.

Social benefits

Regarding social benefits, the FW reduction scenario has added benefits in that it avoids a lot of upstream processes involved in producing the food that is wasted, such as the production, processing and transport phases. Besides the environmental and economic benefits previously mentioned, avoiding these phases helps alleviate pressures such as land use change, as well as potentially freeing up land and increasing food security (Beretta and Hellweg, 2019). Desiccation with animal feed production also alleviates land use pressures by reducing the need to grow crops for animal consumption. Additionally, the redistribution of surplus food at Indian institute A redistributes surplus food to a local charity, meaning that the food helps nourish those in need, thus directly tackling issues of poverty and malnourishment. In addition, both the FW reduction and recycling scenarios bring about social benefits in the form of awareness raising and enforcing positive sustainable behaviours (FW reduction and recycling) that the students affected may keep after they leave their university residences (Quested et al., 2013).

Wider environmental implications

Concerning other (non-GHG related) environmental impacts of the different FW management strategies, different scenarios have different issues and benefits associated with them. AD, composting and HTC with soil amendment all bring about benefits in the form of nutrient recycling (nitrogen and phosphorous) and improving soil health, while resulting in little air pollution (WRAP, 2018a). Conversely, desiccation and combustion (for heat and CHP production) does not involve the recycling of nutrients and also leads to significantly more air pollution than AD, composting and HTC with soil amendment, as nutrients such as nitrogen are volatilised rather than recycled, forming compounds that are deleterious for human health (Davison et al., 2022). HTC with combustion (for either heat, or CHP generation), leads to some air pollution and for some nutrients to be volatilised, but also some nutrient recycling and less air pollution than with desiccation, as a significant quantity of the nutrients contained in the raw FW forms in the PW which is in turn anaerobically digested (He et al., 2004). In addition, as FW recycling diverts FW from incineration, to AD, this scenario also leads to reductions in air pollution and increases in nutrient recycling. Both FW reduction, as well as desiccation with animal feed generation lead to the avoidance of upstream processes involved in growing the food that is substituted, as mentioned. Related reductions in land use change could lead to a reduction in biodiversity loss by avoiding deforestation, or other ecosystem losses (Bajželj et al., 2020). Additionally, freeing up the land that would otherwise be used to grow the wasted, or substituted crops could open up opportunities for reforestation, or habitat restoration (Gerten et al., 20202). In addition, avoiding the production process (for wasted, or substituted food) would likely lead to a reduction in the use of ecologically harmful chemical fertiliser and pesticide usage (Conrad et al., 2018).

Ease of implementation

Another key factor influencing the viability of a scenario, not considered in the GHG and economic analysis, is ease of implementation, with certain scenarios being considerably easier to implement than others. For the behavioural change scenarios, FW reduction through awareness campaigns is relatively straightforward (Reynolds et al., 2019). All that is needed is a range of awareness raising materials to be printed and displayed; however, the implementation of infrastructural interventions, such as a standardised menu and improved demand estimation requires careful consideration, while a switch to table service requires the recruitment and training of staff (Paprgyropoulou et al., 2014; Reynolds et al., 2019).

Of the FW treatment scenarios, those involving desiccation would be the easiest to implement, due to the simplicity and ease of use of the desiccation machines (Dhar, 2016). Desiccation with BAU would be the easiest to implement, as all it would require is the purchasing of the machine, the machines to be filled (by canteen staff), the on button to be pressed and the

desiccated FW to be emptied into the same FW bins that would normally be filled with the raw FW. Desiccation and animal feed production would perhaps be the second easiest scenario, as it would require the same steps as with desiccation and BAU; however, the desiccated FW would not be put in a FW bin, but instead be used to feed animals. This would require finding someone to purchase the animal feed at the Chinese University and Indian institute B; however, the FW could be used to feed the cows onsite at Indian institute A, or the pigs at the university farm at the UK University (legislation permitting). Desiccation and combustion would be slightly less straight-forward, as it would require the additional purchasing and running of a pelletizing machine and biomass boiler, as well as setting up the biomass boiler to the University heating and energy system, which would require a certain level of expertise and consideration not required with the other desiccation scenarios. On the other hand, the AD and HTC scenarios would be less straight-forward to implement, as they are both complex systems that need to be run by staff with a greater level of expertise and training when compared to desiccation (Corvalán et al., 2021; Khalid et al., 2020). These scenarios would likely require specialised staff to be recruited especially to run the units (Corvalán et al., 2021).

5.10.5.3. The value of CO_2 mitigation

For the purpose of this assessment, the value of CO_2 mitigation was set at 60 USD per tonne CO_2eq, as an average figure taken from a study by the High-Level Commission on Carbon Prices, where they estimated CO_2 should be priced at 40-80 USD per ton by 2020. On the other hand, they reported that the value of CO_2 should rise to between 50 and 100 USD per ton by 2030 (Stiglitz et al., 2017). There is a lot of debate around the social value that should be put on CO_2 mitigation, with more than 50% of current GHGs that are covered by carbon pricing initiatives being priced at below 10 USD per tonne CO_2 (World bank, 2017). On the other hand, a study by Rennert et al. (2022) estimated that the social value of GHG mitigation should be set at 185 USD per tonne of CO_2. Overall, the value used for this assessment (60 USD per tonne CO_2) was not enough to substantially influence overall combined savings for scenarios with high economic cost increases associated with them (especially Indian FW reduction), or scenarios with high economic savings (especially UK heat and energy generating scenarios). On the other hand, it could help incentivise scenarios that have a marginal net LCC expense, but a substantial GHG reduction, making them economically worthwhile adopting. Moreover, if this value rose over time, as suggested by Stiglitz et al. (2017), or was to be valued much higher, such as the 185 USD per tonne of CO_2 suggested by Rennert et al. (2022), it could have a real impact in steering the decision-making process in FW management. In addition, if carbon credits at these values became widely implemented and available to universities such as those studied, then it would provide a tangible real monetary incentive to choose FW management

strategies with GHG mitigation associated, and may drive sustainable FW management in sites like these.

5.11. Conclusion

In conclusion, FW management changes can bring about combined GHG and cost savings, and behavioural change and FW treatment scenarios can be combined to bring about enhanced savings. Moreover, some FW management scenarios could increase food and energy security, and increase nutrient recycling, thus creating the potential for wide-ranging benefits. In addition, geographic factors and business as usual FW treatment strategies of universities influence GHG and economic performances of different food waste management strategies in the UK, India and China.

While certain scenarios may be better suited to Universities in different countries, site-specific factors mean that individual assessments need to be conducted at each University to understand the best ways for them to optimise their food waste management strategy. The specific objectives are addressed as follows:

1. Identify the main country-specific, site-specific and general factors leading to GHG mitigation from FW management in the UK, Indian, and Chinese Universities.

The business as usual FW treatment strategy in place at the university had the greatest influence on what environmental benefits were possible from different food waste treatment scenarios. Almost all scenarios provided significant GHG reductions when there was a high GHG business as usual treatment strategy, such as with Indian institute A where most food waste generated was landfilled. Meanwhile very few scenarios brought GHG reductions when a low GHG business as usual treatment strategy was in place, such as at the UK University and the Chinese University with offsite anaerobic digestion of their food waste. Food waste reduction also led to substantial GHG reductions; however, FW recycling led to comparatively small GHG reductions.

The carbon intensity of grid energy was the key factor determining differences in optimal FW treatment strategies for GHG reduction in the UK, India and China. Low GHGs associated with grid energy in the UK meant that non-energy generating scenarios such as desiccation and animal feed had a greater GHG mitigation. Conversely, high GHGs associated with grid energy in India and China meant that net energy generating scenarios such as anaerobic digestion had the greatest GHG mitigation. Regarding behavioural change, the Indian Universities achieved the greatest levels of food waste reduction and associated GHG mitigation (primarily due to Covid-19 impacts).

Powering desiccators on green grids would increase GHG mitigation, while a decarbonisation of energy intensity would reduce GHG mitigation from anaerobic digestion. Moreover, suboptimal running of anaerobic digesters leading to reduced energy and heat generation, as well as fugitive methane emissions would substantially reduce GHG mitigation. In theory Covid-19 would lead to GHG mitigation from food waste reduction in canteens; however, this waste would likely be diverted into general waste bins outside campus, without food waste recycling, leading to increased GHGs.

2. Identify the main country-specific, site-specific and general factors leading to cost savings from FW management in the UK, Indian, and Chinese Universities.

The business as usual strategy had the greatest influence on economics. If a university has a costly business as usual strategy (such as the UK University), most scenarios will reduce costs, while no scenarios will bring cost reductions if a university already has cost-effective onsite treatment implemented (such as Indian Institute B). Furthermore, food waste reduction has a much greater potential for cost savings than recycling, as shown at the UK University.

The main element affecting differences in costs associated with management strategies between countries was the domestic prices of heat and energy. Very high heat and energy costs in the UK meant that heat and energy generating scenarios could bring substantially greater cost savings than in India and China with state-subsidised heat and energy, or with technologies that generate different products. The cost implications of FW reduction depends on the nature of FW reduction strategies. In the UK, food waste reduction involved minimal annual costs and brought about substantial net savings; however, in India, FW reduction was economically unviable due to prohibitively high serving costs from hiring additional servers. If food waste reduction could be achieved without requiring additional servers then food waste reduction in India would become cost effective however.

3. Understand the primary drivers affecting the combined GHG and economic performance of FW management strategies.

Extra savings associated with the social value of GHG reductions were overshadowed by the scale of savings possible from heat and energy generation in the UK, meaning market costs will likely drive optimal food waste management approaches in the UK for the near future. On the other hand, In India, when net costs and savings were marginal, yet GHG reductions were substantial, the inclusion of the social cost could turn scenarios from being a net cost, to a net saving.

CHAPTER 6: DECISION-MAKING TOOL METHODOLOGY PILOT STUDY

6.1. Introduction

Following on from the lifecycle assessment and lifecycle cost chapter, this section utilises surveys and interviews with food waste management stakeholders at the Universities in order to establish how the methodology and findings could be translated to form a decision-making tool. This pilot study is an exploratory study and proposes how the hypothetical food waste management decision-making tool could be a technological platform such as a computer software programme, or mobile phone app. The tool could ask food waste management stakeholders at universities simple, clear questions concerning food waste management with easily available answers. In order to aid the food waste management decision-making process, the tool could then generate useful outputs such as the cost and GHG impacts, as well as practical considerations involved in adopting different behavioural change and technological food waste management strategies at the University.

This chapter aims to ascertain what the most suitable data inputs, data outputs and formats would be if a pilot tool were built, in order to help optimise food waste management in the studied Universities. This in turn, creates a framework for assessing key inputs and outputs for food waste management optimisation that could be tested across a large sample of UK, Indian and Chinese Universities in order to validate the findings and form the basis of a decision-making tool capable of aiding decision-making across the higher education setting in these countries.

This involves assessing what information would be readily available for food waste managers at the assessed universities to input into a decision-making tool and what information would be difficult to gain without having an active researcher in the field. This aims to ascertain whether it would be possible to use the data inputs identified as essential for conducting the assessments in the previous chapter, and understand what mitigations may be required if the food waste managers were unable to input important data. It also includes making efforts to determine what kind of information from the data generated on GHG emissions, costs, and practical considerations the food waste managers would find useful for deciding on an optimal food waste management approach. Additionally, it includes aiming to understand what format would be most helpful and understandable for aiding the food waste management decision-

making process at the Universities. Following this, the data is analysed to form a framework for the creation of a food waste decision-making tool. This could allow the food waste managers at the studied universities to input available data and gain outputs for the food waste management approaches with the greatest GHG and cost performance, along with steps on how to set up the management approach.

Makarichi et al. (2018) and Hénault-Ethier et al. (2017) conducted assessments on the economic and environmental impacts of solid waste management approaches respectively. These studies used similar key data inputs as required for the lifecycle assessment and lifecycle cost in the previous chapter, in order to support multi-criteria analysis in solid waste management decision-making. Key environmental inputs used by Makarichi et al. (2018) and this study included waste generation rates, recycling rates, transport distances and business as usual waste management approaches, while key economic inputs used by Hénault-Ethier et al. (2017) and this study included capital and installation costs, and annual costs associated with the business as usual approaches. Moreover, AHP and MAUT, decision-making methods have been used in the selection of waste management approaches, with them also considering similar aspects to those included in this chapter. Decision-making tool outputs considered in this study as well as the AHP and MAUT approaches include resource outputs, lifecycle cost assessments, environmental issues relating to waste management, as well as policy considerations (Hartman and Goltz, 2001), and risks associated with different scenarios when looking at environmental management (Ralston et al., 1996). Moreover, Rose et al. (2016) considered the perceptions of stakeholders on the outputs and functionality of decision-making tools used in sustainable food systems, among relevant decision makers, as is being proposed in this study.

Following the introduction, the chapter outlines the materials and methods used in the study and the results are then discussed. The results include an analysis of interviews and surveys on food waste management stakeholders in the UK, India and China to find out what useful data they could input into the decision-making tool and what data outputs they would like the decision-making tool to provide for them and why. The results also include a formation of a methodological framework for the creation of the hypothetical decision-making tool that could help guide a software developer to create a useful, easy to use decision-making tool. Finally, the chapter outlines practical considerations relating to the construction of the decision-making tool, considers the scale of opportunities if the decision-making tool was to be adopted at all UK, Indian and Chinese universities bringing about similar benefits to these proposed for the studied Universities in Chapter 5, and makes suggestions for future research.

6.2. Materials and methods

6.2.1. Surveys

A 27-question survey was developed and carried out to identify preferences for decision-making tool outputs, as well as information on possible inputs (Appendix C1.). The survey was formed with questions pertaining to the key data inputs from the preliminary assessment, as well as the key data outputs from the LCA and lifecycle cost chapter, and was revised based on feedback after pilot testing. It included three sections. Section 1 involved desired outputs for the decision-making tool, assessing how useful FW managers would find different environmental, economic, and combined environmental and economic results. Section 2 assessed how useful different advice and considerations concerning the establishment and running of different FW management strategies would be for FW managers. Section 3 involved ascertaining what formats for the results and outputs would be the most useful and desirable for the FW managers. Section 4 involved finding out which of the key data inputs used for the LCC and LCA could be provided by the FW managers (if I had not been there to gain the data), and thus which data they could input into the hypothetical decision-making tool. Specifically, this section included questions relating to FW generation and composition, food waste treatment, canteens and catering, as well as self-catered FW management.

Finally, there were some questions regarding sociodemographics, including which country the participant was working in (UK, India, or China) and the sector that they were working in (catering, residences, or sustainability services). The surveys were carried out online on JISC; an online survey tool designed for academic research, for all universities, as conducting surveys in person was not possible due to COVID-19 and travel restrictions. In addition, the survey was translated into Chinese so that participants in China could participate in the research.

6.2.2. Semi-structured interviews

Semi-structured interviews lasting approximately 45 min each were also conducted in the UK in English. Interviews in India and China were not possible due to language difficulties interviewing stakeholders there. Interviews were conducted with representatives in the catering services (Head of Retail Catering), residential services (Residential Property Manager), and sustainability services (Sustainability Manager) to build a deeper understanding of what decision-making tool inputs FW managers could provide, what data outputs they would require and why. Questions were formed with the intention of expanding upon the decision-making tool survey questions (Appendix C2). The interviews involved inquiring about what kind of environmental and economic outputs the participants would be interested in, what kind of advice and considerations they would be interested in, as well as what kind of formats would be most

helpful and why. The interviews also asked which key information inputs would be difficult and why. They then asked whether there were any further relevant insights pertaining to the proposed decision-making tool.

Interviews and focus groups were conducted with the informed consent of the participants and in accordance with data protection after ethical approval was granted. They were conducted remotely on Microsoft Teams and were recorded using the recording function on Microsoft Teams. They were then transcribed, analysed, and coded into themes on Nvivo, before being written up and discussed with the use of illustrative quotes.

6.2.3. Decision-making tool methodology framework

A decision-making tool methodology framework was created to illustrate how the methods used in the LCA and LCC could be utilized to form a FW management decision-making tool. From analyzing the surveys and interviews, the available data inputs, and desirable data outputs for the decision-making tool were identified based on the remits of what was needed for the LCA and LCC, as well as what data outputs could be formed. This could then be used to create a decision-making tool, or be used for policy makers, or universities to optimize their FW management.

6.3. Results

6.3.1. Socio-demographics

As shown in Table 6.1, a mixture of UK, Indian and Chinese FW management stakeholders from the catering, residential, and sustainability services were surveyed online on JISC. Altogether, there were 13 participants who were primarily from the UK (9) due to there being more stakeholders involved in FW management at the UK University. Additionally, sustainability services were only represented at the UK University as these services are not present at the Indian and Chinese Universities, while residential services only participated in the UK and Indian Universities due to them not being involved in FW management in China. Overall, while there was a relatively low participation, a range of key FW management stakeholders (as ascertained in Chapter 3), were surveyed at all sites, so the responses included all key insights by FW management at the different sites.

Table 6.1. Socio-demographics of FW managers surveyed.

Sector	**Country**			
	UK	**India**	**China**	**Totals**
Catering services	1	1	2	4
Residential services	6	1	0	7
Sustainability services	2	0	0	2
Totals	9	2	2	13

To gain a further understanding of FW managers' insights into the decision-making tool, Semi-structured interviews with FW managers at the UK University were conducted, consisting of three FW managers representing the catering, residential and sustainability services. It was not possible to conduct focus groups on FW managers in the Indian and Chinese Universities however, due to linguistic barriers, meaning deeper insights from FW managers on the proposed decision-making tool was not possible at the Indian and Chinese Universities. The first part of the session concerned participants' desired data output requirements for the proposed decision-making tool. The second part discussed the desired format requirements for the outputs of the proposed decision-making tool. The third part considered what key data inputs, used in the study to assess FW management options at the Universities, could be gained and inputted into the proposed decision-making tool if I was not working on the project. The characteristics of the participants and themes identified are displayed in Table 6.2. The themes are discussed in the results section below to support and further explain the survey findings.

Table 6.2. Key characteristics of participants

Number	Country/University	Organization	Role
1	UK University	Catering services	head of retail catering
2	UK University	Residential services	Residential property manager
3	UK University	Sustainability services	Senior residences manager

Theme	Description
(1) **Desired data outputs**	Concerns what decision-making tool outputs would be useful and why.
(2) **Desired format for outputs**	Considers what formats would be the most useful for the decision-making tool outputs and why.
(3) **Available data inputs**	Considers which key data inputs are known and which are not known to the FW managers and why.

6.3.2. Desired data outputs

Surveys and interviews first focussed on what kind of data outputs the FW managers would be most interested in. This included inquiring about desired theoretical data outputs (GHG, economics and combined GHG and economic indicators), before asking about desired practical outputs (steps and information on how to implement FW management strategies, and key factors to consider when adopting these strategies).

6.3.2.1. Theoretical data

GHG assessment

When considering desired GHG-related data outputs for the decision-making tool, it appears that the FW managers are relatively interested in both total lifecycle and annual GHG reduction; however, there was a slightly greater interest in the lifecycle GHG reductions, as

shown in Table 6.3. Specifically, UK participants appeared particularly interested in GHG outputs, while Chinese participants appeared least interested.

When going deeper into why FW managers would be interested in gaining this kind of data, the interview responses differed between the catering, residential and sustainability services. The catering service would be keen to get this data, to be able to provide it to their customers.

> "It's something that our students are interested in and it obviously it's not information we're able to provide at the moment" [1].

At the same time, the residential services would be interested in gaining the data to help with environmental auditing and gaining environmental accreditations.

> "We need it on the environmental management system so that auditors could then see what's happening" [2].

Meanwhile, sustainability services were interested in having the data to report progress in GHG mitigation, as well as using the data to improve practices.

> "Emissions data (CO_2eq) would be beneficial for net zero reporting, as well as having sources of food waste by location to identify areas across the university with worse or better performance" [3].

Table 6.3. Environmental output preferences of FW managers

How useful the following results would be				
Environmental: Greenhouse gas reduction over lifecycle (tonne CO_2eq over 20 year lifecycle)	Country			
	UK	India	China	Totals
A great deal (n)	4	0	0	4
A fair amount (n)	2	1	0	3
A little (n)	0	0	0	0
Not very much (n)	1	0	0	1
Not at all (n)	0	0	1	1
Don't know (n)	1	0	1	2
No answer(n)	0	0	0	0
Environmental: Greenhouse gas reduction annually (tonne CO_2eq annual)				
	UK	India	China	Totals
A great deal (n)	3	0	0	3
A fair amount (n)	3	1	0	4
A little (n)	0	0	0	0
Not very much (n)	1	0	0	1
Not at all (n)	0	0	0	0
Don't know (n)	1	0	2	3

Economics

When considering desired economics-related data outputs for the decision-making tool, it appears that the interest from FW managers in lifecycle savings, simple payback time, and capital and installation cost, varied considerably between countries and participants, as shown in Table 6.4. Generally, FW managers were most interested in lifecycle savings and least interested in capital and installation costs. Overall, the UK participants were most interested in the economic outputs, while the Chinese participants were least interested. Overall, the participants were marginally less interested in the economic outputs when compared to the environmental outputs.

When exploring more deeply why FW managers would be interested in gaining this kind of data, the interview responses differed depending on the sector of the participant. The catering service would be keen to get this data, to be able to understand the business case for establishing the FW management strategy.

> "Obviously, it could help with a business case for the purchasing of the piece of kit" [1].

The residential services also argued that it would be useful for the University to understand the costs, but would not be of particular interest to the students in the same way as climate change data.

> "I'm not so sure that would be great for the students would have that much more interest, but I think certainly is a business, yes, we would" [2].

Table 6.4. Economic output preferences of FW managers

How useful the following results would be				
Economic: Cost reduction over lifecycle (£ reduction over 20 year lifecycle, compared to business as usual)	Country			
	UK	India	China	Totals
A great deal (n)	4	0	0	4
A fair amount (n)	2	0	0	2
A little (n)	1	1	1	3
Not very much (n)	0	0	0	0
Not at all (n)	0	0	0	0
Don't know (n)	1	0	1	2
Economic: Payback time (years to pay off capital and installation cost of initial investment through annual savings)				
A great deal (n)	2	0	0	2
A fair amount (n)	3	0	0	3
A little (n)	2	1	1	4
Not very much (n)	0	0	0	0
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Economic: Initial cost (£ initial investment cost for purchasing treatment technology/management strategy components)				
A great deal (n)	2	0	0	2
A fair amount (n)	3	0	0	3
A little (n)	1	1	0	2
Not very much (n)	1	0	0	1
Not at all (n)	0	0	1	1
Don't know (n)	1	0	1	2

Combined GHGs and economics

When considering desired combined economic and environmental data outputs for the decision-making tool, the FW managers' interest in identifying the FW management strategies with the cheapest GHG reduction over the lifecycle, and the cheapest GHG reduction per capital and installation cost, varied considerably in the different countries, as shown in Table 6.5. Generally, FW managers were more interested in identifying the cheapest lifecycle GHG reductions, with UK participants being the most interested and Chinese participants the least interested. In addition, when looking at all of the theoretical outputs, the participants were most interested in the cheapest GHG reduction over the lifecycle, including individual environmental and economic outputs.

When exploring the responses more deeply, the residential services believed that the combined environmental and economic impacts were the most important output.

> "I think a combination of the two [environmental and economic outputs] to be fair. You might you might get different answers across different parts of the university, but I'm sure commercial operations have to justify what they do and why they do it" [2].

This was echoed by the sustainability services, albeit with a preference for prioritising environmental benefits ahead of economic benefits.

> "Realistically probably the latter (greatest mix of environmental and economic benefits) would be the most useful, but I would like to see more weighting towards emissions reduction that cost reduction. We should be willing to pay more (a small amount) to achieve a better environmental outcome" [2].

The catering service had a clear preference for prioritising GHG reductions first and then later seeing if the FW management was economically viable.

> "I think that the environmental impact initially is the most important and, then looking at economic impacts after that, but, definitely the environmental impact is the key one for us" [1].

Table 6.5. Combined GHG and economic output preferences of FW managers

How useful the following results would be				
Environmental and economic: Cheapest greenhouse gas reduction over lifecycle (tonne CO_2eq mitigated/£ cost increase over 20 year lifecycle)	Country			
	UK	India	China	Totals
A great deal (n)	5	0	0	5
A fair amount (n)	1	1	0	2
A little (n)	0	0	1	1
Not very much (n)	1	0	0	1
Not at all (n)	0	0	0	0
Don't know (n)	1	0	1	2
Environmental and economic: Cheapest greenhouse gas reduction for capital and installation cost (tonne CO_2eq mitigated/£ initial investment cost)				
A great deal (n)	1	0	0	1
A fair amount (n)	4	1	0	5
A little (n)	0	0	1	1
Not very much (n)	2	0	0	2
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1

6.3.2.2. Practical information

Steps/information to proceed

When considering desired practical information outputs for the decision-making tool, it appears that there was a lot of variation in the perceived usefulness of the different data outputs by the FW managers from the different countries, as shown in Table 6.6. Altogether,

UK participants appeared to be the most interested in the practical information, while Chinese participants appeared the least interested.

More specifically, the FW managers were most interested in gaining approximate prices for specific components required for adopting the FW management strategies. In addition, they were also interested in having a list of suppliers in the country and contact details, as well as information on labour and maintenance requirements associated with the different strategies.

When going deeper into why FW managers would be interested in gaining this kind of information, all of the participants stated the importance of having practical information. The catering service would be keen to get this data, as they acknowledged that they are not experts in this field and would require some advice on the practicalities associated with setting up the FW management strategies.

> "We're caterers which double up in sustainability, but we're not experts in that, so definitely the guidance would be helpful" [1].

At the same time, the residential services would be interested in gaining the information to help offer further insights, but would need to conduct further assessments to be confident that they were making the right decisions and had all the information they required.

> "If we have that information that would be great, but we would want to do some due diligence. So, I think it would give us a steer but we'd want to test the viability of it" [2].

Meanwhile, sustainability services believed that there would be limited use in the data, due to circumstances such as University requirements changing regularly.

> "I feel like how to proceed would be very difficult to keep relevant and up to date e.g. with university supplier frameworks etc" [3].

Table 6.6. Perceived usefulness of steps and information to proceed by FW managers

How useful the following information would be				
Steps/information to proceed: List of suppliers in the country and contact details	Country			
	UK	India	China	Totals
A great deal (n)	2	1	0	3
A fair amount (n)	5	0	1	6
A little (n)	0	0	0	0
Not very much (n)	0	0	0	0
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Steps/information to proceed: Components required for strategy change (materials, technological components etc)				
A great deal (n)	3	0	0	3
A fair amount (n)	4	1	0	5
A little (n)	0	0	0	0
Not very much (n)	0	0	1	1
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Steps/information to proceed: Approximate prices for components				
A great deal (n)	4	0	0	4
A fair amount (n)	3	1	0	4
A little (n)	0	0	0	0
Not very much (n)	0	0	1	1
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Steps/information to proceed: Labour and maintenance requirements (staff hours and approximate wages, annual maintenance costs etc)				
A great deal (n)	3	0	0	3
A fair amount (n)	4	1	0	5
A little (n)	0	0	2	2
Not very much (n)	0	0	0	0
Not at all (n)	0	0	0	0
Don't know (n)	1	0	0	1
Steps/information to proceed: Uses for the outputs (description of applications, quality levels, and market cost etc where appropriate)				
A great deal (n)	2	0	0	2
A fair amount (n)	3	1	0	4
A little (n)	2	0	1	3
Not very much (n)	0	0	0	0
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Steps/information to proceed: Policy implications (requirements, subsidies, grants available etc)				
A great deal (n)	2	0	0	2
A fair amount (n)	3	0	1	4
A little (n)	2	1	1	4
Not very much (n)	0	0	0	0
Not at all (n)	0	0	0	0
Don't know (n)	1	0	0	1

Key considerations

Regarding desired considerations for inclusion in the decision-making tool, it appears that there was a lot of difference in opinion by the FW managers from the different countries, as

shown in Table 6.7. As with the other output categories, UK participants appeared to be the most interested in the different key considerations, while Chinese participants appeared least interested.

More specifically, FW managers were most interested in gaining information on potential future developments in waste management policy in the countries, while they were also interested in potential risks or problems that may develop related to specific waste management strategies such as machines not functioning properly, or behavioural change strategies not working effectively.

When going deeper into why FW managers would like the decision-making tool to include the aforementioned considerations, the FW managers believed it was particularly important for the decision-making tool to help highlight the risks associated with the FW management strategies. Residential services believed it was key to know the risks, to avoid investing heavily in setting up a FW management strategy based on certain expectations, only for something unexpected to develop, rendering the strategy no longer desirable.

> "You know we don't want to be in a position where we like to get something and then suddenly something comes out of the woodwork" [1].

This was mirrored by the sustainability services, which believed that providing a consideration of the potential risks associated with each FW management strategy would be the most important of the advice and considerations, as it would aid the FW management decision-making process.

> "Risks associated seems the most useful as it would help with decision-making" [3].

Meanwhile, the catering services also believed it was important that the decision-making tool included these key considerations. In particular, they wanted to ensure that the University did not publicise that it was adopting an environmentally sustainable FW management strategy to the students, only to halt the strategy due to unforeseen issues developing, as they were concerned this would negatively affect the credibility of the University.

> "I think that is something that does actually really need to be thought through really carefully before embarking on a project. Especially if you're then going to publicize the fact that you're doing it, because what you don't want to be doing is saying you're doing it, but actually there's an issue and you're no longer doing it, because then then it calls into question all your other messages" [1].

Table 6.7. Perceived usefulness of on key considerations by FW managers

How useful the following considerations would be				
Key considerations (risks and opportunities): Potential future developments in waste management in the country (policy changes such as targets, regulations, subsidies, grants and taxes)	**What country are you based in?**			
	UK	India	China	Totals
A great deal (n)	4	0	0	4
A fair amount (n)	1	0	1	2
A little (n)	2	1	0	3
Not very much (n)	0	0	0	0
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Key considerations (list and explanation of risks and opportunities): Potential risks related to specific waste management changes (Specific technological, or practical risks and concerns related to technologies and waste management strategies)				
A great deal (n)	2	0	0	2
A fair amount (n)	3	0	1	4
A little (n)	2	1	0	3
Not very much (n)	0	0	0	0
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Key considerations (risks and opportunities): Likelihood of such technology/strategy specific issues developing				
A great deal (n)	1	0	0	1
A fair amount (n)	4	0	0	4
A little (n)	2	1	0	3
Not very much (n)	0	0	0	0
Not at all (n)	0	0	1	1
Don't know (n)	1	0	1	2
Key considerations (risks and opportunities): Scale of technology/strategy issue (extra costs £, or GHG emissions tonne CO_2eq)				
A great deal (n)	1	0	0	1
A fair amount (n)	6	0	0	6
A little (n)	0	1	0	1
Not very much (n)	0	0	0	0
Not at all (n)	0	0	2	2
Don't know (n)	1	0	0	1

6.3.3 Desired data formats

When considering which formats the FW managers would want regarding the presentation of the theoretical outputs in the decision-making tool, there was a lot of difference in opinion regarding the desired decision-making tool considerations by the FW managers from the different countries, as shown in Table 6.8. As with the other output categories, UK participants appeared to be the most interested in the different data formats, while Chinese participants appeared the least interested.

More specifically, participants were most interested in yes, or no responses to options (such as yes this would reduce GHGs, and/or costs), while they were also interested in having a score

for each option (such as a score out of 100 based on greenhouse gas reductions, cost reduction, or combined environmental and economic benefits). In addition, UK and Indian participants were all interested in all formats, at least “a little”, whereas Chinese participants were mostly interested in the ranking options, based on criteria (for example 1. Composting on site, 2. Anaerobic digestion on site), as well as figures and graphs illustrating greenhouse gas emissions and economic considerations.

When going deeper into why FW managers would like the decision-making tool to include these formats, the FW managers believed it was important for the decision-making tool to include a mixture of format options. The catering services believed it was important to have general information outputs prescribing the best option, as well as more detailed information to understand why these options were chosen.

> “The scores out of 100 side is really good and then if you can drill into that with specifics I think that would be really useful as well depending on what angle you're coming at it from” [1].

Meanwhile, the sustainability services believed that providing a scaling of the best FW management options, as well as a visualisation of the results in the form of figures and graphs would be most helpful for aiding the FW management decision-making process.

> “Visual representation of the data is important I think as it makes it much easier to interpret. I would personally prefer something that ranks the strategies in order” [3].

On the other hand, residential services thought that the scaling would be of some help, but the specific information would be much more useful. They also believed that it would be important to explore the detail further beyond the decision-making tool through contacting suppliers and potentially doing trials of the best performing strategies to ensure due diligence has been followed.

> “The scaling will be fine, but it would only be like an introduction to the equipment would then need to sort of drill down into what are the pros and cons of the equipment and then see what is the best fit for the situation that we have” [2].

Table 6.8. Desired data output formats by FW managers

How useful the following considerations would be				
Specific information: Yes, or no responses to options (i.e. Yes this would reduce greenhouse gas emissions, and/or reduce costs, or no this would not reduce greenhouse gas emissions and/or costs)	What country are you based in?			
	UK	India	China	Totals
A great deal (n)	4	1	0	5
A fair amount (n)	3	0	0	3
A little (n)	0	0	0	0
Not very much (n)	0	0	1	1
Not at all (n)	0	0	1	1
Don't know (n)	1	0	0	1
Specific information: Ranking options, based on criteria (i.e. 1. Composting on site, 2. Anaerobic digestion on site)				
A great deal (n)	2	0	0	2
A fair amount (n)	4	1	1	6
A little (n)	1	0	0	1
Not very much (n)	0	0	1	1
Not at all (n)	0	0	0	0
Don't know (n)	1	0	0	1
Specific information: Score for each option (i.e. score out of 100 based on greenhouse gas reductions, cost reduction, or combined environmental and economic benefits)				
A great deal (n)	4	0	0	4
A fair amount (n)	2	1	0	3
A little (n)	2	0	1	3
Not very much (n)	0	0	1	1
Not at all (n)	0	0	0	0
Don't know (n)	0	0	0	0
Specific information: Figures/graphs illustrating greenhouse gas emissions, economic considerations (savings against capital and installation costs)				
A great deal (n)	3	0	0	3
A fair amount (n)	3	1	1	5
A little (n)	2	0	0	2
Not very much (n)	0	0	1	1
Not at all (n)	0	0	0	0
Don't know (n)	0	0	0	0
Specific information: Specific figures (i.e. kgCO_2eq reduction/kg food waste, payback time etc)				
A great deal (n)	3	0	0	3
A fair amount (n)	3	1	0	4
A little (n)	2	0	0	2
Not very much (n)	0	0	1	1
Not at all (n)	0	0	1	1
Don't know (n)	0	0	0	0

6.3.4. Available data inputs

After considering desirable data outputs, the surveys and interviews then focussed on what kind of key decision-making tool data inputs the FW managers would be able to provide. This included inquiring about data inputs pertaining to FW generation and composition, FW treatment, canteens and catering, as well as self-catering and related FW management information.

6.3.4.1. Food waste generation and composition

Regarding FW generation and composition data, while a significant amount of data was easily accessible for inputting on FW generation levels, all relevant data on FW composition was not attainable at any of the Universities, as shown in Table 6.9. Specifically, it was possible to have data inputs for total generation (tonnes of FW per year at university), as well as seasonality (monthly generation of FW in tonnes of FW per month) in all Universities, but input data on either the tonnes per year, or percentage FW generated from catering was only possible at the UK University.

Table 6.9. Available food waste generation and composition data inputs

Which of the following food waste generation and composition information would it be possible for you to provide?	**Country**			
	UK	**India**	**China**	**Totals**
Food waste generation levels: Total generation (tonnes of food waste per year at University) (n)	2	0	2	4
Food waste generation levels: Seasonality (monthly generation of food waste in tonnes of food waste per month) (n)	2	1	1	4
Food waste generation sources: Tonnes/year, or percentage food waste from catering (n)	3	0	0	3
Food waste generation sources: Tonnes/year, or percentage from self-catered residences/students (n)	0	0	0	0
Food waste generation sources: Tonnes/year, or percentage from other sources (n)	0	0	0	0
Food waste generation sources: If applicable, specify the other sources (n)	0	0	0	0
Food waste composition, Typical values for: Moisture content of food waste (n)	0	0	0	0
Food waste composition, Typical values for: Carbon, hydrogen, nitrogen and oxygen content of food waste (figures in %, or g/kg) (n)	0	0	0	0
Food waste composition, Typical values for: Higher heating values, or other calorific value (i.e. higher heating value (HHV), or lower heating value (LHV) (n)	0	0	0	0
None of the above (n)	3	0	0	3

6.3.4.2. Food waste treatment

Concerning FW treatment data, data availability varied considerably depending on the country that the University was situated in, as shown in Table 6.10. Specifically, it was possible to get some information on the general waste treatment strategy, such as general waste treatment technology. On the other hand, all the Universities had data limitations, with it not being possible to know costs associated with general waste treatment in India and China, and there being a lack of knowledge of transportation methods at the UK University. Likewise, while it

was possible to know the specific FW treatment technology at all sites, there were knowledge gaps in all countries regarding BAU FW treatment strategies. Conversely, it was not possible to know the transport distances at all the Universities, the costs associated with FW treatment at the Indian and Chinese Universities, and the transport method used at the UK and Chinese Universities. Regarding technological feasibility, and understanding what FW treatment strategies would be possible at the different Universities, the UK and Chinese FW managers would be unable to input any of the key information regarding space, cost and any other limitations for the FW treatment equipment; however, the Indian Institute B would be able to provide all relevant inputs on technological feasibility.

Table 6.10. Available food waste treatment data inputs

Which of the following information on food waste treatment would it be possible for you to provide?	**Country**			
	UK	**India**	**China**	**Totals**
Business as usual strategy: Current general waste treatment costs (collection cost/tonne of general waste If waste is collected) (n)	3	0	0	3
Business as usual strategy: General waste treatment technology (i.e. landfilling, or incineration) (n)	2	1	2	5
Business as usual strategy: general waste Onsite, or offsite treatment (n)	0	1	1	2
Business as usual strategy: general waste distance to treatment facility (i.e. km from university to treatment site) (n)	1	0	1	2
Business as usual strategy: general waste transport method (i.e. diesel truck, electric powered train etc) (n)	0	1	2	3
Business as usual strategy: Current food waste treatment costs (collection cost/tonne of food waste, if waste is collected) (n)	1	0	0	1
Business as usual strategy: Current food waste treatment technology (i.e. composting, or incineration) (n)	2	1	1	4
Business as usual strategy: Current food waste treatment Onsite, or offsite treatment (n)	0	1	0	1
Business as usual strategy: Current food waste treatment Distance to treatment facility (i.e. km from university to treatment site) (n)	0	0	0	0
Business as usual strategy: Current food waste treatment Transport method (i.e. diesel truck, electric powered train etc) (n)	0	1	0	1
Technological feasibility: Space requirements (dimensions any treatment site would need to fit into) (n)	0	1	0	1
Technological feasibility: Cost requirements (maximum capital and installation cost, maximum payback time etc) (n)	0	1	0	1
Technological feasibility: Any other feasibility constraints (n)	0	1	0	1
None of the above (n)	4	0	0	4

6.3.4.3. Canteens and catering

Concerning data on canteens and catering, data availability varied considerably depending on the country that the University was situated in, as shown in Table 6.11. The UK University was able to provide all relevant data; however, the Indian and Chinese Universities had notable knowledge gaps. Specifically, the FW managers at Indian Institute B could provide all relevant data on canteen meal types, payment types, and rough contributions to FW by catering stage, but could not provide any information regarding food donation of surplus food to charity. On the other hand, the Chinese FW managers could not provide any information on the rough

contributions to FW by catering stage, but could provide information on charity surplus food donation (albeit not specific quantities possible for redistribution), and could also provide information on canteen meal type and payment type.

Table 6.11. Available canteen and catering data inputs

Which of the following information on canteens and catering would it be possible for you to provide?	**Country**			
	UK	**India**	**China**	**Totals**
Meal type (i.e. all you can eat buffet, Set meals, Flexible build your own food) (n)	5	1	1	7
Payment type (i.e. pre-paid, or pay as you go) (n)	4	1	2	7
Rough contributions to food waste by stage: Food preparation waste in kitchens (tonnes/year, or percentage of total food waste) (n)	4	1	0	5
Rough contributions to food waste by stage: Surplus unserved food left at the end of service (tonnes/year, or percentage of total food waste) (n)	2	1	0	3
Rough contributions to food waste by stage: Plate scrapings from food customers took, but didn't finish (tonnes/year, or percentage of total food waste) (n)	1	1	0	2
Charity surplus food donation: Does the canteen send surplus food to charity? (yes, or no) (n)	3	0	1	4
Charity surplus food donation: If yes, how much (tonnes/year, or percentage of total food waste) (n)	1	0	0	1
Charity surplus food donation: If not, would it be possible to start? (n)	2	0	2	4
None of the above (n)	2	0	0	2

6.3.4.4. Self-catering

Concerning data on self-catering related to FW management, data availability varied considerably depending on the country that the University was situated in, as shown in Table 6.12. The UK University was able to provide all relevant data, however the Indian and Chinese Universities had notable knowledge gaps. Specifically, the Indian and Chinese University FW managers could determine whether there were self-catered students and residences at the Universities, while the Indian FW managers could also determine the number of self-catered residences and students. On the other hand, both the Indian and Chinese FW managers could not provide data on self-catered FW recycling rates, details of current FW recycling strategies, or the feasibility of setting up a strategy if there is not currently one in existence.

Table 6.12. Available self-catering data inputs

Which of the following information on self-catered food waste management would it be possible for you to provide?	**Country**			
	UK	**India**	**China**	**Totals**
Self-catered residences: Are there self-catered residences, at the university? (yes, or no) (n)	3	1	2	6
Self-catered residences: If so, how many? (number of residences/proportion of residences) (n)	3	1	0	4
Self-catered students: Are there self-catered students at the University? (yes, or no) (n)	3	1	1	5
Self-catered students: If so, how many self-catered residents are there? (number of students/proportion of total students at the university) (n)	3	1	0	4
Self-catered students: If so, what is the recycling rate for students (proportion of self-catered students, or flats that recycle their food waste) (n)	2	0	0	2
Self-catered recycling: If there is a food waste recycling strategy for self-catered students, what is the current recycling strategy (optional opt-in, optional opt-out, compulsory, other) (n)	1	0	0	1
Self-catered recycling: If there is not a food waste recycling strategy for self-catered students, what would be the feasibility to have FW recycling (possible easy, possible difficult, not possible/unviable) (n)	2	0	0	2
None of the above (n)	4	0	0	4

6.3.5. Decision-making tool framework

After analysing the desirable data outputs, and what kind of key decision-making tool data inputs the FW managers would be able to provide from the survey and interview responses, efforts were made to understand how this information could translate to the formation of a decision-making tool by creating a decision-making tool framework. This included identifying suitable outputs for the decision-making tool, suitable formats for the outputs, as well as suitable inputs and mitigations for any key data inputs that could not be provided by FW managers.

6.3.5.1. Desired data outputs

From analysing the responses regarding desired data outputs, it is clear that it would be useful to have a range of environmental, economic, and combined environmental and economic indicators for the theoretical outputs. Moreover, there was a particular desire to have indicators that take into account the full lifecycle perspective, with the cheapest GHG mitigation over the lifecycle being the most desired theoretical output. Furthermore, there was a preference to have an option to have a heavier weighting on GHG reduction, over cost reduction as environmental aspects were slightly more prioritised by the FW managers overall.

Regarding the practical information, all of the advice and considerations were considered useful, at least by some FW managers surveyed, including steps on how to proceed to establish the FW management strategy, as well as policy implications, opportunities and risks related to each strategy. There was however, a particular interest in having a detailing of the specific risks associated with each technology. This was to ensure that there were no unexpected surprises rendering the scenario unviable in reality.

Concerning the desired format, the FW managers wanted to have a range of data formats. They desired an initial scoring and/or ranking of the FW management options, before the ability to expand upon this in more detail with the visualisation of data in the form of charts and graphs, as well as specific detailed data on GHG mitigations and economic cost and savings. With this being said, it was mentioned that the tool could be used as something to help narrow down options and provide an initial assessment, before a more thorough detailed assessment was carried out to determine the best FW management scenario to adopt in reality.

6.3.5.2. Available inputs

Food waste generation and composition data

Regarding FW generation and composition data, although data inputs would be possible concerning total FW generation levels and seasonality at all the Universities, there was a lack of data on specific FW sources. For this reason, the data inputs could include total annual FW generation (tonnes) and rough generation each month (for example approximate tonnes of FW generated on campus in January), while leaving out inputs concerning sources of FW. Moreover, data was unavailable for composition; however, it would be possible to use general FW compositional data from similar university sites in the specific country (and ideally the same region) to estimate FW composition onsite. From these inputs, it would therefore be possible to ascertain total annual FW quantities at the sites, rough seasonal variation, and relatively representative FW compositions from the data available. This would mean that there would be no substantial issues regarding the data gaps, assuming that a University-wide FW management strategy was adopted, and the specific University site had a relatively typical FW composition for FW in the country/region.

Food waste treatment data

Concerning FW treatment data, different countries had different data gaps. At the UK University specifically, all knowledge was available regarding current general waste treatment apart from transport methods. Transport distance was known however, meaning that transport method could be excluded as an input and an assumption could be made that a typical diesel lorry was used to carry the FW the required distance. There was a lack of data at the Chinese and Indian Universities regarding general waste management, but due to the Universities not having self-catered students, the general waste data was not relevant and therefore not required in these countries anyway.

Likewise, while it was possible to know the specific FW treatment technology at all sites, there were knowledge gaps in all countries regarding BAU FW treatment strategies. Specifically, it was not possible to know the transport distances at all the Universities, and the transport

method was not known at the UK and Chinese Universities. If the transport distance and method could not be determined, it would then be assumed, according to the literature, that the FW was treated at a site an average distance away using a typical transport method (diesel truck) for the country; however, if FW was treated onsite, it would be assumed that there were no transport distances associated. It was also not possible to ascertain the costs associated with FW treatment at the Indian and Chinese Universities. If the FW treatment cost could not be determined, it would be assumed, according to the literature, that the university would pay typical FW collection fees (per tonne) in the country. Regarding technological feasibility, the UK and Chinese FW managers would be unable to input any of the key information regarding space, cost, and any other limitations for the FW treatment equipment. If no requirements could be determined, it would therefore be assumed that there would be no related restraints; however, the related information would be provided alongside a reminder to check restraints before pursuing the FW treatment strategy further. With the data input limitations being considered, it would still be possible to estimate rough economic assessments, assuming that the University does not have unusually high or low FW collection costs. Additionally, rough transport related emissions could be estimated, assuming the University does not have unusually high or low FW transport distances, or have an unorthodox method of transport associated with its FW collection.

Catering data

Concerning data on canteens and catering, the UK University could provide all relevant information, although the Indian and Chinense Universities did have notable knowledge gaps. Specifically, the Indian University FW managers could not provide any information regarding surplus food donation to charities. If FW managers could not provide data on food donation, it would be assumed that it would not be possible. On the other hand, the Chinese FW managers could not provide any information on the rough contributions to FW by catering stage. If this data could not be determined, then it would be assumed that the rough FW contributions from the different stages were similar to that in the literature for similar universities in the same country/region.

Self-catering data

With regard to data on self-catering related to FW management, the UK University could provide all relevant information; however, the Indian and China Universities had notable knowledge gaps. Specifically, both Indian and Chinese FW managers could not provide data on self-catered FW recycling rates, details of current FW recycling strategies or the feasibility of setting up a strategy if there is not currently one in existence. This, however, was not an issue, as the University catered for all students in India and China, therefore the self-catered FW

management data was not relevant and not required in these countries anyway. It would be essential to ascertain whether the University had self-catered students and if so how many self-catered students were present at the university in order to assess opportunities from the FW recycling scenario. On the other hand, if necessary, recycling rates could be assumed based on recycling rates gained at the UK University in this study, and the other questions are useful but not essential.

6.3.5.3. Specific questions, outputs, structure and format of decision-making tool

Inputs

When considering the specific questions and structure of the decision-making tool, the FW managers would first be asked where the University is based in section 1, with all of the proposed questions displayed in the appendix.

The FW managers would then be asked to input key inputs on FW generation in section 2. They would first be asked a required question about approximate annual FW generation, before being asked optional questions on seasonality and specific FW sources.

The next set of questions (section 3) would involve asking about waste treatment strategies. It would first ask one required question about the current FW treatment strategy, before asking optional questions about the current FW treatment strategy and technological feasibility. Finally, UK-based FW managers would be asked further optional questions on current general waste management strategies, with these questions being excluded from the decision-making tool in India and China.

The FW managers would then be asked to input key inputs on canteens and catering in section 4. It would first ask two required questions on the canteen meal type (buffet, set meals, or build your own meals) and the payment type (pre-paid, or pay as you go), before optional questions on FW contribution by stage (preparation, plate scrapings, and surplus food) and the feasibility of sending surplus FW to charity.

The next section only concerns UK universities (as there are no self-catered students in India and China), and thus only UK FW managers would be asked questions in section 5. UK FW managers would be asked to input FW-related information related to self-catering. The tool would first ask three required questions on the presence of self-catered students, numbers of these students, and the availability of FW recycling for self-catered students at the university. It would then ask optional questions on the current FW recycling strategy and recycling rate if there is self-catered FW recycling, or the feasibility of setting up FW recycling if FW recycling is not currently in place.

Outputs

Regarding the specific outputs, the FW managers could select whether they wanted to assess environmental, economic or combined environmental and economic indicators. The FW management options would then be ordered from best to worst according to the category selected, according to GHG and/or cost savings over the lifecycle. For the combined environmental and economic assessment option, the FW managers could be given options to scale their interest in a particular indicator. The options included heavy prioritisation of GHG mitigation, slight prioritisation of GHG mitigation, equal prioritisation of GHG mitigation and economic savings, slight prioritisation of economic savings, and heavy prioritisation of economic savings.

There would be the possibility to expand upon the results for each FW management option and gain specific information on each category. Specifically, the decision-making tool could generate figures and graphs illustrating greenhouse gas emissions, economic considerations (savings against capital and installation costs), as well as specific information, such as $kgCO_2eq$ and cost reductions over the lifecycle, cost per tonne of GHG mitigated, payback time, and capital and installation cost.

After looking at all of this information, it would be possible to select one or more FW management options to look at the practical considerations, risks, and opportunities associated. It would tell the key steps, such as components needed, rough costs, and supplier information, with the possibility to expand upon practical considerations such as staffing requirements, uses for any products created, and policy implications. It would also be possible to expand even further to gain information on potential risks and opportunities such as the potential risks associated with the specific FW management option chosen, as well as potential future policy changes.

6.3.5.4. Framework

A framework was created based on the refinement of the inputs and the outputs through the analysis of the FW managers insights. Figure 6.1, shows that there are both essential and nonessential inputs that are used to generate both key and additional outputs, in the form of theoretical and practical information, with the arrow from left to right showing the flow of information from inputs, to form the outputs, to aid the final selection of treatment strategy at the university. This information can then be used by FW managers to either select a FW management strategy, based on the recommendations, or can be utilised to form a further assessment of options, with this additional information then being used to identify a preferred FW management strategy for the university. This therefore provides the basis in which to form

an easily understandable, easily usable, simple FW management decision-making tool that could aid FW managers in optimising their FW management strategies in UK, Indian and Chinese Universities, thus resulting in GHG and cost savings associated with FW management at the universities assessed by the tool.

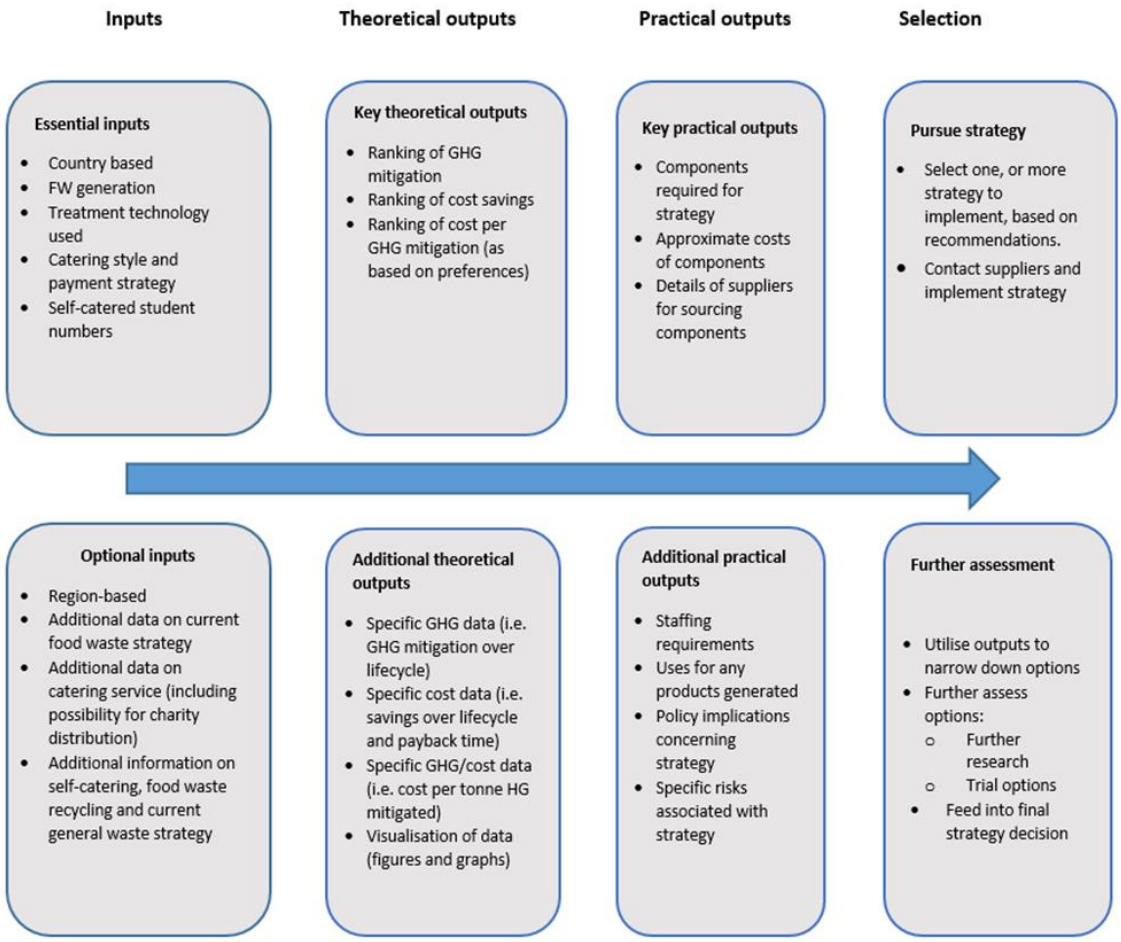


Figure 8.1.

6.4. Discussion

This Chapter has identified the possible inputs, as well as the desired outputs and formats for the hypothetical FW management decision-making tool, which informed the formation of a framework for the creation of said tool. This section aims to examine the practical issues that would need to be considered when developing this tool, and the potential scale of opportunities that the tool could provide if it were to be created.

6.4.1. Practical considerations

There are a number of practical considerations that would need to be considered if the tool were to be built. This would help allay any potential concerns by FW managers at universities, as well as meet certain practical requirements relating to general FW management practices onsite. It is very important to ensure that any data is anonymous, confidential, and secure, to

ensure that no confidential data is shared outside the university causing any ethical, reputational, or competition related concerns. This is something that was mentioned during the interviews as essential for the university adopting the tool. A further key consideration that was also mentioned in the interviews was that the tool would need to be trialled as a prototype to ensure that it works well in practice, and that any issues are ironed out before it is fully adopted by universities. A further requirement would be that it would need to fit into the operational systems of the universities, such as having data outputs compatible with any institutional systems for operation and reporting. For example, the output data would need to be easily applicable and also useful for annual reviews and auditing schemes used such as the Blueprint scheme used by the UK University (University of Leeds, 2022a), or to assess any contributions towards any environmental targets such as the 2030 net zero target by the UK University (University of Leeds, 2022b). Moreover, the outputs of the tool should be easily understandable to publicise the benefits achieved from the resultant FW management changes for use in University PR, in order to entice current and prospective students, fellow staff and engage members of the public, as mentioned in the interviews. Furthermore, circumstances affecting the validity of certain FW management options can change rapidly, such as with the current heat and energy price hikes in the UK and Europe (Benton et al., 2022). It would therefore be important to have an option to review the economic and environmental performance of the strategies for when there is a major change in circumstances (such as with Covid-19, or Ukraine), or a general annual review. This could allow the users to ascertain whether the chosen FW management strategy is still the best option of those available, or whether any changes have meant that another option is now optimal. The review could also provide updated figures on costs and GHGs, which could be useful in financial planning, as well as PR reporting, auditing and progress on meeting related environmental targets.

6.4.3. Scale of opportunities

When considering the scale of the opportunities in FW management that could come about if the framework were validated and the tool was formed and adopted across UK, Indian, and Chinese universities, it is hard to accurately quantify potential benefits, due to site-specific differences in the different universities. With this being said, as the Universities studied were considered to be broadly representative of typical universities in their respective countries, in terms of FW generation and management approaches, and data was available for total FW generation from university students in the studied countries, it was possible to estimate approximate total benefits. Specifically, it was possible to identify the best economic, environmental, and combined economic and environmental scenarios for each site, and scale

up the benefits for each country. This was based on estimates of total annual FW generation at universities across the countries from FW per capita generation and total student numbers, based on figures from the literature. The estimated impacts based on scaling up the benefits from optimal scenarios in the studied sites are displayed in Table 6.13.

6.4.3.1. Scale of GHG mitigation opportunities

It is likely that India would have the greatest potential for GHG mitigation, potentially totalling over 2 million tonnes of CO_2eq per year. This is due to a high FW reduction potential and mitigation from avoiding landfill avoidance, as well large FW generation from having a high per capita FW generation level among students and high total student number. The FW reduction estimates were primarily due to a specific scenario created in this study, which may not truly represent GHG mitigation potentials across the country. In addition, GHG mitigation from FW treatment changes would mitigate substantially less GHGs if the BAU treatment strategy was not primarily to landfill the FW, with many Indian Universities sustainably treating their waste on, or offsite.

It is probable that China would have a lower GHG mitigation potential than India, totalling over 8 thousand tonnes of CO_2eq. Despite Chinese students generating more FW than India, the migration potential per quantity of FW would likely be lower, due to a more sustainable BAU approach. In reality, it is possible that the average GHG mitigation per tonne could be greater in Chinese Universities, as it would likely be possible to implement some form of FW reduction, and also certain universities may have less sustainable BAU FW treatment strategy than the Chinese University assessed, allowing for enhanced GHG mitigation.

The UK would likely have the lowest GHG mitigation potential of all of the different countries of around 6 thousand tonnes of CO_2eq, because total FW generation in UK universities is only a small fraction of that in India and China. This was caused by lower FW generation rates per capita (attributable to a higher proportion of students living in self-catered accommodation without FW recycling, or living offsite, when compared to India and China), as well as there being substantially fewer student numbers in the country.

6.4.3.2. Scale of economic opportunities

Regarding economic opportunities, China likely has the highest cost reduction potential of around 200 million USD per year, due to having the highest total FW generation. In reality, if cost effective FW reduction was possible, even higher total economic savings may be possible. The UK may have the next greatest potential for cost savings altogether also totalling around 200 million USD per year. Although UK universities generate substantially less FW than the other countries, it is probable that savings per quantity of FW would be much higher due to the current high cost of heating in the UK, and the high cost saving from the FW desiccation

and combustion with heat generation scenario. This cost saving may decrease in the future if heating costs decrease however. India would likely have the lowest potential for cost reduction of around 180 million USD, due to India having lower cost saving opportunities per tonne of FW when compared to the UK, and generating considerably less FW than China. If cost effective FW reduction was possible however (through avoiding the requirement for additional servers), higher cost savings may be possible.

6.4.3.3. Scale of combined GHG and cost savings

The addition of the social value of CO_2eq mitigation could be an opportunity to substantially increase cost savings in India, due to FW management options that could provide large GHG reductions and cost savings. These savings could likely be further increased if a cost effective FW reduction strategy was found. The addition of the social value of GHG mitigation could slightly increase savings in the UK, but opportunities would be relatively unsubstantial when compared to the economic opportunities from heat and energy generation. In China, the addition of the social value of GHG mitigation would potentially have negative impacts on cost savings, as the most cost effective option (onsite composting), would lead to an increase in GHGs, when compared to the BAU strategy of the Chinese University (offsite AD).

Table 6.13. Estimation of potential GHG and cost savings from the decision-making tool

Estimated potential of the benefits if the decision-making tool was rolled out across the UK, India and China				
Country	UK	India	China	Sources
Average annual per capita FW per student (kg capita/year)	5.6	34.9	69.8	Table 2.8.
Total student numbers across all universities in country (million)	2.75	34.6	30.3	Statista, 2022; Zhou et al., 2021
Total annual FW across all universities in country (tonnes)	15,400	1,207,540	2,114,940	Preliminary assessment, Statista, 2022; Zhou et al., 2021
Potential GHG mitigation (tCO_2eq/tFW)	0.41	1.99	0.004	LCA
Potential cost saving (USD/tFW)	14563.5	153.07	111.59	LCC
Potential combined economic value of cost and GHG savings (USD/tFW)	14,580.11	195.71	100.19	LCA and LCC
Potential GHG mitigation (tCO_2eq)	**6,314**	**2,403,004.6**	**8,459.76**	LCA, Preliminary assessment, Statista, 2022; Zhou et al., 2021
Potential cost saving (USD)	**224,277,900**	**184,838,147.8**	**236,006,154.6**	LCC, Preliminary assessment, Statista, 2022; Zhou et al., 2021
Potential combined economic value of cost and GHG savings (USD)	**224,533,694**	**236,327,653**	**211,895,838.6**	LCA and LCC, Preliminary assessment, Statista, 2022; Zhou et al., 2021

6.5. Conclusions

The findings generally show that the essential data inputs, as identified in the lifecycle analysis and lifecycle cost chapter, could be provided by the food waste management stakeholders at

the studied universities. The study also found that all stakeholders in all the studied universities would generally consider the proposed decision-making tool useful. The food waste managers stated their preference for the food waste management options to be ranked from best to worst, based on their environmental and economic benefits. There was also a preference to have the possibility to expand upon this ranking further, to gain more detailed and visual data, and practical information. Following this, they wanted to have an option to select a desired food waste management approach to gain steps on how to implement the strategy. A framework for the creation of the proposed decision-making tool was then formed based on these key findings. This framework could then be applied to numerous and diverse universities in the UK, India and China, to validate the results in order to understand possible inputs and desirable outputs across all universities in the respective countries. Once validated and/or adjusted accordingly, there would be the possibility to create a high-impact decision-making tool aimed at aiding food waste managers to optimise their food waste management approaches in UK, Indian and Chinese Universities.

CHAPTER 7: CONCLUSION

The overall aim of this study was to investigate the optimisation of food waste management in UK, Indian and Chinese universities. This included looking at the GHG, economic, and combined GHG and economic savings from reducing food waste, increasing food waste recycling, and changing food waste treatment strategies at the different universities. It also included utilising knowledge gained from the study, as well as insights from food waste managers to design a framework for the creation of a decision-making tool that could aid food waste managers in optimising food waste management at their universities. This chapter will outline the key conclusions and how these link to the overall aims and objectives of this study. Additionally, suggestions for future work are highlighted in order to understand how the research methods could be applied or expanded upon in order to implement real-world impacts.

7.1. Contribution to the optimisation of food waste management

7.1.1. Achieving GHG and cost savings through food waste management optimisation

Perhaps the main conclusion from this thesis was that it would be possible to have sizeable GHG mitigation from food waste management changes in universities that would also provide significant cost savings. To quantify the benefits, it was estimated that, if all universities in each country could achieve similar improvements as those identified in the studied universities, GHG savings of around six thousand tonnes of CO_2eq in the UK, two million tonnes of CO_2eq in India and eight thousand tonnes of CO_2eq in China, could be achieved, if GHG mitigation was prioritised. Furthermore, it was estimated that it might be possible to have cost savings of around 200 million USD in the UK, 180 million USD in India, and 230 million USD in China if all universities in each country could achieve similar economic savings as the studied universities, and cost savings were optimised.

Opportunities for GHG mitigation are likely greatest in India, due to India having the least sustainable food waste treatment strategies and greater food waste reduction opportunities than in the UK and China. UK likely has the lowest GHG mitigation potential because there is considerably less food waste generated in UK Universities when compared to India and China. China would likely have a lower GHG mitigation potential than India, because of a limited potential to improve upon an already sustainable food waste treatment strategy at the studied university and other Chinese universities (Table 2.8). Although, China's GHG mitigation could

potentially be higher if food waste reduction opportunities were incorporated into this assessment (as they were for the UK and India).

Cost reduction opportunities may be highest in the UK, despite the UK generating substantially less food waste than the other countries. This is because of the enormous cost saving opportunities associated with generating heat from food waste dwarfing food waste management savings in other countries, per tonne of food waste treated.

While the potential benefits associated with food waste management optimisation at universities are clear, there are difficulties posed at universities that provide barriers for a food waste optimisation approach being adopted in practice. Such barriers include a lack of understanding by university food waste managers as to the best ways to improve their food waste management strategies, as well as the practical information and considerations required to implement the optimal strategy. The pilot study of the decision-making tool methodology addresses this issue by identifying data inputs that could easily be provided by food waste managers at the studied universities, as well as mechanisms that could provide easily understandable outputs that could help them implement optimal food waste management strategies. Thus, if these findings were to be tested and validated in other UK, Indian and Chinese universities, and then the decision-making tool was to be created, it could facilitate universities achieving enormous GHG and cost savings as discussed.

7.1.2. Understanding food waste treatment opportunities

The cost of food waste products generated was the key factor in determining the level of economic savings that were possible. Potential savings per tonne of food waste at the UK University were enormous, due to the scale of cost savings associated with the heat generating scenarios, with food waste desiccation and combustion for heat generation leading to savings of over 14,500 USD per tonne of food waste processed, when the heat generated was used to substitute natural gas. Savings were much lower from heat generation in China and India however, due to state-subsidised heating in these countries, with anaerobic digestion being the most cost-effective strategy in the Indian Universities, and composting having the best economic performance in China.

The GHGs associated with energy usage was the main aspect influencing the optimal food waste treatment approach for GHG mitigation in the different countries. Due to the carbon intensity of grid energy in the UK being relatively low, high product mitigation should be prioritised (with the greatest GHG mitigation coming from animal feed, and soil amendment products) because the impact of high energy inputs was less significant. On the other hand, due to the carbon intensity of grid energy being high in India and China, low energy inputs, and

ideally net energy outputs should be prioritised, due to the high GHG emissions associated with energy usage, and the high GHG mitigation associated with energy production in the countries. For these reasons, desiccation with animal feed generation was clearly the best food waste treatment strategy in the UK, while anaerobic digestion was the best strategy in India and China. Moreover, with the energy intensity of grid energy decreasing, energy inputs associated with food waste treatment technologies will have less GHGs associated with them in the future, with the carbon intensity of grid energy in the UK, India, and China reducing by 2040. Furthermore, issues associated with high energy inputs can be mitigated through supplying the energy required from green, renewable sources thus improving net GHG mitigation of food waste treatment strategies with high energy inputs.

The business as usual approach used by the university to treat the food waste is the most important factor in determining the scale of cost and GHG savings that can be achieved. If the university already has a very economically and environmentally sustainable strategy in place, it may not be possible to achieve any cost, or GHG savings; however, if the university has a particularly poor current treatment strategy, any changes in the treatment approach may bring about both cost and GHG savings. The Chinese University had a very environmentally sustainable food waste treatment strategy of offsite anaerobic digestion already in place, so the only scenario that provided GHG savings was onsite anaerobic digestion, while Indian institute A had a very environmentally unsustainable strategy of mostly landfilling its food waste, and thus all assessed onsite treatment strategies brought about significant GHG savings. Additionally, Indian institute B had a very cost-effective food waste treatment strategy of onsite composting, meaning that all proposed food waste treatment scenarios brought about net costs. Meanwhile the Chinese University's environmentally sustainable strategy of offsite anaerobic digestion was not very cost effective, meaning that almost all scenarios resulted in net savings.

The scale of the economic savings at the UK University associated with the heat and energy-generating scenarios were so high that any extra savings associated with including the social cost of CO_2 were highly insignificant. This means that when economic savings associated with a scenario in a country are particularly high, only market forces could drive GHG mitigation in food waste management. On the other hand, when economic savings or costs associated with a scenario were marginal, while the GHG reductions were large, the social value of the CO_2 mitigated had a significant contribution to the combined cost. In particular, the introduction of carbon credits could help persuade universities, through financial means, to move their food waste treatment strategy away from landfilling, towards economically competitive alternatives

that provide significant GHG savings. The addition of the social cost of CO_2 could therefore be significant if carbon credits are introduced in countries to promote GHG reductions in the future.

7.1.3. Understanding behavioural change opportunities in food waste management

A simple awareness campaign of introducing printed materials could decrease food waste levels by almost 15% in UK university canteens. This can lead to large GHG reductions from the upstream emissions associated with producing the food that would have been wasted without the interventions, and sizable cost reductions from avoiding purchasing, preparing and cooking the food that would have been wasted. Meanwhile the interventions would require very few economic inputs, and negligible environmental inputs. Additionally, a combination of covid-19 related interventions, and the same awareness campaign can lead to a significantly higher 50% per capita food waste reduction in Indian university canteens, providing enormous GHG savings that significantly outweighed any GHG reductions from optimised food waste treatment at the Indian Universities. On the other hand, the covid-19 related infrastructural interventions included table service, requiring a significant increase in the number of servers, with associated costs massively outweighing food waste avoidance related savings, making the food waste reduction scenario economically unviable. In addition, Covid-19 led to food waste roughly halving at the UK, Indian and Chinese universities over 2020, theoretically leading to major GHG savings; however, the food waste was likely still created, but displaced out of the university campuses, meaning the estimated GHG reductions are likely misleading.

Food waste recycling rates of self-catered students could be increased by around 72% from 5.2kg to 8.8kg per capita per year after the introduction of the interventions such as informative fridge magnets, public pledges, and the provision of oral information concerning food waste recycling. While the introduction of food waste recycling and associated interventions could provide economic and GHG savings, even if food waste recycling and the interventions were expanded to all university residences at the UK University, the cost reductions would be dwarfed by the savings associated with food waste reduction. Altogether, the GHG and cost savings per tonne of food waste reduced are so much higher than the savings from recycling a tonne of food waste when the general waste is incinerated and not landfilled, that UK universities should focus their efforts on food waste reduction, while the perceived benefits of food waste recycling can easily be overestimated.

During the behavioural study, many differences in food waste management strategies, and food waste behaviours among student were identified. Indian students were the most bothered by food waste and made the most effort to reduce their waste, whereas Chinese students were the

least bothered and put the least amount of effort into minimising their food waste. Indian students were primarily bothered about the social impacts of food waste, while UK students were most concerned about economic and environmental impacts. Meanwhile, Chinese students were particularly bothered about food waste being sustainably treated, but had very little concern for the economic cost of food waste when compared to students in the other countries. Cultural diversity, food preferences and university cuisine not catering to students from different parts of the country were a key reason for food waste in India and China, but not in the UK. In India, poor food demand estimation was also a key reason for food waste, while in China a lack of flexibility in meal portions was a key reason for waste generation. Moreover, student engagement projects, and surplus food redistribution to charities were identified as real opportunities for food waste reduction at all studied universities. Altogether, it was clear that there were significant differences in cultures, and an ability to understand these differences could present real opportunities to instigate improvements associated with food waste and behavioural change in UK, Indian and Chinese universities.

7.2. Contributions to practice

7.2.1. Achieving food waste management optimisation in universities

From the pilot study of the decision-making tool methodology, it is recommended that the framework should be tested and validated on other UK, Indian and Chinese universities. Once validated, these universities should consider the framework that was created when assessing GHG mitigation and cost reduction potentials from different food waste management scenarios. This study therefore shows the importance of understanding country-specific factors, and not undergoing a one-size-fits-all approach regarding geography when assessing food waste treatment optimisation at universities. It also shows how the proposed tool, once validated, could provide the advice and guidance required for the food waste managers to select and set up an optimal food waste management strategy, helping the universities benefit from the GHG and cost reductions associated.

Universities present a good opportunity for food waste management optimisation, as improving food waste management offers multiple benefits in the form of meeting internal sustainability targets, utilising good practices to entice students and staff, and utilising opportunities associated with the new sustainable food waste management approaches for research and teaching. Universities and academics may also be able to access specific funding opportunities for making improvements that would not be available for other sectors. Moreover, universities rely on public money to fund the running of the institutions, meaning that governments are well placed to implement policy geared at improving the sustainability of

food waste management at universities. Additionally, academics are more likely to possess the technical expertise to establish, run and test the benefits associated with improvements, making it easier for universities to adopt food waste management strategies when compared to other organisations.

7.2.2. Informing policies for optimising food waste management

It is recommended that governments and organisations highlight and facilitate the economic opportunities associated with heat generation from food waste treatment in the UK. Specifically, the possibility of setting up a policy to help organisations with getting loans for investing in onsite food waste treatment strategies that generate heat should be explored, while local councils should prioritise the generation of heat from food waste collected from residences. Moreover, desiccation with animal feed had the greatest GHG mitigation in the UK, but the utilisation of food waste for animal feed is not legally possible in the UK currently, due to safety fears. With this in mind, the government should perhaps reassess the safety of using desiccated food waste for animal consumption and revise their policy if appropriate. Furthermore, energy generation scenarios had the greatest GHG mitigation in both India and China; therefore, the possibility of providing subsidies for energy generation in these countries should be explored. Concerning behavioural change opportunities, it is recommended that typical catering styles and the differing nature of concerns over food waste in the different countries be considered when deciding on food waste reduction interventions. In particular, catering for diverse culinary preferences in India and China could be key to reducing food waste, while Chinese cuisines could substantially reduce food waste by having flexible meal portions, and improvements in food demand estimation could greatly reduce the amount of surplus food produced in Indian canteens.

It is recommended that universities with particularly poor current food waste treatment strategies prioritise food waste treatment changes, with those having environmentally sustainable onsite treatment perhaps struggling to make GHG and economic savings. Moreover, behavioural change improvements should be focussed upon if the food waste treatment strategy is already relatively sustainable. Policies should be considered that financially incentivise food waste reduction, as well as a switch away from environmentally unsustainable food waste treatment practices. Perhaps the implementation of carbon credits throughout the studied countries, or specific policies rewarding food waste reduction, and discouraging landfilling, such as the EU landfill directive, could stimulate improvements in food waste management.

The opportunities for utilising food waste treatment technologies for increasing affordability and energy security should be explored in the UK and other countries affected by the Ukraine war and rising heat and energy bills. Policies for facilitating a switch to desiccation, hydrothermal carbonisation, and anaerobic digestion with heat generation should be explored, including looking into accessible loans for businesses and councils to purchase the facilities to treat food waste in these ways, as well as increased information and awareness campaigns for highlighting relevant opportunities. Moreover, opportunities should be taken in the catering sector to utilise the increased adaptability and food waste awareness of customers since the emergence of Covid-19, with Covid-19 related health and safety interventions being adopted to instigate infrastructural interventions, such as improved food demand estimation, and standardised menus to provide food waste reduction.

7.3. Contributions to literature

7.3.1. Optimal food waste management approaches

When considering the specific optimisation of food waste management at universities, studies by Takata et al. (2012), Salamdeeb et al. (2017) and Kim et al. (2011) have looked at the different food waste management scenarios included in the thesis. On the other hand, no other study has compared the credentials of food waste management scenarios in the UK, India, and China, identifying key country-specific differences influencing key opportunities in each country. Regarding food waste treatment, the study ascertained the importance of the varying market costs of food waste treatment inputs and outputs (particularly heat and energy) in the different countries on determining the economic viability of the different food waste treatment scenarios, with heat generating scenarios performing best in the UK, but considerably less well in India and China. Moreover, the research highlighted the significance of the differing grid carbon energy intensity in the different countries in determining the environmentally optimal food waste treatment strategy, with energy inputs being much more carbon intense in China and India. Regarding behavioural change aspects, no other study had compared food waste management and behavioural change differences in UK, Indian, and Chinese universities. The research identified that food waste recycling opportunities were only present in the UK, due to all Indian and Chinese students being catered. The food waste reduction study also found that there were major differences in catering styles and food waste attitudes in the different countries, presenting different barriers and opportunities at the different sites.

Regarding non-country specific food waste management optimisation in universities, while all food waste treatment and behavioural change options had been researched separately before

(Takata et al., 2012; Salamdeeb et al., 2017; Kim et al., 2011), no study had compared all of the technologies and product utilisation options. Moreover, no research has studied food waste reduction and recycling opportunities together, comparing the potential GHG and economic benefits when universities had different business as usual food waste treatment strategies. The study highlighted the importance of the sustainability of the current food waste treatment strategy in influencing the level of GHG and economic savings possible from changes. The research also highlighted that food waste reduction and recycling interventions could be combined with food waste treatment changes to bring about enhanced GHG and cost savings. Furthermore, the findings that food waste reduction brought about substantially greater GHG and cost savings than food waste recycling, supported the WRAP hierarchy on food waste management, arguing that food waste reduction brings about significantly greater benefits than recycling.

7.3.2. Impact of current trends on food waste management

This research also helped add to studies such as Benton et al. (2022), highlighting the influence of highly topical current trends such as the Ukraine war leading to enormous economic opportunities in heat and energy generating scenarios in the UK, and presumably other countries moving away from using Russian gas and energy. The research identified that the increasing heat and energy prices in western countries such as the UK, related to the Ukraine conflict, meaning that there are massive opportunities for economic savings from food waste treatment with heat and energy generation in the UK. Conversely, these opportunities are not present in countries such as India and China that have subsidised heat and energy and a continuing supply of Russian gas. Moreover, the research added to the limited novel studies on Covid-19 implications on food waste management by Burlea-Schiopoiu, (2021) and Principato et al., (2020), showing that Covid-19 related behavioural change, and health and safety related infrastructural changes could greatly enhance food waste reduction.

7.4. Future work

7.4.1. Decision-making tool creation

It would be highly worthwhile, if the framework created in this study could be validated through assessing different universities in the UK, India and China. Once validated, it could be utilised to form the decision-making tool software, so that the environmental and economic benefits for food waste managers at universities highlighted in this study could be realised. Someone with expertise in programming could utilise the methodological framework created in this study to design a desktop software, or a mobile phone application that could be utilised by food waste managers in the UK, India, and China.

7.4.2. Food waste reduction research expansion

Furthermore, the behavioural change research generated highly replicable methods that could be expanded to identify even more opportunities regarding food waste reduction. It would be useful to conduct the food waste reduction research in China and compare the findings with the UK and Indian Universities, as it was not possible to conduct the food waste reduction interventions at the Chinese University. This would help ascertain whether the addition of the food waste reduction scenario in China had the potential to bring about enhanced GHG and cost reduction benefits in the country's universities. It would also be beneficial to add additional types of food waste reduction interventions, such as trayless canteens, and reduced plate sizes, to assess maximum achievable food waste reduction levels and understand which intervention was the most effective.

7.4.3. Exploring policy for facilitating food waste management optimisation

When considering the findings of the economic analysis, it was noted that policy should be explored to facilitate the massive benefits associated with generating heat from food waste. With this in mind, further research could be conducted to understand how to facilitate a switch towards heat generation from food waste. This could include speaking to stakeholders such as food waste managers at universities and other large food waste generators, as well as waste managers in local municipalities to know what information they would require to understand the economic benefit of switching to onsite treatment of food waste with heat generation. Additionally, further research could explore what financial and technical support food waste managers would require to implement this food waste treatment approach, such as governmental policies offering interest free loans or offering free consultancy on how to set up and implement a new food waste treatment strategy.

When considering the findings of the GHG assessment, it was noted that food waste treatment technologies with energy generating scenarios had particularly high GHG mitigation potentials in India and China, meanwhile animal feed generation performed particularly well in the UK Food waste reduction also brought about significant GHG reductions in all countries. With this in mind, further research could be conducted to understand how to facilitate a switch towards GHG reduction from food waste management in the different countries. This could include speaking to stakeholders in the different countries, such as university food waste managers and other large food waste generators, as well as waste managers in local municipalities, to explore what financial support would be required to implement such a food waste treatment approach. Researching specific subsidies for treating food waste onsite in the most sustainable way in the country, such as subsidising energy generation in India and China, would be worthy of research. Additionally, understanding what level of subsidy would be required to make the

food waste management strategies with the greatest GHG mitigations the most cost effective in the different countries would be beneficial. It would also be worth exploring the opportunities associated with carbon credits and emission trading schemes for economically incentivising GHG mitigation in food waste management, by including the social cost of GHG emissions. The research could identify what values would need to be put on GHG mitigation in the different countries to make the scenarios with the greatest GHG mitigation associated also be the most cost-effective, thus identifying which of the studied countries would have the most cost-effective GHG mitigation opportunities in food waste management.

7.4.4. Food waste drying research

The greatest economic benefits in the UK came from desiccation of food waste with the combustion of the dried food waste for heat generation. With this being said, there is a lack of research into the practicalities and effectiveness of utilising dried food waste for heating. Further research to expand what is known about the fuel properties of dried food waste such as the exact calorific value, ease of pelletizing or bricketing, fuel storage properties, as well as any issues with corrosion, fouling, and slagging would be helpful. Moreover, researching the logistics around integrating dried food waste with current heating equipment, such as biomass boilers, and heating systems in buildings, such as central heating systems, would be worth exploring given the potential scale of economic benefits.

The greatest GHG mitigation opportunities in the UK University came from food waste desiccation and animal feed generation, something that is currently not legally possible due to health risks, but would comply with health and safety standards in other countries. Due to the sizeable GHG mitigation opportunities offered by this technology, it is recommended that further research be conducted into the effectiveness of the desiccation process in eradicating pathogens and providing a safe feed for animals, leading to suitable policy recommendations based on the findings. Moreover, there is a lack of research into the suitability of using dried food waste as animal feed. Further research could help understand the nutritional content of the food, the practical and logistical issues associated with its utilisation as animal feed, and understand which animals to feed with it.

7.4.5. Expanding the scope of the research

While this thesis generated useful methods and findings regarding the optimisation of food waste management strategies at the UK, Indian and Chinese Universities that were researched, the methodologies created in this thesis could be utilised at other universities in the studied countries. This would increase the understanding of country-specific and non-country-specific trends in food waste management optimisation. This could help identify any anomalous

characteristics and outliers, while also helping to increase understanding of regional factors influencing food waste management optimisation in UK, Indian and Chinese Universities.

References

Abrahamse, W. and Steg, L., 2013. Social influence approaches to encourage resource conservation: A meta-analysis. *Global environmental change*, **23**(6), pp.1773-1785.

Ahamed, A., Yin, K., Ng, B.J.H., Ren, F., Chang, V.C. and Wang, J.Y., 2016. Life cycle assessment of the present and proposed FW management technologies from environmental and economic impact perspectives. *Journal of cleaner production*, **131**, pp.607-614.

Ahmed, S., Shanks, C.B., Lewis, M., Leitch, A., Spencer, C., Smith, E.M. and Hess, D., 2018. Meeting the food waste challenge in higher education. *International Journal of Sustainability in Higher Education*.

Albizzati, P.F., Tonini, D. and Astrup, T.F., 2021. High-value products from food waste: An environmental and socio-economic assessment. *Science of the Total Environment*, **755**, p.142466.

Aldaco, R., Hoehn, D., Laso, J., Margallo, M., Ruiz-Salmón, J., Cristobal, J., Kahhat, R., Villanueva-Rey, P., Bala, A., Batlle-Bayer, L. and Fullana-i-Palmer, P., 2020. Food waste management during the COVID-19 outbreak: a holistic climate, economic and nutritional approach. *Science of the Total Environment*, **742**, p.140524.

Alexander, C. and Smaje, C., 2008. Surplus retail food redistribution: An analysis of a third sector model. *Resources, conservation and recycling*, *52*(11), pp.1290-1298.

Amicarelli, V. and Bux, C., 2021. Food waste in Italian households during the Covid-19 pandemic: a self-reporting approach. *Food Security*, **13**(1), pp.25-37.

Andreadou, C. (2017). Waste valorization in Developing countries. Masters Report (Unpublished).

Arlt, D., Hoppe, I. and Wolling, J., 2011. Climate change and media usage: Effects on problem awareness and behavioural intentions. *International Communication Gazette*, **73**(1-2), pp.45-63.

Arramark, 2008. The Business and Cultural Acceptance Case for Trayless Dining. [Online]. [Accessed on 13th November 2017]. Available at: http://www.carbonindependent.org/sources_home_energy.html http://www.elon.edu/docs/e-web/bft/sustainability/ARAMARK%20Trayless%20Dining%20July%202008%20FINAL.pdf

Bajželj, B., Quested, T.E., Röös, E. and Swannell, R.P., 2020. The role of reducing food waste for resilient food systems. *Ecosystem services*, 45, p.101140.

Bandaw, T. and Herago, T., 2017. Review on abattoir waste management. *Global Veterinaria*, *19*(2), pp.517-524.

Banik, D., 2016. The Hungry Nation: Food Policy and Food Politics in India. *Food Ethics*, **1**(1), pp.29-45.

Barlaz, M.A., Chanton, J.P. and Green, R.B., 2009. Controls on landfill gas collection efficiency: instantaneous and lifetime performance. *Journal of the Air & Waste Management Association*, *59*(12), pp.1399-1404.

Batlle-Bayer, L., Aldaco, R., Bala, A., Puig, R., Laso, J., Margallo, M., Vázquez-Rowe, I., Antó, J.M. and Fullana-i-Palmer, P., 2020. Environmental and nutritional impacts of dietary changes in Spain during the COVID-19 lockdown. *Science of The Total Environment*, **748**, p.141410.

Benavente, V., Fullana, A. and Berge, N.D., 2017. Life cycle analysis of hydrothermal carbonization of olive mill waste: Comparison with current management approaches. *Journal of cleaner production*, **142**, pp.2637-2648.

Benton, T.G., Froggatt, A., Wellesley, L., Grafham, O., King, R., Morisetti, N., Nixey, J. and Schröder, P., 2022. The Ukraine war and threats to food and energy security. *Chatham House—International Affairs Think Tank*.

Berge, N.D., Li, L., Flora, J.R. and Ro, K.S., 2015. Assessing the environmental impact of energy production from hydrochar generated via hydrothermal carbonization of food wastes. *Waste management*, **43**, pp.203-217.

Berge, N.D., Ro, K.S., Mao, J., Flora, J.R., Chappell, M.A. and Bae, S., 2011. Hydrothermal carbonization of municipal waste streams. *Environmental science & technology*, **45**(13), pp.5696-5703.

Beretta, C. and Hellweg, S., 2019. Potential environmental benefits from food waste prevention in the food service sector. *Resources, Conservation and Recycling*, **147**, pp.169-178.

Bergmann Direct, 2019. ES15 FW dryer. [Online]. [Accessed on 15th December 2018]. Available at: https://www.bergmanndirect.co.uk/food-waste-dryers/es15-food-waste-dryer/

Bernstad, A., la Cour Jansen, J. and Aspegren, A., 2013. Door-stepping as a strategy for improved FW recycling behaviour–Evaluation of a full-scale experiment. *Resources, Conservation and Recycling*, **73**, pp.94-103.

BIO Intelligence Service (2010) Technical support to identify product categories with significant environmental impact and with potential for improvement by making use of ecodesign measures, 07.0307/2008/517777/ETU/G4 Paris, France

Borbolla-Gaxiola, J.E., Ross, A.B. and Dupont, V., 2022. Multi-Variate and Multi-Response Analysis of Hydrothermal Carbonization of Food Waste: Hydrochar Composition and Solid Fuel Characteristics. *Energies*, **15**(15), p.5342.

Bradbury, A., McGimpsey, I. and Santori, D., 2013. Revising rationality: The use of 'Nudge'approaches in neoliberal education policy. *Journal of Education Policy*, *28*(2), pp.247-267.

Breitenmoser, L., Gross, T., Huesch, R., Rau, J., Dhar, H., Kumar, S., Hugi, C. and Wintgens, T., 2019. Anaerobic digestion of biowastes in India: Opportunities, challenges and research needs. *Journal of environmental management*, *236*, pp.396-412.

Burlea-Schiopoiu, A., Ogarca, R.F., Barbu, C.M., Craciun, L., Baloi, I.C. and Mihai, L.S., 2021. The impact of COVID-19 pandemic on food waste behaviour of young people. *Journal of Cleaner Production*, **294**, p.126333.

Burn, S.M., 1991. Social psychology and the stimulation of recycling behaviors: The block leader approach. *Journal of applied social psychology*, **21**(8), pp.611-629.

Burn, S.M. and Oskamp, S., 1986. Increasing community recycling with persuasive communication and public commitment. *Journal of Applied Social Psychology*, **16**(1), pp.29-41.

Busch, D. and Glaser, B., 2015. Stability of co-composted hydrochar and biochar under field conditions in a temperate soil. *Soil use and management*, **31**(2), pp.251-258.

Cialdini, R.B. and Goldstein, N.J., 2004. Social influence: Compliance and conformity. *Annu. Rev. Psychol.*, *55*, pp.591-621.

Canellada, F., Laca, A., Laca, A. and Díaz, M., 2018. Environmental impact of cheese production: A case study of a small-scale factory in southern Europe and global overview of carbon footprint. *Science of the total Environment*, **635**, pp.167-177.

Cangialosi, F., Intini, G., Liberti, L., Notarnicola, M. and Stellacci, P., 2008. Health risk assessment of air emissions from a municipal solid waste incineration plant–A case study. *Waste Management*, **28**(5), pp.885-895

Cantaragiu, R., 2019. The impact of gender on food waste at the consumer level. *Studia Universitatis Vasile Goldiș Arad, Seria Științe Economice*, **29**(4), pp.41-57.

Caraza, C. (2018). Consumer FW behaviour in University's self-catered accommodation: The case of St. Mark's residence and the use of a food sharing app as a potential tool to avoid FW. Masters' Thesis (Unpublished).

CEICTM, 2020. Chapter, 2.2., Committee of Experts on International Cooperation in Tax Matters Twentieth session.

Chen, Y.C., 2016. Potential for energy recovery and greenhouse gas mitigation from municipal solid waste using a waste-to-material approach. *Waste management*, **58**, pp.408-414.

Cherubini, F., Bargigli, S. and Ulgiati, S., 2008. Life cycle assessment of urban waste management: Energy performances and environmental impacts. The case of Rome, Italy. *Waste management*, **28**(12), pp.2552-2564.

Cobern, M.K., Porter, B.E., Leeming, F.C. and Dwyer, W.O., 1995. The effect of commitment on adoption and diffusion of grass cycling. *Environment and Behavior*, **27**(2), pp.213-232.

Cohen, J.F., Richardson, S., Parker, E., Catalano, P.J. and Rimm, E.B., 2014. Impact of the new US Department of Agriculture school meal standards on food selection, consumption, and waste. *American journal of preventive medicine*, **46**(4), pp.388-394.

Conrad, Z., Niles, M.T., Neher, D.A., Roy, E.D., Tichenor, N.E. and Jahns, L., 2018. Relationship between food waste, diet quality, and environmental sustainability. *PloS one*, **13**(4), p.e0195405.

Cantaragiu, R., 2019. The impact of gender on food waste at the consumer level. *Studia Universitatis Vasile Goldiş, Arad-Seria Ştiinţe Economice*, *29*(4), pp.41-57.

Corvalán, C., Espinoza Pérez, A.T., Díaz-Robles, L.A., Cubillos, F., Vallejo, F., Gómez, J., Pino-Cortés, E., Espinoza-Pérez, L., Pelz, S.K., Paczkowski, S. and Rumberg, M., 2021. Life cycle assessment for hydrothermal carbonization of urban organic solid waste in comparison with gasification process: A case study of Southern Chile. *Environmental Progress & Sustainable Energy*, **40**(6), p.e13688.

Chen, H., Wang, W., Xue, L., Chen, C., Liu, G. and Zhang, R., 2016. Effects of ammonia on anaerobic digestion of food waste: process performance and microbial community. *Energy & Fuels*, **30**(7), pp.5749-5757.

Cherubini, F., Bargigli, S. and Ulgiati, S., 2008. Life cycle assessment of urban waste management: Energy performances and environmental impacts. The case of Rome, Italy. *Waste management*, *28*(12), pp.2552-2564.

CPHEEO, 2016. Manual on Municipal Solid Waste Management. Part III: The Compendium. Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, India.

Dansie, G., Lanteigne, M. and Overland, I., 2010. Reducing energy subsidies in China, India and Russia: Dilemmas for decision makers. *Sustainability*, **2**(2), pp.475-493.

Davison, N., Borbolla Gaxiola, J., Gupta, D., Garg, A., Cockerill, T., Tang, Y., Yuan, X. and Ross, A., 2022. Potential Greenhouse Gas Mitigation for Converting High Moisture Food Waste into Bio-Coal from Hydrothermal Carbonisation in India, Europe and China. *Energies*, **15**(4), p.1372.

Davison, N., Brown, A. and Ross, A., 2023. Potential Greenhouse Gas Mitigation from Utilising Pig Manure and Grass for Hydrothermal Carbonisation and Anaerobic Digestion in the UK, EU, and China. *Agriculture*, *13*(2), p.479.

Davison, N., Fenwick, S., Sherwood, H. (2017). An Assessment of FW Management Options for the University of Leeds: A Living Lab Approach. Masters Report (Unpublished).

DEFRA, 2011. Recycling of catering and FW. Department for Environment, Food and Rural Affairs, UK.

DEFRA, (2013), Environmental Permitting, Environmental Permitting Core Guidance, Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2017a. FW in England. Eighth Report of Session 2016–17 Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2017b. FW in England. Redistribution. Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2018a. Gove launches landmark blueprint for resources and waste

Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2018b. Animal Feed Statistics for Great Britain – December 2017. Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2018c. Action to reduce FW announced

Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2019- Supplying and using animal by products as farm animal feed. Department for Environment, Food and Rural Affairs, UK.

DEFRA, 2022- UK statistics on waste. Department for Environment, Food and Rural Affairs, UK.

Dhar, A. (2016). Evaluation of FW Diversion Potential and Economics Of Using FW Dehydrators. Masters Dissertation (Unpublished).

Dwivedi, A., Dubey, R., Singh, P.K. and Ohri, A., 2019. Scientific management of municipal solid waste in an academic campus–A case study of IIT (BHU). *J. Mater. Environ. Sci*, **10**(10), pp.909-917.

EC, 2010. PREPARATORY STUDY ON FW ACROSS EU 27, Technical Report - 2010 – 054, October 2010, Paris, France http://ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf

Edge Hill University, 2022. Edge Hill University Waste Strategy Development [Online]. [Accessed on 29th September 2022]. https://www.edgehill.ac.uk/sustainability/files/2018/10/Waste-Management-Strategy.pdf

Ekpo, U., Ross, A.B., Camargo-Valero, M.A. and Williams, P.T., 2016. A comparison of product yields and inorganic content in process streams following thermal hydrolysis and hydrothermal processing of microalgae, manure and digestate. *Bioresource technology*, **200**, pp.951-960.

EIA, 2022. SHORT-TERM ENERGY OUTLOOK. [Online]. [Accessed on 11th October 2022]. Available at: https://www.eia.gov/outlooks/steo/

El Hanandeh, A. and El-Zein, A., 2010. The development and application of multi-criteria decision-making tool with consideration of uncertainty: The selection of a management strategy for the bio-degradable fraction in the municipal solid waste. *Bioresource Technology*, **101**(2), pp.555-561.

Ellison, B., Savchenko, O., Nikolaus, C.J. and Duff, B.R., 2019. Every plate counts: Evaluation of a food waste reduction campaign in a university dining hall. *Resources, Conservation and Recycling*, **144**, pp.276-284.

ETC/SCP, 2009 Via EC, 2010 paper

Falco, C., Marco-Lozar, J.P., Salinas-Torres, D., Morallon, E., Cazorla-Amorós, D., Titirici, M.M. and Lozano-Castelló, D., 2013. Tailoring the porosity of chemically activated hydrothermal carbons: influence of the precursor and hydrothermal carbonization temperature. *Carbon*, **62**, pp.346-355.

Fantozzi, F. and Buratti, C., 2010. Life cycle assessment of biomass chains: Wood pellet from short rotation coppice using data measured on a real plant. *Biomass and bioenergy*, **34**(12), pp.1796-1804.

Feeding India, 2019. Feeding India [Online]. [Accessed on 10th May 2019]. Available at: https://www.feedingindia.org/

Field, A. and Hole, G., 2002. *How to design and report experiments*. Sage.

Finglas, P.M., Roe, M.A., Pinchen, H.M., Berry, R., Church, S.M., Dodhia, S.K., Farron-Wilson, M. and Swan, G., 2015. McCance and Widdowson's the composition of foods, seventh summary edition. *Cambridge: Royal Society of Chemistry. Fitzpatrick T (1975)" Soleil et peau"[Sun and skin]. Journal de Médecine Esthétique*, **2**, pp.33-34.

Flesch, T.K., Desjardins, R.L. and Worth, D., 2011. Fugitive methane emissions from an agricultural biodigester. *Biomass and bioenergy*, *35*(9), pp.3927-3935.

Freedman, L., 2020. Strategy for a Pandemic: The UK and COVID-19. *Survival*, **62**(3), pp.25-76.

Friedl, A., Padouvas, E., Rotter, H. and Varmuza, K., 2005. Prediction of heating values of biomass fuel from elemental composition. *Analytica chimica acta*, **544**(1-2), pp.191-198.

FSA, 2018. Proposed Approach to Retained EU Law for Food and Feed Safety and Hygiene. Food Standards agency, UK

FSSAI, 2019. IFSA. [Online]. [Accessed on 11th May 2019]. Available at: https://sharefood.fssai.gov.in/what_ifsa.html

Gao, A., Tian, Z., Wang, Z., Wennersten, R. and Sun, Q., 2017. Comparison between the technologies for food waste treatment. *Energy Procedia*, **105**, pp.3915-3921.

Garnett, K., Cooper, T., Longhurst, P., Jude, S. and Tyrrel, S., 2017. A conceptual framework for negotiating public involvement in municipal waste management decision-making in the UK. *Waste Management*, *66*, pp.210-221.

Geislar, S., 2017. The new norms of food waste at the curb: Evidence-based policy tools to address benefits and barriers. *Waste Management*, **68**, pp.571-580.

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B.L., Fetzer, I., Jalava, M., Kummu, M., Lucht, W., Rockström, J., Schaphoff, S. and Schellnhuber, H.J., 2020. Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, **3**(3), pp.200-208.

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A. and Struijs, J., 2008. van Zelm. R., 2009. *Recipe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition. Report I: Characterisation.*Golechha, M., 2020. COVID-19, India, lockdown and psychosocial challenges: What next?. *International Journal of Social Psychiatry*, **66**(8), pp.830-832.

Goonan, S., Mirosa, M. and Spence, H., 2014. Getting a taste for food waste: a mixed methods ethnographic study into hospital food waste before patient consumption conducted at three

New Zealand foodservice facilities. Journal of the Academy of Nutrition and Dietetics, 114(1), pp.63-71.

Grainger, M.J., Aramyan, L., Logatcheva, K., Piras, S., Righi, S., Setti, M., Vittuari, M. and Stewart, G.B., 2018. The use of systems models to identify food waste drivers. *Global food security*, **16**, pp.1-8.

Graham-Rowe, E., Jessop, D.C. and Sparks, P., 2014. Identifying motivations and barriers to minimising household food waste. *Resources, conservation and recycling*, **84**, pp.15-23.

Grilli, G. and Curtis, J., 2021. Encouraging pro-environmental behaviours: A review of methods and approaches. *Renewable and Sustainable Energy Reviews*, *135*, p.110039.

Gupta, D., Mahajani, S.M. and Garg, A., 2019. Effect of hydrothermal carbonization as pretreatment on energy recovery from food and paper wastes. *Bioresource technology*, **285**, p.121329.

Gustavsson, J., Cederberg, C., van Otterdiijk, R. & Meybeck, A. Global Food Losses and Food Waste (FAO, 2011).

Hampshire County Council and Brook Lyndhurst, 2008. Small Changes Big Difference Towards a Materials Resource Authority: Promoting Practical Waste Prevention and Exploring Options for Resource Management.

Harriss-White, B., 2020. Waste, social order, and physical disorder in small-town India. *The Journal of Development Studies*, *56*(2), pp.239-258.

He, P.J., Zhang, H., Zhang, C.G. and Lee, D.J., 2004. Characteristics of air pollution control residues of MSW incineration plant in Shanghai. *Journal of hazardous materials*, **116**(3), pp.229-237.

Heidari, M., Dutta, A., Acharya, B. and Mahmud, S., 2018. A review of the current knowledge and challenges of hydrothermal carbonization for biomass conversion. *Journal of the Energy Institute*.

Heng, Y. and House, L., 2022. Consumers' perceptions and behavior toward food waste across countries. *International Food and Agribusiness Management Review*, **25**(1030-2022-421), pp.197-209.

Hermann, B.G., Debeer, L., De Wilde, B., Blok, K. and Patel, M.K., 2011. To compost or not to compost: Carbon and energy footprints of biodegradable materials' waste treatment. *Polymer Degradation and Stability*, **96**(6), pp.1159-1171.

Hitzl, M., Mendez, A., Owsianiak, M. and Renz, M., 2018. Making hydrochar suitable for agricultural soil: A thermal treatment to remove organic phytotoxic compounds. *Journal of environmental chemical engineering*, **6**(6), pp.7029-7034.

Hopper, J.R. and Nielsen, J.M., 1991. Recycling as altruistic behavior: Normative and behavioral strategies to expand participation in a community recycling program. *Environment and behavior*, **23**(2), pp.195-220.

HMRC, 2016. Landfill Tax: increase in rates. HM Revenues and customs, London, UK

Huang, W., Wang, J., Dai, X., Li, M. and Harder, M.K., 2014. More than financial investment is needed: food waste recycling pilots in Shanghai, China. *Journal of Cleaner Production*, **67**, pp.107-116.

Iacovidou, E., Ohandja, D.G. and Voulvoulis, N., 2012. Food waste disposal units in UK households: The need for policy intervention. *Science of the Total Environment*, **423**, pp.1-7.

IEA, 2020. Development of CO_2 Emission Intensity of Electricity Generation in Selected Countries, 2000–2020. 2020. [Online]. (Accessed on 12 October 2021). https://www.iea.org/data-and-statistics/charts/development-of-co2-emission-intensity-of-electricity-generation-in-selected-countries-2000-2020

IPCC. (2014). Climate change 2014: Impacts, adaptation and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press.

Jingura, R.M. and Kamusoko, R., 2017. Methods for determination of biomethane potential of feedstocks: A review. *Biofuel Research Journal*, **4**(2), pp.573-586.

Joensuu, K., Hartikainen, H., Karppinen, S., Jaakkonen, A.K. and Kuoppa-Aho, M., 2021. Developing the collection of statistical food waste data on the primary production of fruit and vegetables. *Environmental Science and Pollution Research*, *28*, pp.24618-24627.

Jörissen, J., Priefer, C. and Bräutigam, K.R., 2015. Food waste generation at household level: Results of a survey among employees of two European research centers in Italy and Germany. *Sustainability*, **7**(3), pp.2695-2715.

Joshi, R. and Ahmed, S., 2016. Status and challenges of municipal solid waste management in India: A review. *Cogent Environmental Science*, **2**(1), p.1139434.

Kallbekken, S. and Sælen, H., 2013. 'Nudging'hotel guests to reduce FW as a win–win environmental measure. *Economics Letters*, **119**(3), pp.325-327.

Katzev, R., Cooper, L. and Fisher, P., 1981. Effect of feedback and social reinforcement on residential electricity consumption. J. *ENVIRON. SYS.*, **10**(3), pp.215-227.

Kaushal, R.K., Varghese, G.K. and Chabukdhara, M., 2012. Municipal solid waste management in India-current state and future challenges: a review. *International Journal of Engineering Science and Technology*, **4**(4), pp.1473-1489.

Khalid, H., Zhang, H., Liu, C., Li, W., Abuzar, M.K., Amin, F.R., Liu, G. and Chen, C., 2020. PEST (political, environmental, social & technical) analysis of the development of the waste-to-energy anaerobic digestion industry in China as a representative for developing countries. *Sustainable Energy & Fuels*, **4**(3), pp.1048-1062.

Kim, M.H. and Kim, J.W., 2010. Comparison through a LCA evaluation analysis of food waste disposal options from the perspective of global warming and resource recovery. *Science of the total environment*, **408**(19), pp.3998-4006.

Kim, M.H., Song, Y.E., Song, H.B., Kim, J.W. and Hwang, S.J., 2011. Evaluation of FW disposal options by LCC analysis from the perspective of global warming: Jungnang case, South Korea. *Waste management*, **31**(9-10), pp.2112-2120.

Kim, M.H., Song, H.B., Song, Y., Jeong, I.T. and Kim, J.W., 2013. Evaluation of FW disposal options in terms of global warming and energy recovery: Korea. *International Journal of Energy and Environmental Engineering*, **4**(1), p.1.

Koivupuro, H.K., Hartikainen, H., Silvennoinen, K., Katajajuuri, J.M., Heikintalo, N., Reinikainen, A. and Jalkanen, L., 2012. Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. *International journal of consumer studies*, **36**(2), pp.183-191.

Kosters, M. and Van der Heijden, J., 2015. From mechanism to virtue: Evaluating Nudge theory. *Evaluation*, **21**(3), pp.276-291.

Kruse, A., 2009. Hydrothermal biomass gasification. *The Journal of Supercritical Fluids*, **47**(3), pp.391-399

Kumar, S., Smith, S.R., Fowler, G., Velis, C., Kumar, S.J., Arya, S., Rena, Kumar, R. and Cheeseman, C., 2017. Challenges and opportunities associated with waste management in India. *Royal society open science*, **4**(3), p.160764.

Latha, K., Velraj, R., Shanmugam, P. and Sivanesan, S., 2019. Mixing strategies of high solids anaerobic co-digestion using food waste with sewage sludge for enhanced biogas production. *Journal of cleaner production*, **210**, pp.388-400.

LeAF, (2009). Development of decentralised anaerobic digestion systems for application in the UK. Phase 1- Final report. Available at: http://www.communitycompost.org/CCN_documents/Small_scale_AD_for_CCN_Phase1_report.pdf

LeAF, (2010). Development of decentralised anaerobic digestion systems for application in the UK. Phase 2- Final report. Available at: http://www.communitycompost.org/CCN_documents/Small_scale_AD_for_CCN_Phase2_report.pdf

Le Couteur, C., 2004. Not-so-dirty Dairying. *E. nz Magazine: The Magazine of Technical Enterprise*, *5*(4), pp.22-26.

Lelicińska-Serafin, K., Manczarski, P. and Rolewicz-Kalińska, A., 2023. An Insight into post-consumer food waste characteristics as the key to an organic recycling method selection in a circular economy. *Energies*, *16*(4), p.1735.

Leverenz, D., Hafner, G., Moussawel, S., Kranert, M., Goossens, Y. and Schmidt, T., 2021. Reducing food waste in hotel kitchens based on self-reported data. *Industrial Marketing Management*, **93**, pp.617-627.

Li, C.J., Huang, Y.Y. and Harder, M.K., 2017. Incentives for FW diversion: Exploration of a long term successful Chinese city residential scheme. *Journal of Cleaner Production*, **156**, pp.491-499.

Li, Y., Jin, Y., Borrion, A. and Li, H., 2019. Current status of food waste generation and management in China. *Bioresource technology*, **273**, pp.654-665.

Li, J., Li, W., Wang, L. and Jin, B., 2021. Environmental and Cost Impacts of Food Waste in University Canteen from a Life Cycle Perspective. *Energies*, **14**(18), p.5907.

Li, L., Diederick, R., Flora, J.R. and Berge, N.D., 2013. Hydrothermal carbonization of food waste and associated packaging materials for energy source generation. *Waste management*, **33**(11), pp.2478-2492.

Lin, C.H., Wen, L. and Tsai, Y.M., 2010. Applying decision-making tools to national e-waste recycling policy: an example of analytic hierarchy process. *Waste management*, **30**(5), pp.863-869.

Liu, J., Lundqvist, J., Weinberg, J. and Gustafsson, J., 2013. Food losses and waste in China and their implication for water and land. *Environmental science & technology*, **47**(18), pp.10137-10144.

Liu, H., Zhang, X. and Hong, Q., 2021. Emission Characteristics of Pollution Gases from the Combustion of Food Waste. *Energies*, *14*(19), p.6439.

Lorenzoni, I., Nicholson-Cole, S. and Whitmarsh, L., 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global environmental change*, **17**(3-4), pp.445-459.

Lowes, R., Woodman, B. and Fitch-Roy, O., 2019. Policy change, power and the development of Great Britain's Renewable Heat Incentive. *Energy Policy*, *131*, pp.410-421.

Lu, X., Jordan, B. and Berge, N.D., 2012. Thermal conversion of municipal solid waste via hydrothermal carbonization: Comparison of carbonization products to products from current waste management techniques. *Waste management*, **32**(7), pp.1353-1365.

Luecke, L., 2015. Haste to no waste: A multi-component food waste study in a university dining facility.

Liu, G., 2014. Food losses and food waste in China: a first estimate. OECD Food, Agriculture and Fisheries Papers 66, OECD Publishing.

Liverpool Hope University, 2022. Food and Drink [Online]. [Accessed on 25th September 2022]. Available at: https://www.hope.ac.uk/gateway/sustainability/foodanddrink/

Maganti, V. (2018). Sustainability architect final report for the University of Leeds (Unpublished).

Maheshwari, S., 2017. Towards A Waste Neutral College Campus: Case Study of Indraprastha College for Women, University of Delhi. *Journal of innovation for inclusive development*, **2**(2).

Manfredi, S., Tonini, D., Christensen, T.H. and Scharff, H., 2009. Landfilling of waste: accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, **27**(8), pp.825-836.

Manomaivibool, P., Chart-asa, C. and Unroj, P., 2016. Measuring the Impacts of a Save Food Campaign to Reduce FW on Campus in Thailand. *Appl. Environ. Res*., **38**, pp.13-22.

Malghani, S., Gleixner, G. and Trumbore, S.E., 2013. Chars produced by slow pyrolysis and hydrothermal carbonization vary in carbon sequestration potential and greenhouse gases emissions. *Soil Biology and Biochemistry*, **62**, pp.137-146.

Malefors, C., Sundin, N., Tromp, M. and Eriksson, M., 2022. Testing interventions to reduce food waste in school catering. *Resources, Conservation and Recycling*, **177**, p.105997.

Mata-Alvarez, J., Mace, S. and Llabres, P., 2000. Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource technology*, **74**(1), pp.3-16.

Matzembacher, D.E., Brancoli, P., Maia, L.M. and Eriksson, M., 2020. Consumer's food waste in different restaurants configuration: A comparison between different levels of incentive and interaction. *Waste Management*, **114**, pp.263-273.

Mbah, R.E. and Wasum, D.F., 2022. Russian-Ukraine 2022 War: A review of the economic impact of Russian-Ukraine crisis on the USA, UK, Canada, and Europe. *Advances in Social Sciences Research Journal*, **9**(3), pp.144-153.

McMichael, A.J., Powles, J.W., Butler, C.D. and Uauy, R., 2007. Food, livestock production, energy, climate change, and health. *The lancet*, **370**(9594), pp.1253-1263.

Mehta, Y.D., Shastri, Y. and Joseph, B., 2018. Economic analysis and life cycle impact assessment of municipal solid waste (MSW) disposal: A case study of Mumbai, India. *Waste Management & Research*, **36**(12), pp.1177-1189.

Michelini, L., Principato, L. and Iasevoli, G. 2018. Understanding Food Sharing Models to Tackle Sustainability Challenges. *Ecological Economics*. **145**(2018) pp. 205-217.

Mirosa, M., Yip, R. and Lentz, G., 2018. Content analysis of the 'clean your plate campaign'on sina weibo. *Journal of Food Products Marketing*, **24**(5), pp.539-562.

Midgley, J.L., 2014. The logics of surplus food redistribution. *Journal of Environmental Planning and Management*, **57**(12), pp.1872-1892.

Mondello, G., Salomone, R., Ioppolo, G., Saija, G., Sparacia, S. and Lucchetti, M.C., 2017. Comparative LCA of alternative scenarios for waste treatment: The case of food waste production by the mass-retail sector. *Sustainability*, **9**(5), p.827.

Mourad, M., 2016. Recycling, recovering and preventing "food waste": Competing solutions for food systems sustainability in the United States and France. *Journal of Cleaner Production*, **126**, pp.461-477.

Naughton, C.C., 2020. Will the COVID-19 pandemic change waste generation and composition?: The need for more real-time waste management data and systems thinking. *Resources, conservation, and recycling*, **162**, p.105050.

Navin, C.V., 2012. Large-scale food waste anaerobic digester. *International Journal of Current Science*. *J CURR SCI*, **2**: 37-40

Nielfa, A., Cano, R. and Fdz-Polanco, M., 2015. Theoretical methane production generated by the co-digestion of organic fraction municipal solid waste and biological sludge. *Biotechnology Reports*, **5**, pp.14-21.

NYU. (2016). New York University's Micro Anaerobic Digester: A Renewable Energy Solution Fueled by Table Scraps. REV Campus Challenge Submission. Available at: https://www.nyu.edu/content/dam/nyu/publicAffairs/documents/PDF/NYU_DigesterProposal.pdf

Obernberger, I. and Supancic, K., 2009, June. Possibilities of ash utilisation from biomass combustion plants. In *Proceedings of the 17th European biomass conference & exhibition* (Vol. 29).

Ofgem. (2017). Tariffs and payments: Non-Domestic RHI. [online]. [Accessed on 1st December 2017]. Available at: https://www.ofgem.gov.uk/environmental-programmes/nondomestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-non-domestic-rhi

Ofei, K.T., Werther, M., Thomsen, J.D., Holst, M., Rasmussen, H.H. and Mikkelsen, B.E., 2015. Reducing food waste in large-scale institutions and hospitals: insights from interviews with danish foodservice professionals. *Journal of Foodservice Business Research*, **18**(5), pp.502-519.

Okin, G.S., 2017. Environmental impacts of food consumption by dogs and cats. *PloS one*, **12**(8), p.e0181301.

OLIO. 2018. Join the food sharing revolution. [Online]. [Accessed 25 May 2018]. Available from: https://olioex.com/

Olleco, 2017. What happens to your FW. [Online]. [Accessed on 10th October 2017]. Available at: https://www.olleco.co.uk/food-waste/our-green-story

O'Shea, C.E., Merritt, K.A. and Cooney, R.J., 2017. Reducing Food Waste at IIT Mandi.

Pan, Y., Li, M., Guo, H., Li, Y. and Han, J., 2022. Influencing factors and reduction of domestic solid waste at university dormitory in Shanghai, China. *Scientific reports*, **12**(1), pp.1-12.

Papargyropoulou, E., Lozano, R., Steinberger, J.K., Wright, N. and bin Ujang, Z., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of cleaner production*, **76**, pp.106-115.

Papargyropoulou, E., Steinberger, J.K., Wright, N., Lozano, R., Padfield, R. and Ujang, Z., 2019. Patterns and causes of food waste in the hospitality and food service sector: Food waste prevention insights from Malaysia. *Sustainability*, **11**(21), p.6016.

Principato, L., Secondi, L., Cicatiello, C. and Mattia, G., 2020. Caring more about food: The unexpected positive effect of the Covid-19 lockdown on household food management and waste. *Socio-Economic Planning Sciences*, p.100953.

Puccini, M., Ceccarini, L., Antichi, D., Seggiani, M., Tavarini, S., Hernandez Latorre, M. and Vitolo, S., 2018. Hydrothermal carbonization of municipal woody and herbaceous prunings: hydrochar valorisation as soil amendment and growth medium for horticulture. *Sustainability*, **10**(3), p.846.

Qian, L., Li, F., Cao, B., Wang, L. and Jin, S., 2021. Determinants of food waste generation in Chinese university canteens: Evidence from 9192 university students. *Resources, Conservation and Recycling*, **167**, p.105410.

Quested, T.E., Marsh, E., Stunell, D. and Parry, A.D., 2013. Spaghetti soup: The complex world of food waste behaviours. *Resources, Conservation and Recycling*, **79**, pp.43-51.

Rajaram, V., Siddiqui, F.Z. and Khan, M.E., 2011. From landfill gas to energy: Technologies and challenges. *CRC press*.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.P., Suh, S., Weidema, B.P. and Pennington, D.W., 2004. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment international*, **30**(5), pp.701-720.

ReFED, 2018a. FEDERAL TAX INCENTIVES. https://www.refed.com/tools/food-waste-policy-finder/federal-policy/federal-tax-incentives

ReFED, 2018b. FEDERAL ANIMAL FEED POLICY. https://www.refed.com/tools/food-waste-policy-finder/federal-policy/federal-animal-feed-policy

ReFED, 2018c. FOOD RECOVERY ACT. https://www.refed.com/tools/food-waste-policy-finder/federal-policy/food-recovery-act

Refsgaard, K. and Magnussen, K., 2009. Household behaviour and attitudes with respect to recycling food waste–experiences from focus groups. *Journal of Environmental management*, **90**(2), pp.760-771.

Rennert, K., Errickson, F., Prest, B.C., Rennels, L., Newell, R.G., Pizer, W., Kingdon, C., Wingenroth, J., Cooke, R., Parthum, B. and Smith, D., 2022. Comprehensive evidence implies a higher social cost of CO2. *Nature*, **610**(7933), pp.687-692.

Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V.K., Evans, D., Koh, L., Kanyama, A.C., Katzeff, C. and Svenfelt, Å., 2019. Consumption-stage food waste reduction interventions–What works and how to design better interventions. *Food Policy*, **83**, pp.7-27.

Robin Hood Army, 2019. The Idea. [Online]. [Accessed on 10th May 2019]. Available at: https://robinhoodarmy.com/

Rodrıguez-Arias, D. and Morgan, M., 2016. “Nudging” Deceased Donation Through an Opt-Out System: A Libertarian Approach or Manipulation?. *The American Journal of Bioethics*, **16**(11), pp.25-28.

Romani, S., Grappi, S., Bagozzi, R.P. and Barone, A.M., 2018. Domestic food practices: A study of food management behaviors and the role of food preparation planning in reducing waste. *Appetite*, **121**, pp.215-227.

Roy, P., Dutta, A. and Gallant, J., 2020. Evaluation of the life cycle of hydrothermally carbonized biomass for energy and horticulture application. *Renewable and Sustainable Energy Reviews*, **132**, p.110046.

Russell, S.V., Young, C.W., Unsworth, K.L. and Robinson, C., 2017. Bringing habits and emotions into food waste behaviour. *Resources, Conservation and Recycling*, *125*, pp.107-114.

Salemdeeb, R., zu Ermgassen, E.K., Kim, M.H., Balmford, A. and Al-Tabbaa, A., 2017. Environmental and health impacts of using FW as animal feed: a comparative analysis of FW management options. *Journal of cleaner production*, **140**, pp.871-880.

Sander, K., 2008. Climate protection potentials of eu recycling targets. Ökopol GmbH. ETC/SCP working paper 1/2009, using the NAMEA framework.

Schmidt, K., 2016. Explaining and promoting household food waste-prevention by an environmental psychological based intervention study. *Resources, Conservation and Recycling*, **111**, pp.53-66.

Schwartz, M.B., Henderson, K.E., Read, M., Danna, N. and Ickovics, J.R., 2015. New school meal regulations increase fruit consumption and do not increase total plate waste. *Childhood Obesity*, **11**(3), pp.242-247.

Selincourt, K., 2008. A comparison of greenhouse gas flux from composting compared to landfill and fertilizer production. *Growing Heap*, **43**, pp.11-13.

Shearer, L., Gatersleben, B., Morse, S., Smyth, M. and Hunt, S., 2017. A problem unstuck? Evaluating the effectiveness of sticker prompts for encouraging household FW recycling behaviour. *Waste Management*, **60**, pp.164-172.

Silvennoinen, K., Heikkilä, L., Katajajuuri, J.M. and Reinikainen, A., 2015. Food waste volume and origin: Case studies in the Finnish food service sector. *Waste management*, **46**, pp.140-145.

Singh, C.K., Kumar, A. and Roy, S.S., 2018. Quantitative analysis of the methane gas emissions from municipal solid waste in India. *Scientific reports*, **8**(1), p.2913.

Artiuch, P. and Kornstein, S., 2012. Sustainable approaches to reducing FW in India. *Journal of Massachusetts Institute of Technology. February*, *10*.

Song, C., Zhao, T. and Wang, J., 2022. Analyzing driving forces of China's carbon emissions from 1997 to 2040 and the potential emission reduction path: Through decomposition and scenario analysis. *Clean Technologies and Environmental Policy*, **24**(4), pp.1219-1240.

Statista, 2019. Per capita FW of selected countries worldwide in 2017. [Online]. [Accessed on 10th November 2018]. Available at: https://www.statista.com/statistics/933059/per-capita-food-waste-of-selected-countries/

Statista, 2022. Number of students enrolled in higher education in the United Kingdom from 2009/10 to 2020/21. [Online]. [Accessed on 20th October 2022]. https://www.statista.com/statistics/875015/students-enrolled-in-higher-education-in-the-uk/

Stiglitz, J.E., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G.M., La Rovere, E.L., Morris, A., Moyer, E., Pangestu, M. and Shukla, P.R., 2017. Report of the high-level commission on carbon prices.

Strotmann, C., Baur, V., Börnert, N. and Gerwin, P., 2022. Generation and prevention of food waste in the German food service sector in the COVID-19 pandemic–Digital approaches to encounter the pandemic related crisis. *Socio-Economic Planning Sciences*, **82**, p.101104.

Suryanarayana, M.H. and Silva, D., 2007. Is targeting the poor a penalty on the food insecure? Poverty and food insecurity in India. *Journal of Human Development*, **8**(1), pp.89-107.

Takata, M., Fukushima, K., Kino-Kimata, N., Nagao, N., Niwa, C. and Toda, T., 2012. The effects of recycling loops in FW management in Japan: based on the environmental and economic evaluation of food recycling. *Science of the Total Environment*, **432**, pp.309-317.

Thaler, R.H. and Sunstein, C.R., 2009. *Nudge: Improving decisions about health, wealth, and happiness*. Penguin.

Thorneloe, S.A., Weitz, K. and Jambeck, J., 2007. Application of the US decision support tool for materials and waste management. *Waste Management*, **27**(8), pp.1006-1020.

Toor, S.S., Rosendahl, L. and Rudolf, A., 2011. Hydrothermal liquefaction of biomass: a review of subcritical water technologies. *Energy*, **36**(5), pp.2328-2342.

UFZ, 2018. Hydrothermal Carbonization HTC. [Online]. [Accessed on 5th June 2018]. Available at: https://www.ufz.de/index.php?en=37433

UK government, 2022. Food waste in the UK. [Online]. [Accessed on 28th May 2023]. https://lordslibrary.parliament.uk/food-waste-in-the-uk/

UK government, 2022. Renewable energy innovation boosted by £37 million government funding across the UK. [Online]. [Accessed on 13th October 2022]. https://www.gov.uk/government/news/renewable-energy-innovation-boosted-by-37-million-government-funding-across-the-uk

University of Bradford, 2022. University of Bradford case study [Online]. [Accessed on 29th September 2022]. Available at: https://nanopdf.com/download/university-of-bradford-case-study_pdf

University of Edinburgh, 2022. The University of Edinburgh Waste Strategy 2018/19 – 2022/23 [Online]. [Accessed on 29th September 2022]. Available at: https://www.ed.ac.uk/files/atoms/files/waste_strategy.pdf

University of Leeds, 2022a. Blueprint. [Online]. [Accessed on 1st October 2022]. https://sustainability.leeds.ac.uk/get-involved/make-an-impact/blueprint/

University of Leeds, 2022b. Our Climate Plan. [Online]. [Accessed on 1st October 2022]. https://sustainability.leeds.ac.uk/climate-

principles/#:~:text=Delivering%20net%20zero%20by%202030,zero%20direct%20emissions%20by%202050

University of Manchester, 2022. Food Waste [Online]. [Accessed on 29th September 2022]. Available at: https://www.estates.manchester.ac.uk/services/operationalservices/envsvcs/waste/foodwaste/

University of the West of England, 2022. UWE Bristol Statement on Food Waste [Online]. [Accessed on 29th September 2022]. Available at: file:///C:/Users/pmned/Downloads/Food-Waste-Statement.pdf

University of Wolverhampton, 2022. What happens to University waste [Online]. [Accessed on 29th September 2022]. Available at: https://www.wlv.ac.uk/about-us/corporate-information/sustainability-and-the-environment/what-happens-to-our-waste/

Van Dyk, J. S., R. Gama, D. Morrison, S. Swart, and B. I. Pletschke. "Food processing waste: Problems, current management and prospects for utilisation of the lignocellulose component through enzyme synergistic degradation." *Renewable and Sustainable Energy Reviews* 26 (2013): 521-531.

Vassilev, S.V., Baxter, D., Andersen, L.K. and Vassileva, C.G., 2013. An overview of the composition and application of biomass ash.: Part 2. Potential utilisation, technological and ecological advantages and challenges. *Fuel*, **105**, pp.19-39.

Vego, G., Kučar-Dragičević, S. and Koprivanac, N., 2008. Application of multi-criteria decision-making on strategic municipal solid waste management in Dalmatia, Croatia. *Waste management*, **28**(11), pp.2192-2201.

Velavan, T.P. and Meyer, C.G., 2020. The COVID-19 epidemic. *Tropical medicine & international health*, **25**(3), p.278.

Veldkamp, E., 2009. The emergence of “pets as family” and the socio-historical development of pet funerals in Japan. *Anthrozoös*, **22**(4), pp.333-346.

Vision 2020, 2013. Roadmap to zero waste to landfill UK. [Online]. [Accessed on 8th October 2018]. Available at: https://www.vision2020.info/assets/pdf/Vision_2020_roadmap.pdf

Visschers, V.H., Gundlach, D. and Beretta, C., 2020. Smaller servings vs. information provision: Results of two interventions to reduce plate waste in two university canteens. *Waste Management*, **103**, pp.323-333.

Walsh, M.E., 2014. Biomass Resource Assessment.

Wang, T.H. and Katzev, R.D., 1990. Group Commitment and Resource Conservation: Two Field Experiments on Promoting Recycling 1. *Journal of Applied Social Psychology*, **20**(4), pp.265-275.

Wansink, B. and Van Ittersum, K., 2013. Portion size me: Plate-size induced consumption norms and win-win solutions for reducing food intake and waste. *Journal of Experimental Psychology: Applied*, **19**(4), p.320.

Wen, Z., Wang, Y. and De Clercq, D., 2016. What is the true value of food waste? A case study of technology integration in urban food waste treatment in Suzhou City, China. *Journal of Cleaner Production*, **118**, pp.88-96.

Whitehair, K.J., Shanklin, C.W. and Brannon, L.A., 2013. Written messages improve edible FW behaviors in a university dining facility. *Journal of the Academy of Nutrition and Dietetics*, **113**(1), pp.63-69.

Wong, N.W., 2016. Environmental protests and NIMBY activism: Local politics and waste management in Beijing and Guangzhou. *China Information*, *30*(2), pp.143-164.

Wood, W. (2019) Devonshire Hall FW Survey Results. Sustainability architect final report for the University of Leeds (Unpublished).

World bank, 2017. Carbon Pricing. [Online]. [Accessed on 20th October 2022]. https://www.worldbank.org/en/results/2017/12/01/carbon-pricing

World Data, 2021. Comparison of worldwide cost of living. [Online]. [Accessed on 11th October 2022]. Available at: https://www.worlddata.info/cost-of-living.php

WRAP, 2006. Food consumer research: Quantitative phase. [Online]. [Accessed on 8th October 2018]. Available at: http://www.wrap.org.uk/sites/files/wrap/Food%20behaviour%20consumer%20research%20quantitative%20jun%202007.pdf

WRAP, 2007. Food Consumer Research: Quantitative Phase.. Available online: http://www.wrap.org.uk/sites/files/wrap/Food%20behaviour%20consumer%20research%20quantitative%20jun%202007.pdf (accessed on 8 October 2018).

WRAP, 2009. Evaluation of the WRAP Separate FW Collection Trials [Online]. [Accessed on 10th October 2018]. Available at: http://www.wrap.org.uk/sites/files/wrap/Evaluation_of_the_WRAP_FW_Collection_Trials_Update_June_2009.pdf

WRAP (2010) Waste Arisings in the Supply of Food and Drink to Households in the UK. Final report United Kingdom.

WRAP, 2013. Household Food and Drink Waste in the United Kingdom 2012. [Online]. [Accessed on 10th November 2018]. Available at: http://www.wrap.org.uk/sites/files/wrap/hhfdw-2012-summary.pdf

WRAP. (2016). Digestate and compost use in agriculture: Good Practice Guidance. [Online]. [Accessed on 11th November 2017]. Available at: http://www.wrap.org.uk/sites/files/wrap/Digestate_compost_good_practice_guide_reference_version.pdf

WRAP, 2017. Estimates of Food Surplus and Waste Arisings in the UK. [Online]. [Accessed on 20th August 2018]. Available at: http://www.wrap.org.uk/sites/files/wrap/Estimates_%20in_the_UK_Jan17.pdf

WRAP, 2018a. Why take action: legal/policy case. [Online]. [Accessed on 15th July 2018]. Available at: http://www.wrap.org.uk/content/why-take-action-legalpolicy-case

WRAP, 2018b. Using surplus food in animal feed. [Online]. [Accessed on 25th September 2018]. Available at: http://www.wrap.org.uk/content/using-surplus-food-animal-feed

WRAP and the Women's Institute, 2008. Love Food Champions. [Online]. [Accessed on 8th October 2019]. Available at: https://www.wrap.org.uk/sites/files/wrap/LFC%20draft%20FINAL%20report%20171008-FINAL.pdf

WRAP, 2022. Food surplus and waste in the UK – key facts. [Online]. [Accessed on 3rd June 2023]. Available at: https://wrap.org.uk/sites/default/files/2023-01/Food%20Surplus%20and%20Waste%20in%20the%20UK%20Key%20Facts%20December%202022.pdf

Wu, Y., Tian, X., Li, X., Yuan, H. and Liu, G., 2019. Characteristics, influencing factors, and environmental effects of plate waste at university canteens in Beijing, China. *Resources, Conservation and Recycling*, **149**, pp.151-159.

Xiao, S., Dong, H., Geng, Y., Francisco, M.J., Pan, H. and Wu, F., 2020. An overview of the municipal solid waste management modes and innovations in Shanghai, China. *Environmental Science and Pollution Research International*.

XE, 2022. Xe currency converter. [Online]. [Accessed on 19th May 2022]. Available at: https://www.xe.com/currencyconverter/convert/?Amount=1&From=CNY&To=USD

XE, 2023. Xe currency converter. [Online]. [Accessed 6th July 2023]. Available at: https://www.xe.com/currencyconverter/convert/?Amount=1&From=CNY&To=USD

Yang, L., Zhao, Y., Niu, X., Song, Z., Gao, Q. and Wu, J., 2021. Municipal solid waste forecasting in China based on machine learning models. *Frontiers in Energy Research*, p.715.

Yong, Z., Dong, Y., Zhang, X. and Tan, T., 2015. Anaerobic co-digestion of food waste and straw for biogas production. *Renewable energy*, **78**, pp.527-530.

Zhang, H., Li, S., Wei, D., He, J., Chen, J., Sun, C., Vuppaladadiyam, A.K. and Duan, H., 2021. Characteristics, environmental impact, and reduction strategies of food waste generated by young adults: Case study on university canteens in Wuhan, China. *Journal of Cleaner Production*, **321**, p.128877.

Zhou, Y., Engler, N. and Nelles, M., 2018. Symbiotic relationship between hydrothermal carbonization technology and anaerobic digestion for FW in China. *Bioresource technology*, **260**, pp.404-412.

Zhang, D., Hao, M., Chen, S. and Morse, S., 2020. Solid waste characterization and recycling potential for a university campus in China. *Sustainability*, **12**(8), p.3086.

Zhou, M.H., Shen, S.L., Xu, Y.S. and Zhou, A.N., 2019. New policy and implementation of municipal solid waste classification in Shanghai, China. *International journal of environmental research and public health*, **16**(17), p.3099.

Zhou, H., Yang, Q., Gul, E., Shi, M., Li, J., Yang, M., Yang, H., Chen, B., Zhao, H., Yan, Y. and Erdoğan, G., 2021. Decarbonizing university campuses through the production of biogas from food waste: An LCA analysis. *Renewable Energy*, **176**, pp.565-578.

Appendices

Appendix A behavioural change chapter

Appendix A1: Food waste attitudes survey

Filter question:

FQ. Last week roughly what % of your meals were…? **Please tick 1 box for each section**						
	All	75-100%	50-75%	25-50%	0-25%	None
Catered by the University						
Self-cooked						
Other (such as take-aways, eating out etc)						

If answered **'All'** for **'Catered by the University'** please **skip** to **section 3**, **question 5**

Section 1: Shopping Habits

Q1. How often do you usually do your main shopping trip? **Please tick 1 box** **Q2.** How often do you usually do smaller 'top up' shops? **Please tick 1 box**		
	Q1. Main	**Q2.** Top up
Every day		
Every 2-3 days		
About once a week		
A couple of times a month		
Less often		
Never		

Section 2: Shopping habits and routines

Q3. Thinking about your normal FOOD shopping routine and habits involving food, how would you rate yourself on the following? **Please tick 1 box for each section**						
	Very good	Fairly good	Average	Not very good	Definitely not one of my strengths	Don't do this
Pre-shopping planning (e.g. making a list, checking the cupboards to see what you already have)						
Discipline in the store (e.g. sticking to the list, avoiding 'impulse' buys)						
Looking at labels in the store to check "use by" and "best before" dates that indicate how fresh food is and how long it will last						
Fridge/cupboard organisation at home (e.g. knowing what you have and when products' "use by" or "best before" dates are coming up)						
Meal planning (e.g. knowing what you are going to prepare in the week ahead)						
Cooking skills (e.g. the range of things you can prepare from raw/fresh ingredients)						
Combining foods (e.g. taking food leftovers/random ingredients and making a meal)						

Section 3: Cooking & eating habits

Q4. Thinking about how you use best-before dates, which of the following statements best describes you? **Please tick 1 box**	
I never eat past the date on the label	
I occasionally eat past the date on the label	
I often eat past the date on the label	
I don't look at the date on the label	
I don't eat this food	
Don't know	

Q5. Thinking generally, how much of the following have you thrown away into the bin? **Please tick 1 box for each section**						
	Quite a lot	A reasonable amount	Some	A small amount	Hardly any	None
Food left on the plate after the meal						
Food you cooked/prepared too much of but didn't serve up						
Food from previous meals that you initially saved but didn't get around to eating/using up						
Products you opened and used but didn't finish (e.g. deli foods, sauces, cans/jars, spreads)						
Products you bought but didn't open (e.g. deli foods, cans/jars, spreads, bakery goods)						

Q6. Again, thinking generally, how much uneaten food – overall - would you say you throw away in general? Would you say…? **Please tick 1 box**	
Quite a lot	
A reasonable amount	
Some	
A small amount	
Hardly any	
None	

Q7. Everyone has to throw food away sometimes. Which of the following factors do you think cause you to throw away food? **Please tick all relevant boxes for each section**
Q8. And which of these would you say are the main reasons why you throw away food? **Please tick 1 box for each section**

	Q7. Issue	**Q8. Main**
Shopping for food		
Buying too much when shopping		
Buying things you already have at home		
Not making a list before shopping		
Not sticking to a list in the store		
Tempted by "multi-packs"		
Tempted by price reductions on products approaching their "use by" or "best before" date		
Tempted by special offers e.g. 'buy one get one free'		
Trying to buy more fresh food (that doesn't last as long)		
Portion sizes of products are too big		
Don't check the "use by" or "best before" dates in store		
Buying takeaways and not eating everything		
Storing food		
Needing to make space in the fridge/cupboards for new things		
Not eating the foods that need to be eaten first		
Not keeping the fridge cold enough		
Not knowing the use by dates of products in fridge/cupboards		
Not always sure of how to store certain products		
Doing a 'spring clean' of the cupboards to get rid of old products		
Not resealing/repackaging opened products so they stay fresh		
Preparing and cooking food		
Not planning meals		
Food gone past its use by or best before date		
Food visibly gone bad or smells bad		
Food not visibly bad but not worth the risk		
Food burnt/ruined during cooking/preparation		
Experimenting with new ideas/ingredients		
Need more recipes and ideas for using food		
Lack of confidence in combining leftovers to make a 'new' meal		
Don't like cooking with leftovers/eating leftovers		

Eating food & Lifestyles		
Food didn't taste good		
Made too much food		
Not enough time		
Plans change in the week/can't plan		
Any other		
Don't know		

Q9. Thinking about when you have to throw uneaten food items away, to what extent, if at all, does it bother you? **Please tick 1 box**	
A great deal	
A fair amount	
A little	
Not very much	
Not at all	

(ONLY ANSWER IF YOU PUT 'A GREAT DEAL', 'A FAIR AMOUNT', OR 'A LITTLE' IN Q9!)

Q10. Why does throwing away food bother you? Would you say it's any of the following or something else? **Please tick all relevant boxes**	
It's a waste of my money	
It's bad for the environment	
It makes me feel guilty	
It's dirty/makes the bin smell	
It makes me feel that I haven't planned very well	
I can't afford to throw away food	
It makes me feel like I've wasted my time	
It's a waste of good food	
Other	
Don't know	

(ONLY ANSWER IF YOU PUT 'NOT VERY MUCH', OR 'NOT AT ALL' IN Q9!)

Q11. Why are you not bothered by throwing food away? Would you say it is any of the following or something else?? **Please tick all relevant boxes**	
Doesn't cost that much	
Life's too short/other things to worry about	
Don't consider it a problem	
Want to eat the freshest food so there's bound to be some waste	
I don't throw away much food	
Sometimes I enjoy the freedom to throw food away	
I'd rather throw food away than risk food poisoning	
I have opted in to segregate my food waste	
I'd rather cook more for me/other people than not have enough	
Food waste is natural/breaks down	
Can't be avoided	
Want to keep kitchen clean/organised	
Other	
Don't know	

Q12. Have you opted in to segregate food waste? **Please tick 1 box**	
Yes	
No	

Q13. How much effort do you make to minimise the amount of uneaten food you throw away? **Please tick 1 box**	
A great deal	
A fair amount	
A little	
Not very much	
None at all	

Q14. To what extent, if at all, do you think about the cost of the uneaten food you throw away? **Please tick 1 box**	
A great deal	
A fair amount	
A little	
Not very much	
Not at all	
Don't know	

Q15. To what extent do you agree or disagree with the following statements? **Please tick 1 box for each section**						
	Strongly agree	Tend to agree	Neither agree, or disagree	Tend to disagree	Strongly disagree	Don't know
Food thrown away is not an issue as it is natural and biodegradable						
Discarded food packaging is a greater environmental issue than food thrown away						
Nothing would encourage me to make an effort to throw away less food						

Q16. Thinking about climate change, how much effort do you go to – for example through the products you buy, the way you travel and the things you throw away – in order to minimise your own impact/contribution? **Please tick 1 box**	
A great deal of effort	
Quite a lot of effort	
Some effort	
Not very much effort	
No effort	
Don't know	

Section 4: The University's role in food waste management

Q17. Are you aware of what the University is doing to tackle food waste issues? **Please tick 1 box**	
A great deal	
A fair amount	
A little	
Not very much	
Not at all	
Don't know	

Q18. Should the University do more to tackle issues of food waste? **Please tick 1 box**	
A great deal	
A fair amount	
A little	
Not very much	
Not at all	
Don't know	

Section 5: Effectiveness of the intervention (post intervention survey only!)

Q19. Do you recall seeing any of these behavioural change interventions? Please tick all relevant boxes	
Posters	
Table cards (with food waste facts)	
Signs (telling people to reduce waste)	
Don't know	

Q20. To what extent did the following interventions impact your behaviour? **Please tick 1 box for each section**						
	Quite a lot	A reasonable amount	A little	Hardly at all	Not at all	Don't know
Posters						
Table cards (with food waste facts)						
Signs (telling people to reduce waste)						

Socio-Demographics

Gender Please tick 1 box	
Male	
Female	
Non-binary	
Prefer not to say	

Housing type Please tick 1 box	
Catered	
Self-catered	

Level of study Please tick 1 box	
Undergraduate	
Masters	
PhD	

Nationality Please tick 1 box	
UK	
EU (other than UK)	
Non-EU	

Appendix A2: Semi-structured interview

Background

Could you briefly explain your organisation and key stakeholders within it?
What is your relationship to these other stakeholders?

What is your current role (job remit) in relation to food waste?

What are your organisation's motivations and drivers for more sustainable management of food waste?
Are they driven by the University/organisation, or the students/residents?
Do you care about environmental (greenhouse gas emissions), economic (waste collection costs etc), or social factors (odour, resource use, food security etc) concerning food waste?
Which of these factors does your organisation care about most?

Current waste management strategies

How much food is wasted (quantity/volume in canteen, campus and university)?

What food is wasted?
What are the main sources of food waste (when and where is most of the food wasted)?
What are the main types of food waste (fruit, salad, bread, meat etc)?

What happens to the food that is wasted?
How is the waste treated (how is it segregated, treatment technology, treatment company)?
Why does the organisation get your food waste treated this way?

Is your organisation actively working to tackle food waste issues?
If not, why not?

What food waste issues is your organisation tackling (food waste recycling, or food waste reduction)?
How are you tackling these food waste issues?
What methods do you use?
Why do you use these methods?
When did you start these methods?

How does the organisation monitor the effectiveness of the strategies?
Have these strategies been successful?

Opportunities and barriers experienced

What are the key barriers and constraints to more sustainable management of food waste at the organisation?
Do you have any regulatory constraints?
Do you have any competing priorities?

What are the key opportunities for more sustainable management of food waste at the organisation?
What has helped you in becoming more sustainable in your food waste management?
What are the key opportunities that can help you improve the sustainability of your management further?

Appendix A3: Semi-structured interview

Order

- Consent forms, Introduction/Overview/Ground rules (10 minutes)

- Questions (45 minutes)

- Sum up session and thank participants (5 minutes)

Proposed questions and prompts

Initial questions- General food waste issues

1) Do you consider food waste to be an issue? (personally, at your residence, nationally, or globally, environmentally, economically, or socially) 10 minutes

FW reduction

These questions are for everyone, but I'm particularly interested to hear the thoughts of the catered residents.

2) What do you do to try to reduce your food waste and why? 10 minutes

3) Did you notice any of the materials designed to reduce food waste located in the canteen (posters, table cards, or signs)? (Which did you find most effective?) 5 minutes

Food waste recycling

These next few questions are aimed at the self-catered residents, but if you are a catered student and feel like you have anything relevant to say please feel free to say it.

4) Did you opt-in to segregate food waste? (why, why not?) 5 minutes

5) Did you notice any of the food waste recycling interventions and did they affect your food waste related behaviour (posts/emails, fridge magnets, pledge, oral information and which did you find the most effective?) 10 minutes

University food waste management

6) Are you aware of strategies and policies that the University is doing to tackle food waste issues and what else do you think the University could do to improve food waste management? 10 minutes

Is there anything else anyone else would like to add about anything that we discussed, or that didn't come up, but you think may be relevant? 5 minutes

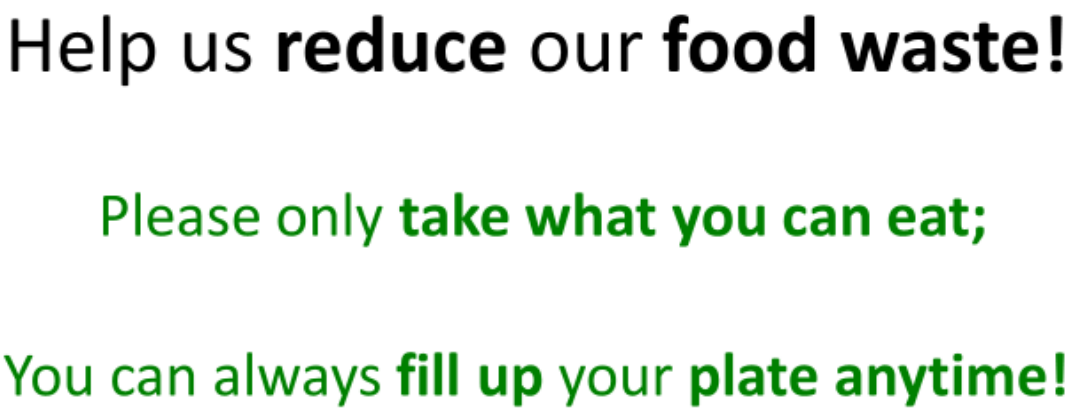
Appendix A4: Food waste reduction materials

Table card example

Prompt poster

Feedback poster

Salient sign example



Appendix A5: Food waste recycling materials

Magnet example

Public pledge poster

Public Pledge

I pledge that I will opt in and commit to segregating my food waste at Devonshire Hall.

Please go to reception to sign up for a food waste bin if you haven't already.

Names	

Appendix A6: Behavioural change previous studies

Paper	Setting and sample size	Aim	Methods	Findings
Pre vs post FW reduction intervention surveys				
Whitehair et al. (2013)	**Setting:** US University canteens **Sample size:** Pre-intervention 133 After prompt posters 194 After feedback posters 150	To assess the effectiveness of using information and group feedback to change FW reduction related behaviours in University canteens	Prompt posters telling people to reduce waste and posters providing group feedback were placed by the menu board, the tray dispenser and serving lines as FW related interventions. A pre intervention survey was conducted, as well as a survey after the prompt poster interventions and another after the group feedback posters were put up. Higher scores indicated that participants were in greater agreements with the statement asked. Participants were asked about their sustainability and FW related beliefs.	The interventions increased the participants' awareness and concern about FW issues. Students also believed that there were less plate scrapings from students at the canteen after the interventions.
Luecke (2015)	**Setting**: US University canteens **Sample size** Pre-intervention 55 Post-intervention 26	To assess the effectiveness of using educational text messages to change FW reduction related behaviours in University canteens	Educational text messages were used as FW related interventions over a 4-week period. They carried out a pre and post intervention survey looking at FW related awareness, behaviour and habits. Higher scores indicated that participants were in greater agreements with the statement asked.	Participants had a greater concern and awareness about the various impacts of FW, such as environmental and social consequences. They also recorded being better at aspects of FW prevention, such as using grocery lists, organising cupboards and freezing food to preserve it.
Ellison et al. (2019)	**Setting:** US University canteens **Sample size:** Pre-intervention 400 Post-intervention 301	To assess the effectiveness of using information and group feedback to change FW reduction related behaviours in University canteens	Visual prompts with educational information and feedback on FW production at the canteens were used as FW related interventions and a pre and post intervention survey was conducted asking whether participants agreed with statements related to FW behaviour and attitudes.	Participants believed they took more food than they could eat after the interventions. On the other hand, more participants believed that it did not matter if they threw away FW and that their individual FW did not make much difference given quantity of FW produced at the studied dining halls.
Visschers et al. (2020)	**Setting:** Swiss University canteens **Sample size:** Information intervention Pre-intervention 338 Post intervention 317	To assess the effectiveness of combining information with smaller portion controls to change FW reduction related behaviours in University canteens	Visual information materials (prompts and detailed information) were displayed and smaller portion sizes (60% of normal size) were introduced as FW related interventions. They conducted just the information intervention in one canteen and both interventions in another canteen. They conducted pre and post intervention surveys separately in both canteens, inquiring about current *FW reduction*	FW reduction behaviour, attitudes and personal norms all changed to show increased FW awareness

	Both interventions Pre-intervention 335 Post intervention 331		*behaviour, Intention to reduce FW and Attitudes* towards FW. Answers were rated on 5-point Likert scales, higher scores indicating stronger agreement with the statement.	
Romani et al. (2018)	**Setting:** Italian households **Sample size:** 30	To assess the effectiveness of providing households with an informative article on how to reduce FW in changing FW reduction related behaviours in households.	An informative article on meal planning was given to participants as a FW related intervention. They were surveyed before and after the intervention on FW prevention behaviours and the effectiveness of the article on a 7-point scale (from 1, corresponding to "completely disagree", to 7, corresponding to "completely agree").	The group who had received the article were better informed to reduce household FW, due to the adaption of practices that can help minimise FW
Schmidt (2016)	**Setting:** German households **Sample size:** Pre-intervention 217 Control group post-test 109 Experimental group post-intervention 108	To assess the effectiveness of information provision, public commitment making and goal setting interventions in changing FW reduction related behaviours in households.	Information provision and public commitment making were used as FW related interventions. Participants were recruited and given a pre-intervention survey. Participants were then divided up into a control group and an experimental group, using a randomization technique. The experimental group were given educational information related to FW and were asked to make public commitments and set goals to reduce the amount of FW they produced. Both groups were given pre and post-test surveys on FW behaviours and attitudes. This was done on a 6-point Likert scale (from 1, corresponding to "completely disagree", to 6, corresponding to "completely agree").	Awareness of the environmental consequences of FW, perceived responsibility for reducing FW and skills in areas of FW minimisation increased after the interventions.
WRAP and the Women's institute (2008)	**Setting**: UK households **Sample size:** Pre intervention 66 Post intervention 42	To assess the effectiveness of providing oral information and education related to FW in changing FW reduction related behaviours in households.	Volunteers engaged with households in England to change their behaviour towards FW by providing related information as FW related interventions. They met households in their communities once a month for four months to discuss a range of topics to do with reducing food waste such as shopping, storage, portion sizing, meal planning and how to use leftovers as an intervention. The households were given surveys before and after the interventions to see if their attitudes had changed on the discussed topics.	Respondents were much more concerned about FW after the interventions, with participants caring much more about the food they wasted and putting more effort into FW minimisation. Respondents were also recorded to have thrown away food less regularly and there was a much lower proportion of respondents who stated they were particularly poor at FW related shopping and habits, such as store discipline, meal planning and using up leftovers.
Pre vs post FW recycling intervention surveys				
Geislar, 2017	**Setting:** US households **Sample size** Pre intervention 1089 Post intervention 168	To assess the effectiveness of providing printed and digital information in changing FW recycling related behaviours in households.	Information provision was used as a FW recycling related intervention. Participants conducting printed surveys were given FW related information in the form of fridge magnets and stickers as printed interventions, and participants conducting digital surveys were given	The interventions improved FW recycling behaviour.

			emails containing the same information. Participants were given pre and post intervention surveys on perceived benefits and barriers to FW segregation. The surveys used a five-point Likert scale, with higher scores indicating greater perception of benefits.	
Hampshire County Council and Brook Lyndhurst (2010)	**Setting**: UK households **Sample size** Pre-intervention 112 Post-intervention 44	To assess the effectiveness of community engagement projects, disseminating information, conducting FW events and encouraging FW related personal self-reflection in changing FW recycling related behaviours in households.	Community engagement projects, disseminating information (leaflets and posters) and self-reflection (FW related diaries being filled out) were conducted as FW recycling related interventions. Pre and post interventions surveys were distributed to participants. The surveys looked at FW reduction and recycling related attitudes and behaviours, as well as their perceptions of the effectiveness of the interventions.	Participants generally had better attitudes and skill sets related to recycling and minimising household FW at the end of the project, when compared to the start.

Paper	Setting and sample size	Aim	Methods	Findings
Interviews on students				
Luecke (2015)	**Setting:** US University canteens **Sample size:** 7	To assess the effectiveness of using educational text messages to try to get students to reduce FW and change their FW related attitudes.	Semi-structured interviews were conducted by the author on students at the University canteen, which lasted between 20-45 minutes. They addressed sustainability knowledge and attitudes, home influence on FW behaviours, effectiveness of the intervention text messages, and modification of eating behaviours. Interviews were thematically coded.	The following themes were identified; "we only have one earth", "family influences food habits", "eating with other people takes time, but builds community", mindfulness of meal selection on days FW is weighed. There was also mixed feedback on the FW interventions, with students saying that the informative texts increased their FW awareness, others saying that they were already aware of FW issues, and others saying that texts were not an effective medium for increasing awareness.
Interviews on households				
Graham-Rowe et al. (2014)	**Setting:** UK households **Sample size:** 15	To identify and explore motivations and barriers to minimising FW among household food purchasers.	Semi-structured Interviews were conducted by the authors on food purchasers in households which lasted around 45 minutes. Recruited through online database. Offered £10 award for participation. Addressed attitudes towards food purchasing, food preparation and wasting food. The Interviews were thematically coded.	Key thematic motivations for reducing FW included; participants' waste concerns and being perceived to be doing the 'right' thing. Key thematic barriers for reducing FW included; having a desire to be seen as a 'good' provider, wanting to minimise inconvenience, FW reduction not being a priority, and participants claiming exemption from FW related responsibilities.
Romani et al. (2018)	**Setting:** Italian households **Sample size:** 514	To gain a deeper understanding what causes those responsible for shopping and cooking in their household to waste food.	Semi-structured interviews were conducted by 103 students that were recruited by the authors. They each interviewed 5 adults responsible for shopping and cooking in their household. Participants were asked about when they had wasted food and what caused the food to be wasted. 2 independent coders thematically coded the responses.	The eight most important thematic categories relating to household FW were; Food Storage, Food Preparation, Planning Food Purchasing, In-Store Food Control, Food Preparation Planning, Leftover Consumption, In-Store Food Purchase Influence, as well as Miscellaneous factors such as communication within Household and Food Literacy.
Interviews with institutions				
Mourad (2016)	**Setting:** US and French FW related organisations **Sample size:** 120	To gain a deeper understanding of how certain institutions manage their FW and what makes them manage the FW in this way.	Semi-structured interviews were conducted by the author on organisations in France and USA, followed by secondary informal, exploratory interviews. The interviews focused on FW related management approaches and objectives at the organisations. The interviews were statistically analysed on Excel and thematically coded.	Key themes identified were in-line with the FW hierarchy and included; FW prevention, surplus food redistribution and recycling FW. Interview analysis showed that organisations working in different areas of the food sector established *competing* solutions, within different FW hierarchy levels, based on environmental, social and economic goals.

Paprgyropoulou et al. (2014)	**Setting:** UK FW related organisations **Sample size:** 23	To gain a deeper understanding of the current FW related practices of FW related organizations, motivation and drivers to improve FW management, as well as barriers and opportunities in improving FW management.	7 Semi-structured, in-depth group interviews were conducted by the authors with 23 FW specialists. The interviews focussed on what the FW management at the organisations, motivations for tackling FW, as well as barriers and opportunities in improving FW management. The interviews were then thematically coded.	Key themes included; Food surplus, food security and waste, Avoidable and unavoidable FW, Waste prevention and waste management which helped them come up with a food surplus and waste framework in turn helping organisations optimise their FW management.
Focus groups and interviews				
Goonan et al. (2014)	**Setting:** New Zealand hospitals **Sample size:** Focus groups 22 Interviews 7	To gain an insight into why FW is produced and how it could be minimised in an institutional setting (hospitals).	Focus groups were conducted by the authors with various FW related kitchen staff members in different roles at the hospitals were selected. The focus groups lasted around 30 minutes and included an introduction, ice breaker, questions related to FW attitudes, training and minimisation strategies, and a wrapping up and conclusion. Semi-structured interviews were also conducted by the authors with members of management of each site and focussed on FW related attitudes, FW management strategies, motivations to reduce FW, as well as barriers and opportunities to improvements. The interviews and focus groups were thematically coded.	FW primarily resulted from overproduction of food and that the attitudes and practices of catering staff was an important factor in FW production, although there were a large number of factors contributing to FW at the hospitals. FW awareness varied significantly among staff. Managers were more concerned about achieving 'good practice' regarding FW minimisation, whereas canteen staff were more concerned about social implications of FW. The conduct of good practices in catering, such as effective planning and preparation contributed to FW minimisation. Understanding the FW related behaviours and attitudes of staff helped identify potential ways to reduce FW in the future.
Refsgaard and Magnussen (2009)	**Setting:** Norwegian households **Sample size:** Focus groups 16-28 Interviews $\geq$ 2	To assess whether household FW related attitudes differ in municipalities with and without FW recycling available and if behaviour changes after residents start recycling FW.	Focus groups were conducted by the authors with household members. 4 focus groups, 2 groups in an area with FW recycling and 2 groups in an area without, were conducted with groups consisting of 4-7 participants that were randomly selected. Focus groups lasted around 3 hours and focussed on waste recycling behaviour, knowledge of and attitudes towards the waste management system, and motivations to make FW related improvements. Semi-structured interviews were also conducted with municipality administrators in both areas focussing on the technological structures of their waste management systems. The results were then analysed and coded.	FW recycling infrastructure was vitally important in improving FW management and also improving FW related awareness and good practice. It also found some increases in FW awareness when comparing pre and post focus group surveys.

Paper	Setting and sample size	Aim	Methods	Findings
FW reduction in households				
WRAP and the Women's institute (2008)	**Setting**: UK households **Sample size:** 81	To assess the effectiveness of using FW related oral information and community engagement to reduce FW in households.	20 volunteers were recruited and trained to engage with households in England to change their behaviour towards FW by offering them practical advice and guidance. They met with members of their community once a month for four months to discuss a range of topics to do with reducing FW. Per household FW (kg/week) was measured before and after the project to see if FW reduced.	The interventions reduced edible, avoidable FW in the studied households by over 50%.
FW reduction in canteens and restaurants				
Manomaivibool et al. (2016)	**Setting**: Thai University canteen **Sample size:** 462 meals 314 pre-intervention 148 post intervention	To assess the effectiveness of using informative table cards to reduce FW in University canteens.	Informative cards on tables stating issues with wasting food (with hard hitting facts) and stickers placed on serving canteens telling people to reduce FW (to consider portion size, meal choice, and implications of FW) were introduced to try to reduce FW at a University campus canteen in Thailand. They assessed the meal waste by taking images of meals before and after the interventions and assessed the proportion of each meal that was wasted.	The proportion of food wasted in the canteens from rice and noodle meals reduced from 52%, before the interventions, to 33%, after the interventions, and the proportion of food wasted from meat-based meals reduced from 18.6% to 8.8%. The proportion of those who finished all of their food rose from 11% to 20%.
Whitehair et al. (2013)	**Setting**: US University canteen **Sample size:** 540	To assess the effectiveness of using educational materials and group feedback to reduce FW in University canteens.	Prompt posters telling people to reduce waste, as well as posters providing feedback on how much food has been wasted and how figures have changed were placed by the menu board, the tray dispenser, serving lines and dish return areas to try to reduce FW. The interventions were tested on the students over the course of 6 weeks (2-week baseline, 2 weeks informative posters, 2 weeks feedback posters).	The interventions resulted in a 15% reduction in overall FW.
Ellison et al. (2019)	**Setting**: US University canteens **Sample size:** ~2125	To assess the effectiveness of using educational information and group feedback to reduce FW in University canteens.	Educational and feedback visual prompt interventions were used to see how much FW reduced in daily grams of waste per student.	The interventions only reduced FW on site by around 4%.

Paper	Setting and sample size	Aim	Methods	Findings
Infrastructural interventions and FW reduction				
Wansak and Van Ittersum, 2013	**Setting**: US restaurants **Sample size:** 43 meals	To assess the effectiveness of reducing plate sizes to reduce FW in restaurants.	Different sized plates were used at 4 self-serving all you can eat Chinese restaurants in New York and Pennsylvania. The study included 43 meals, of which 18 were served on small plates, and 25 used large plates.	With the larger plates, people served on average, 52% more food, ate 45% more, and wasted 135% more, when compared to using smaller plates in the studied restaurants.
Arramark, 2008	**Setting**: US University canteens **Sample size:** 186,000 meals	To assess the effectiveness of removing trays to reduce FW in University canteens.	Trays were removed from University canteens on certain days to try to reduce FW. The study was conducted throughout USA in Aramark run canteens. They measured FW from 25 institutions during different periods over the academic year, collecting FW data per person (ounces per person) and compared measurements on days with trays.	There was a FW reduction of between 25 and 30% on days where the studied cafeterias went trayless. This worked, due to the fact that customers could only eat what they could carry, so they reduced their portion sizes and overbuying thus decreased.
Leverenz et al. 2021	**Setting**: German hotel canteens **Sample size:** 4 canteens	To assess the effectiveness of estimating end of service food surpluses to reduce FW from preparing too much food.	The hotel canteens introduced self-reporting on quantities of food leftover at the end of service. They developed a FW tracking system, which was operated by staff members of the studied kitchens over the course of a year. Self-reporting led to an improvement in operational kitchen processes such as refilling the buffet more carefully, based on expected food demand.	Improved estimation on food demand led to a reduction in surplus food remaining at the end of the day by almost 65%.
Schwartz et al., 2015	**Setting**: US school canteens **Sample size:** 12 school canteens, ~5400 students	To assess the effectiveness of standardizing menus in order to reduce FW.	Daily consumption and FW was assessed at 12 school canteens. The selection and consumption of four food items (fruit, vegetables, starters, and milk) was assessed before and after USDA regulation updates were implemented to school lunches, improving food quality and standards.	A 3-28% reduction in FW was observed after menu standardization was introduced, with reduction dependent on food type (vegetables: 28%, Starters: 15%, milk: 5%, fruit: 3%,)
Papargyropoulou et al. 2019	**Setting**: Malaysian canteens and restaurants **Sample size:** 5 canteens and restaurants ~7540 customers/day	To assess the impact of canteen type on FW generation per customer.	Per capita FW generation was compared in 5 different style restaurants/canteens. FW generation included preparation waste, plate scrapings and surplus leftover food. Total FW was divided by average consumers over the studied period to estimate FW per customer.	Canteen style impacted FW generation levels, with self-service buffets generating around three and 8.5 times more FW per customer than set meals with table service, and counter served pay as you eat food halls respectively.
Studies assessing a combination of infrastructural and awareness interventions				
Ahmed et al. (2018)	**Setting**: US University canteens **Sample size** Interventions ~4,500 Survey 249	To assess the effectiveness of using educational information, reduced portion and utensil	Portion sizes were reduced by at least 25%, smaller utensils were introduced, and posters were also displayed giving group feedback on FW quantities wasted and educational information on the problems related to FW to try to reduce FW. Data on total pre-consumer FW and post-	FW was reduced by around 17% as a result of the interventions at the University canteens in the US. They also found that the vast majority of students found the interventions either 'very effective' (34%), or 'effective' (50%).

		size to reduce FW in University canteens.	consumer plate-waste was collected before and after the food waste interventions. A survey was handed out to students in the canteen asking about the effectiveness of the interventions.	
Kallbekken and Saelen, 2013	**Setting**: US buffet restaurants **Sample size:** 52 hotels 38 hotels control group 7 hotels reduced plate sizes 7 had a salient sign	To assess the effectiveness of reducing plate sizes and introducing a salient sign to reduce FW in restaurants.	Reduced plate sizes and salient signs were introduced in all you can eat buffets in different hotels to reduce FW. 52 hotels took part in the study. 38 hotels acted as the control group, with 7 introducing reduced plate sizes, and 7 using a salient sign saying that customers could return for more food as much as they liked.	Reducing plate size, reduced FW by 19.5% and having the salient sign reduced waste by 20.5% over the course of the study.

Paper	Setting	Aim	Methods	Findings
FW segregation studies in households				
Geislar (2017)	**Setting** US households **Sample size:** 370	To assess the effectiveness of using informative emails, fridge magnets and stickers to increase FW recycling in households.	FW related information were given to participants in the form of fridge magnets and stickers as printed interventions. They assessed the decline of participation in FW recycling over the course of 6 months.	Participants given group feedback were half as likely to stop recycling their FW when compared to the control group and were more likely to continue recycling their FW.
Bernstad et al., (2013)	**Setting**: UK households **Sample size:** 680 apartments Written information 420 Oral information 210 Control 50	To assess the effectiveness of providing written and oral information to increase FW recycling in households.	Written and oral information was used to increase FW segregation in households. FW segregation was assessed in 680 participating households. 420 apartments received written and oral information through doorstopping, 210 received written information, and 50 apartments formed the control group.	The apartments that received oral and written information performed better than the control group, whereas the apartments that only received the written information did not perform significantly better than the control group.
Burn (1991)	**Setting** US households. **Sample size:** ~200 homes	To assess the effectiveness of providing information and using block leaders to increase FW recycling in households.	Information was provided and block leaders (members from within the household's social circle) were used in US households to increase FW recycling. Household segregation rates were compared over the course of 12 weeks in houses that received information, ones that used block leaders and a control group.	Providing information improved waste recycling. With information provision there was a segregation rate of 12% over 12 weeks, which was 9% higher than the control (3%). They also found that the use of block leaders, had a much greater effect than information, resulting in a recycling rate of 28%, compared to 10% with information provision.
Hopper & Nielsen (1991)	**Setting**: US Households **Sample size:** 200 households	To assess the effectiveness of using information, reminders and a block leader to increase FW recycling in households.	Information, a bi-weekly email reminder and block leaders (members from within the household's social circle) were used to increase the rate of recycling in households. Rates of recycling were assessed over the course of 7 months.	Using a block leader increased the rate of recycling much more effectively than both the reminder and provision.
Cobern et al. (1995)	**Setting**: US households **Sample size:** 558 households	To assess the effectiveness of public commitment making to increase FW recycling in households.	Public commitment making with and without the involvement of block leaders was carried out to try to increase FW recycling in households. Recycling rates were assessed over the course of 4 weeks. Some houses formed the control group, some made recycling commitments, and some made a recycling commitment whilst also having a block leader.	Commitment making did improve recycling, however, the group that had made a commitment and also had a block leader performed the best.
Shearer et al. (2016)	**Setting**: UK Households **Sample size:** 64,136 households Control group 30,568 households Test group 33,568 households	To assess the effectiveness of using informative stickers to increase FW recycling in households.	Informative stickers were used in households to prompt increased FW segregation. Baseline data was collected on recycling rates in households in 2 local authorities in S.E. England for 15 weeks, and experimental data was collected for a 16-week period.	Sticker prompts increased FW segregation by 21%.

Lin et al. (2016)	**Setting**: Chinese households **Sample size:** 30 apartments Control group 13 blocks Test group 17 blocks	To assess the effectiveness of introducing FW bins with bright lids and positive patterns as well as volunteer waste reps to increase FW recycling in households.	FW bins with bright lids and positive and eye-catching patterns (sunflowers), as well as volunteer waste reps were introduced to increase FW segregation in apartment blocks. They assessed baseline figures for FW segregation between 2011 and 2015. They then compared the baseline FW segregation figures to the control group, the sunflower bin group and the FW volunteer reps group (present by the bins encouraging segregation).	Compared to the baseline, the control group showed a 7% improvement, the sunflower bin group showed a 32% improvement and the volunteer rep group showed a 44% improvement.
Li et al. (2017)	**Setting**: Chinese households **Sample size:** 23,000 households	To assess the effectiveness of incentivisation FW to increase FW recycling in households.	Incentivisation was used to increase FW segregation in households. Segregating FW gained residents points, which could be exchanged for eggs. FW segregation levels in households were assessed, over a 22-month period.	After 22 months there was a 32% participation rate and 30% food capture rate. Initially incentives were the key motivation, but habitual reinforcement was deemed the key motivation after 22 months.
FW segregation studies in University Halls of residences				
Caraza, 2018	**Setting**: the UK University Halls of residence, UK **Sample size:** Survey 82 Interventions 5 flats	To understand FW related behavior in UK residences and effect of stickers and information on FW segregation rates.	A survey was carried out in a UK halls of residence in person and online asking questions related to FW awareness, related attitudes as well as FW prevention and segregation behaviours. A FW segregation study was also carried out looking at weekly FW recycled in flats for 2 weeks before and after 3 weeks after putting instructive stickers on bins and providing information on FW.	When asked about environmental concerns, climate change was considered to be the most important, with FW ranked 4th, behind air pollution and deforestation, but ahead of overfishing. They also stated, when asked, that the main reasons why they wasted food was due to food spoilage (49%) and overbuying items (24%). The most common strategy to reduce FW was to 'freeze items for longer durability' (86.6%), followed by 'checking stock levels before buying food' (75.6%), followed by 'eating leftovers (74.4%). The FW recycling study found that an average of 5.2Kg of FW was segregated per week in each flat. However, FW segregation did not notably change after the interventions were introduced.
Wood, 2019	**Setting**: the UK University Halls of residence, UK **Sample size:** Survey 31 FW segregation, ~350	To understand FW recycling behavior in UK residences and uptake of opt-In FW segregation rates.	An online survey was sent out to all residents at the halls of residences. Flats were contacted to opt in to segregate and recycle their FW in their residences.	94% of students surveyed would be willing to segregate FW. The primary drivers for students segregating FW, as shown in figure 9b, are environmental factors (69%), with waste reduction also being a common reason for segregation (24%). Major issues with segregating FW were hygiene concerns and bin odour, as well as not knowing where to empty the bin, or finding it too labourious emptying the bin. The study found that FW segregation resulted in around 2 tonnes of FW being recycled over the course of a year.

Appendix B

Appendix B1: LCA assumptions

	the UK University	Indian institute A	Indian institute B	Chinese University	Sources
Construction					
Construction components for technologies	Variable	Variable	Variable	Variable	Based on supplier quotes for desiccation, AD and composting. Based on Roy et al., 2020 for HTC
Kg CO_2/kg material component	Based on GaBi professional database	Based on GaBi professional database	Based on GaBi professional database	Based on GaBi professional database	GaBi professional database
Transport					
Average BAU Transport distances (km)	51.1	14.9	0	33.1	Preliminary assessment
Landfilling transport distances (km)	18.5	17.9	15.7	179.5	Preliminary assessment
Transport emissions	Based on GaBi professional database	Based on GaBi professional database	Based on GaBi professional database	Based on GaBi professional database	GaBi professional database
Heat and energy					
Natural gas (kg CO_2/kWh)	0.185	0.185	0.185	0.185	Carbon Independent, 2022
Grid energy (kg CO_2/kWh)	0.168	0.7072	0.7072	0.58	IEA, 2020; IEA, 2020b
2040 Grid energy (kg CO_2/kWh)	0.0636	0.30876352	0.30876352	0.2726	Statista, 2022; IEA, 2022; IEA, 2020; Song et al., 2022;
Fertilisers and soil amendment					
Kg CO_2/kgN	3.5	5.7	5.7	7.606	Kongshang, 1998
Kg CO_2/kg peat	830.52	830.52	830.52	830.52	Roy et al., 2020
Animal feed					
Kg CO_2/kg feed	1.1	1.1	1.1	1.1	Salemdeeb et al., 2017; Eriksson et al. 2015; Nemecek et al., 2014; Ecoinvent
Atmospheric emissions					
Kg CO_2/kgCH4	28	28	28	28	IPCC, 2014
Kg CO_2/kgN2O	298	298	298	298	IPCC, 2014
Food waste					
Kg CO_2/kg FW	1.98	1.98	1.98	1.98	EC, 2010
Boiler conversion efficiencies					

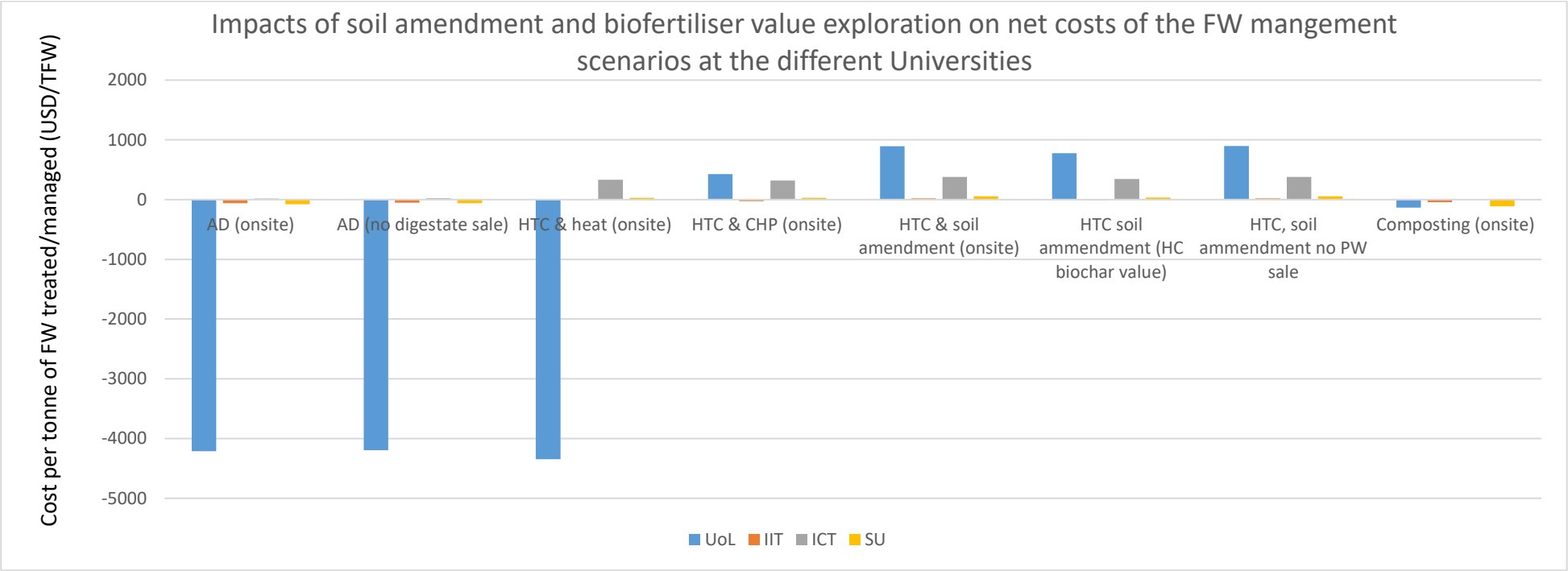
Biomass boiler heat (%)	83	83	83	83	Supplier quotes
Biomass boiler CHP heat/energy (%)	65/15	65/15	65/15	65/15	Supplier quotes
AD CHP heat/energy (%)	55/30	55/30	55/30	55/30	Supplier quotes
Other AD assumptions					
Heat parasitic load (%)	19	19	19	19	Supplier quotes
Energy parasitic load (%)	20	20	20	20	Supplier quotes
Methane content in biogas (%)	70	70	70	70	Supplier quotes
Methane calorific value (Kwh/m^3)	9.8	9.8	9.8	9.8	Forest Research, 2022

Appendix table B2. LCC assumptions

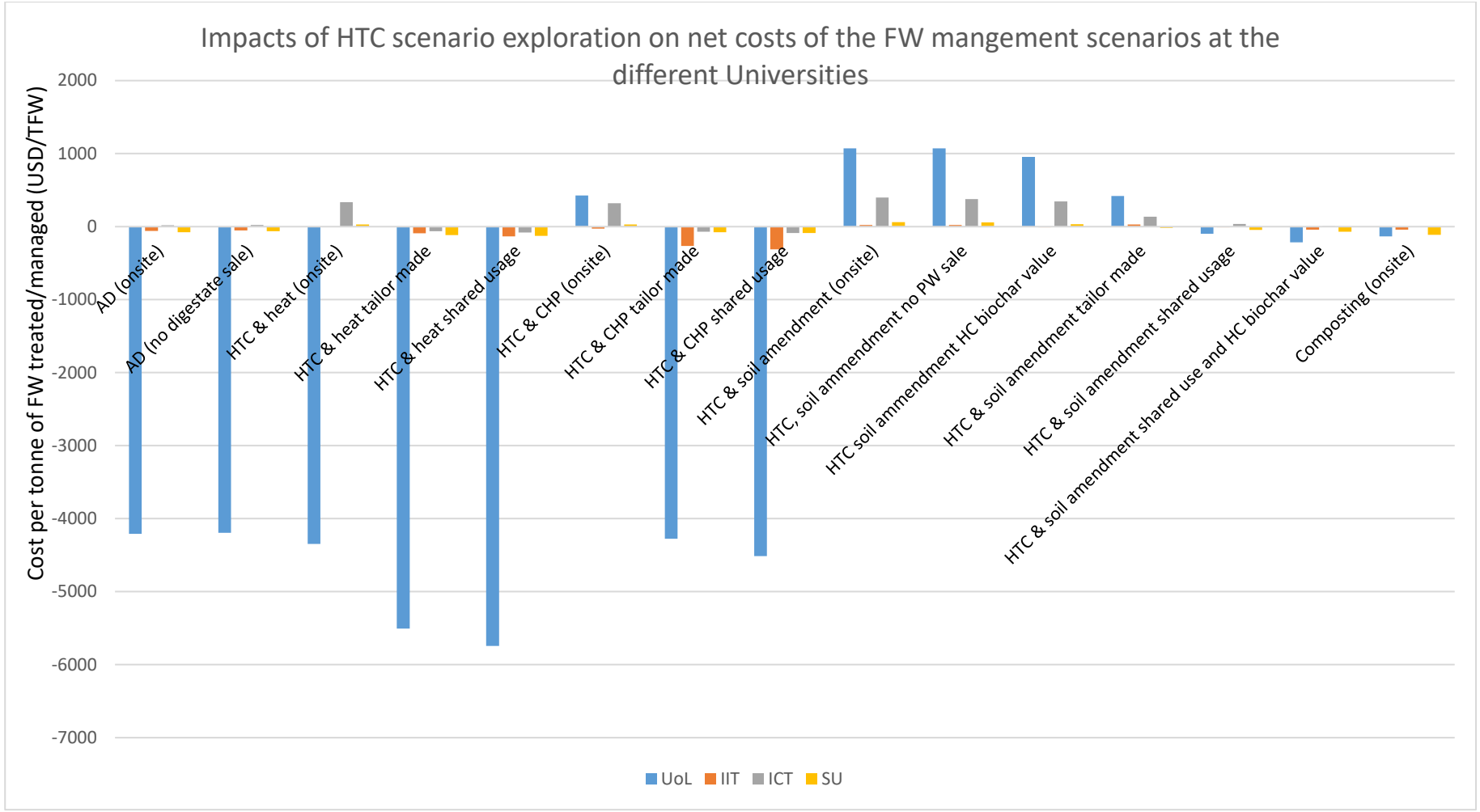
	the UK University	Indian institute A	Indian institute B	Chinese University	Sources
Exchange rates (local currency to dollar)	1.25 GBP	0.01	0.01	0.15	XE, 2022 (exchange rates from 19/05/2022)
FW reduction					
FW reduction materials (USD/100 students)	13.9	3.39	3.39	N/A	Cost payed
Extra staff requirements (Full time staff & proportion extra servers)	0	102 (+44%)	444 (+44%)	N/A	Data from case studies
FW saving per tonne	13120	131.4	117.2	N/A	WRAP, 2013 (UK); Argarwarl et al., 2021 (India)
FW recycling					
Initial cost (USD/student assuming 1 bin between 5 students)	0.83	N/A	N/A	N/A	Supplier quote
FW recycling intervention cost (USD/student)	2.78	N/A	N/A	N/A	Cost payed
Cost saving per tonne	115.37	N/A	N/A	N/A	From contract
Desiccation					
System cost (USD) desiccator only/inc pelletiser & biomass boiler	46844.5/ 51661.9	176882.3 /180965. 5	16080.2/ 2044.1	42850.6/ 44894.7	Supplier quote
Energy requirements (kWh/year) desiccation & BAU/energy/animal feed	80037.2/ 80460.8	931000/ 934491.3	52290/ 52445.6	219000/ 219488.4	Supplier quote
Anaerobic digestion					
System cost	176943. 4	82575	18390.7	34460.2	Supplier quote
Staff requirements (hrs labour)	300	3300	300	900	Supplier quote
Composting cost					
System cost	26626.6	155139.5	0	63643.8	Supplier quote
Staff requirements	912.5	11406.3	228.1	2737.5	Supplier quote
Energy requirements (kWh/year)	13	147.1	4.3	35.2	Supplier quote
HTC cost					
System cost (USD) HTC only/inc AD & biomass boiler	157068. 6/27008 9.6	131492.6 /216475. 3	131492.6 /150251. 8	118759.2 /154656. 8	
Staff requirements	11732.1/ 11732.1	11732.1/ 11732.1	11732.1/ 11732.1	11732.1/ 11732.1	
Energy requirements (kWh/year) soil amendment scenario	44243.7	504260.6	22477.8	112008.8	
Landfill cost (USD/tonne FW)	N/A	14.2	N/A	N/A	Hanrahan et al., 2006
Fertilisers and soil amendment	0	0	0	0	
USD/kgN synthetic fertilizer	345.9	210	210	358.8	ADHB, 2022; LARRDIS, 2021; CEIC, 2022
USD/kg peat-based compost	126	47.1	47.1	120.5	QGS, 2022 (UK); Huang, 2015 (India); supplier quote (China)

Animal feed					
USD/kg feed	133.1	23.6	23.6	90.5	Supplier quotes
Heat and energy costs					
Grid electricity (USD/kWh)	0.24	0.16	0.16	0.09	Ofgen, 2022, PPAC, 2022, CEIC, 2022
Natural gas cost (USD/kWh)	9.92	0.02	0.02	0.05	Ofgen, 2022, IEX, 2022, CEIC, 2022
Staff costs (USD/hr)	14.4	0.8	0.8	2	Paycheck, 2022 (India), supplier quotes (UK &China)
Annual maintenance cost (% of initial investment)	5%	5%	5%	5%	

Appendix table B3. LCC exploration of soil amendment values



Appendix table B4: LCC scenario exploration of HTC



Appendix C

Appendix C1: Food waste decision-making tool survey

2 How useful would you find the following results in a Food waste management decision-making tool ? **在食物垃圾管理决策工具中，以下几**项考量因素，您认为有多大用处?

- Environmental: Greenhouse gas reduction over lifecycle (tonne CO2eq over 20 year lifecycle) 环境方面：生命周期内温室气体减排量（20 **年生命周期内二氧化碳减排量，以吨**计）
- Environmental: Greenhouse gas reduction annually (tonne CO2eq annual) 环境方面：年度温室气体减排量（一个年度内二氧化碳减排量，以吨计）
- Economic: Cost reduction over lifecycle (£ reduction over 20 year lifecycle, compared to business as usual) 经济方面：生命周期内成本缩减金额（20 **年生命周期内少花**费的资金数额，以英镑计，相比常规业务方式）
- Economic: Payback time (years to pay off initial cost of initial investment through annual savings) 经济方面：回本时间（年度节省金额累计等于初始投入金额所需要的年数）
- Economic: Initial cost (£ initial investment cost for purchasing treatment technology/management strategy components) 经济方面：初始成本（购买处理技术或管理策略组件的初始投入金额，以英镑计）
- Environmental and economic: Cheapest greenhouse gas reduction over lifecycle (tonne CO2eq mitigated/£ cost increase over 20 year lifecycle) 环境和经济两方面：生命周期内最低成本温室气体减排量（20 **年生命周期内二氧化碳减排量**（**以吨**计）**/累**计成本金额（以英镑计））
- Environmental and economic: Cheapest greenhouse gas reduction (tonne CO2eq mitigated/£ initial investment cost) 环境和经济两方面：最低成本温室气体减排量（二氧化碳减排量（以吨计）**/初始投入成本**（**以英**镑计））

3 How useful would you find the following advice and considerations would be useful? **以下建**议和考量，您认为有多大用处？

- Steps/information to proceed: List of suppliers in the country and contact details **措施/信息**：**全国供**应商及联系方式清单
- Steps/information to proceed: Components required for strategy change (materials, technological components etc) **措施/信息**：**策略**调整所需的组件（材料，技术组件等）
- Steps/information to proceed: Approximate prices for components **措施/信息**：组件估价
- Steps/information to proceed: Labour and maintenance requirements (staff hours and approximate wages, annual maintenance costs etc) **措施/信息**：**人力及**维护要求（工时和估算工资，年度维护成本等）
- Steps/information to proceed: Expected required inputs (i.e. energy requirements, and any other materials) and outputs (energy outputs, soil amendment products etc) **措施/信息**：预计所需投入（例如：能源需求及其他材料）和产出（能量输出，土壤改良产品等）
- Steps/information to proceed: Uses for the outputs (description of applications, quality levels, and market cost etc where appropriate) **措施/信息**：产出的使用（应用、质量等级及市场成本等适当信息描述）

- Steps/information to proceed: Policy implications (requirements, subsidies, grants available etc) **措施/信息：政策影响（要求、**补贴、补助等）
- Key considerations (risks and opportunities): Potential future developments in waste management in the country (policy changes such as targets, regulations, subsidies, grants and taxes) **重要考量**（风险与机会）：全国垃圾管理行业的发展前景（政策调整，如目标、规则、补贴、补助和税负）
- Key considerations (list and explanation of risks and opportunities): Potential risks related to specific waste management changes (Specific technological, or practical risks and concerns related to technologies and waste management strategies) **重要考量**（风险与机会列举和说明）：与特定垃圾管理变革相关的潜在风险（与技术和垃圾管理策略相关的特定技术风险、现实风险及忧虑）
- Key considerations (risks and opportunities): Likelihood of such technology/strategy specific issues developing **重要考量**（风险与机会）：上述技术**/策略特定**问题继续发展的可能性
- Key considerations (risks and opportunities): Scale of technology/strategy issue (extra costs £, or GHG emissions tonne CO2eq) **重要考量**（风险与机会）：技术**/策略**问题规模（额外成本（以英镑计），或温室气体排放量（二氧化碳，以吨计））

p. 3 p. 3

4 How useful would it be to have the data to conveyed in the following ways concerning optimising food waste management at the University? **按照以下**优化大学校园食物垃圾管理相关的方式传递数据，有多大用处？

- Specific information: Yes, or no responses to options (i.e. Yes this would reduce greenhouse gas emissions, and/or reduce costs, or no this would not reduce greenhouse gas emissions and/or costs) **特定信息：是的，或者各**项都不选（例如：是的，这样可以减少温室气体**排放，和/或**缩减成本；或者，不，这样无法减少温室气体排放，和**/或**缩减成本）
- Specific information: Ranking options, based on criteria (i.e. 1. Composting on site, 2. Anaerobic digestion on site…….10. landfilling offsite) **特定信息：基于**标准进行选项排序（例如：1. **就地堆肥，** 2. **就地**厌氧发酵……10. **异地填埋**）
- Specific information: Score for each option (i.e. score out of 100 based on greenhouse gas reductions, cost reduction, or combined environmental and economic benefits) **特定信息：逐**项赋分（例如：按照百分制对温室气体减排量、成本缩减量，或者综合环境和经济利益，进行打分）
- Specific information: Figures/graphs illustrating greenhouse gas emissions, economic considerations (savings against initial costs) etc **特定信息：温室气体排放、**经济代价解释图表（节约金额对比初始成本）等
- Specific information: Specific figures (i.e. kgCO2eq reduction/kg food waste, payback time etc) **特定信息：特定**图表（例如：二氧化碳减排量（以千克计）**/食物垃圾量（以千克**计），回本时间等）

p. 4 p. 4

5 Which of the following food waste generation and composition information would it be possible for you to provide? **以下有关食物垃圾**产生和堆肥信息，您可能提供哪些？

- Food waste generation levels: Total generation (tonnes of food waste per year at University) **食物垃圾**产生等级：产生总量（大学校园每年产生的食物垃圾量，以吨计）

- Food waste generation levels: Seasonality (monthly generation of food waste in tonnes of food waste per month) **食物垃圾**产生等级：季节性产生量（**食物垃圾每月**产生量，以吨计）
- Food waste generation sources: Tonnes/year, or percentage food waste from catering **食物垃圾**产生来源：餐饮来源食物垃圾每年产生量（以吨计），或者所占百分比
- Food waste generation sources: Tonnes/year, or percentage from self-catered residences/students **食物垃圾**产生来源： **居家**户**/学生自炊造成的食物垃圾每年**产生量（以吨计），或者所占百分比
- Food waste generation sources: Tonnes/year, or percentage from other sources **食物垃圾**产生来源：其他来源的食物垃圾每年产生量（以吨计），或者所占百分比
- Food waste generation sources: If applicable, specify the other sources **食物垃圾**产生来源：如有可能，请对其他来源进行详细说明
- Food waste composition, Typical values for: Moisture content of food waste **食物垃圾堆肥**，**典型**值：食物垃圾中的水分含量
- Food waste composition, Typical values for: Carbon, hydrogen, nitrogen and oxygen content of food waste (figures in %, or g/kg) **食物垃圾堆肥**，**典型**值：食物垃圾中的碳、氢、氮和氧的含量（百分比，或每千克含量（g/kg））
- Food waste composition, Typical values for: Higher heating values, or other calorific value (i.e. higher heating value (HHV), or lower heating value (LHV) **食物垃圾堆肥**，**典型**值：高位热值，或其他热值（例如：高位热值 (HHV)，**或低位**热值 (LHV)）
- None of the above **以上都不是**

a Please elaborate on your answer. Which information would be easy to gain, which would be difficult? Which information could you provide partially and what would this entail? 请详细说明您的答案。哪些信息容易获取，哪些不易获取？您可以部分提供哪些信息，前提条件是什么？

6 Which of the following information on food waste treatment would it be possible for you to provide? **以下有关食物垃圾**处置的信息，您可能提供哪些？

- Business as usual strategy: Current general waste treatment costs (collection cost/tonne of general waste If waste is collected) **常**规业务策略：目前普通垃圾处置一般成本（每吨普通垃圾收集成本）
- Business as usual strategy: General waste treatment technology (i.e. landfilling, or incineration) **常**规业务策略：普通垃圾处置技术（例如：填埋或焚烧）
- Business as usual strategy: general waste Onsite, or offsite treatment **常**规业务策略：普通垃圾就地处置或异地处置现况
- Business as usual strategy: general waste distance to treatment facility (i.e. km from university to treatment site) **常**规业务策略：普通垃圾距离处置设施的距离（例如：大学校园至处置地点距离，以千米计）

- Business as usual strategy: general waste transport method (i.e. diesel truck, electric powered train etc) **常**规业务策略：普通垃圾运送方式（例如：柴油卡车，电**力机**车等）
- Business as usual strategy: Current food waste treatment costs (collection cost/tonne of food waste, if waste is collected) **当前的食物垃圾**处置成本（每吨食物垃圾收集成本）
- Business as usual strategy: Current food waste treatment technology (i.e. composting, or incineration) **当前的食物垃圾**处置技术（例如：堆肥或焚烧）
- Business as usual strategy: Current food waste treatment Onsite, or offsite treatment **常**规业务策略：食物垃圾就地处置或异地处置现况
- Business as usual strategy: Current food waste treatment Distance to treatment facility (i.e. km from university to treatment site) **常**规业务策略：目前，食物垃圾距离处置设施的距离（例如：大学校园至处置地点距离，以千米计）
- Business as usual strategy: Current food waste treatment Transport method (i.e. diesel truck, electric powered train etc) **常**规业务策略：当前的食物垃圾运送方式（例如：柴油卡车，电动机车等）
- Technological feasibility: Space requirements (dimensions any treatment site would need to fit into) **技**术可行性：空间要求（处置地点标定适宜尺寸）
- Technological feasibility: Cost requirements (maximum initial cost, maximum payback time etc) **技**术可行性：成本要求（初始成本上限，最长回本时间等）
- Technological feasibility: Any other feasibility constraints **技**术可行性：其他可行性约束
- None of the above **以上都不是**

a Please elaborate on your answer. Which information would be easy to gain, which would be difficult? Which information could you provide partially and what would this entail? 请详细说明您的答案。哪些信息容易获取，哪些不易获取？您可以部分提供哪些信息，必要条件是什么？

7 Which of the following information on canteens and catering would it be possible for you to provide? **以下有关食堂和餐**饮服务的信息，您可能提供哪些？

- Meal type (i.e. all you can eat buffet, Set meals, Flexible build your own food) **餐食**类型（例如：自助餐、套餐、自制食物等一切可食用的餐食）
- Payment type (i.e. pre-paid, or pay as you go) **付款**类型（例如：先付费后用餐，或者先用餐后付费）
- Rough contributions to food waste by stage: Food preparation waste in kitchens (tonnes/year, or percentage of total food waste) **各**阶段食物垃圾产生量：厨房备餐阶段产生的垃圾（每年产生量，以吨计，或者占食物垃圾总量的百分比）

- Rough contributions to food waste by stage: Surplus unserved food left at the end of service (tonnes/year, or percentage of total food waste) **各**阶段食物垃圾产生量：服务结束后剩余的食物（每年产生量，以吨计，或者占食物垃圾总量的百分比）
- Rough contributions to food waste by stage: Plate scrapings from food customers took, but didn't finish (tonnes/year, or percentage of total food waste) **各**阶段食物垃圾产生量：顾客取餐后盘中剩余的最终未食用的食物（每年产生量，以吨计，或者占食物垃圾总量的百分比）
- Charity surplus food donation: Does the canteen send surplus food to charity? (yes, or no) 过剩食物慈善捐赠：食堂会将过剩的食物捐给慈善机构吗？（是或否）
- Charity surplus food donation: If yes, how much (tonnes/year, or percentage of total food waste) 过剩食物慈善捐赠：如答案为是，请说明数量（吨每年，或者占食物垃圾总量的百分比）
- Charity surplus food donation: If not, would it be possible to start? 过剩食物慈善捐赠：如答案为否，那么可否开始这么做？
- None of the above **以上都不是**

a Please elaborate on your answer. Which information would be easy to gain, which would be difficult? Which information could you provide partially and what would this entail? 请详细说明您的答案。哪些信息容易获取，哪些不易获取？您可以部分提供哪些信息，这需要什么？

8 Which of the following information on self-catered food waste management would it be possible for you to provide? **以下有关自炊食物垃圾**处置的信息，您可能提供哪些？

- Self-catered residences: Are there self-catered residences, at the university? (yes, or no) **自炊居家**户：大学校园内有自炊居家户吗？（有或没有）
- Self-catered residences: If so, how many? (number of residences/proportion of residences) **自炊居家**户：如有，有多少？（自炊居家户数量，或占居家户总数的比例）
- Self-catered students: Are there self-catered students at the University? (yes, or no) **自炊学生：大学校园内有自炊的学生**吗？（有或没有）
- Self-catered students: If so, how many self-catered residents are there? (number of students/proportion of total students at the university) **自炊学生：如有，有多少？（大学校园内的自炊学生数量，或占学生**总数比例）
- Self-catered students: If so, what is the recycling rate for students (proportion of self-catered students, or flats that recycle their food waste) **自炊学生：如有，循**环利用食物垃圾的学生比例有多少（在自炊学生中占比，或回收食物垃圾的公寓占比）
- Self-catered recycling: If there is a food waste recycling strategy for self-catered students, what is the current recycling strategy (optional opt-in, optional opt-out, compulsory, other) **自炊食物垃圾再利用：如果制定了自炊学生食物垃圾再利用策略**，则现行的是何种策略（自愿参加，自愿退出，强制参加，其他）

- Self-catered recycling: If there is not a food waste recycling strategy for self-catered students, what would be the feasibility to have FW recycling (possible easy, possible difficult, not possible/unviable) **自炊食物垃圾再利用：如未制定自炊学生食物垃圾再利用策略，那么**实行食物垃圾再利用的可能性如何（可能较容易，可能较困难，不可能）
- None of the above **以上都不是**

a Please elaborate on your answer. Which information would be easy to gain, which would be difficult? Which information could you provide partially and what would this entail? 请详细说明您的答案。哪些信息容易获取，哪些不易获取？您可以部分提供哪些信息，必要条件是什么？

p. 5 Socio-Demographics 社会人口统计信息

9 What country are you based in? **您目前在哪个国家？**

- UK **英国**
- India **印度**
- China **中国**

10 Which of the following fields are you involved in? **您从事以下哪**项领域相关的工作？

- Catering services **餐**饮服务
- Residential services **居住区服**务
- Sustainability services 资源循环利用服务
- Other **其他**

a If you selected Other, please specify: **如果您**选择了"**其他**"，请具体说明：

Appendix C2: Decision-making tool interview questions

Questions and prompts

Desired decision-making tool outcomes

1) What kind of information would be useful for the decision-making tool to provide and why?

Would you be interested in knowing what food waste management options would bring about the most environmental benefits (i.e. CO_2 savings over 20 years), the most economic benefits (i.e. biggest cost savings over 20 years), or the greatest mix of environmental and economic benefits (cheapest CO_2 reduction over 20 years)?

Which would you be most interested in and why?

Desired advice and considerations offered by the decision-making tool

2) What kind of advice and considerations would be useful for the decision-making tool to provide and why? Would you be interested in steps on how to proceed, such as a list of suppliers, components and requirements to implement the desired food waste management strategy, or a detailing and assessment of the potential risks and opportunities associated with the food waste management strategy, such as possible policy and market changes, what may potentially go wrong with the strategy such as problems with onsite treatment technology?

Which would you be most interested in and why?

Desired format of decision-making tool outcomes

3) What kind of format would you like the results/information to be presented and why? Would you prefer to have a specific yes or no answer on whether a strategy should be adopted, a ranking of the options in order of best to worst (depending on environmental and/or economic credentials), scores out of 100 based on environmental and/or economic credentials, specific data on precise CO_2 reductions, or economic payback time etc, or a visualisation of the specific data? Alternatively, would it be most helpful to have options ranked, with the possibility to expand further upon this and find out specific data on GHG reductions, and cost reductions over time?

4. Information possible to provide

1) Which of the following food waste generation and composition information would it be difficult, or not possible for you to provide and why?

- Food waste generation levels: Total generation (tonnes of food waste per year at University)
- Food waste generation levels: Seasonality (monthly generation of food waste in tonnes of food waste per month)
- Food waste generation sources: Tonnes/year, or percentage food waste from catering
- Food waste generation sources: Tonnes/year, or percentage from self-catered residences/students
- Food waste generation sources: Tonnes/year, or percentage from other sources
- Food waste generation sources: If applicable, specify the other sources
- Food waste composition, Typical values for: Moisture content of food waste
- Food waste composition, Typical values for: Carbon, hydrogen, nitrogen and oxygen content of food waste (figures in %, or g/kg)
- Food waste composition, Typical values for: Higher heating values, or other calorific value (i.e. higher heating value (HHV), or lower heating value (LHV)

2) Which of the following information on food waste treatment would it be it be difficult, or not possible for you to provide and why?

- Business as usual strategy: Current general waste treatment costs (collection cost/tonne of general waste If waste is collected)

- Business as usual strategy: General waste treatment technology (i.e. landfilling, or incineration)
- Business as usual strategy: general waste onsite, or offsite treatment
- Business as usual strategy: general waste distance to treatment facility (i.e. km from university to treatment site)
- Business as usual strategy: general waste transport method (i.e. diesel truck, electric powered train etc)
- Business as usual strategy: Current food waste treatment costs (collection cost/tonne of food waste, if waste is collected)
- Business as usual strategy: Current food waste treatment technology (i.e. composting, or incineration)
- Business as usual strategy: Current food waste treatment Onsite, or offsite treatment
- Business as usual strategy: Current food waste treatment Distance to treatment facility (i.e. km from university to treatment site)
- Business as usual strategy: Current food waste treatment Transport method (i.e. diesel truck, electric powered train etc)
- Technological feasibility: Space requirements (dimensions any treatment site would need to fit into)
- Technological feasibility: Cost requirements (maximum initial cost, maximum payback time etc)
- Technological feasibility: Any other feasibility constraints

3) **Which of the following information on canteens and catering would it be it be difficult, or not possible for you to provide?**

- Meal type (i.e. all you can eat buffet, Set meals, Flexible build your own food)
- Payment type (i.e. pre-paid, or pay as you go)
- Rough contributions to food waste by stage: Food preparation waste in kitchens (tonnes/year, or percentage of total food waste)
- Rough contributions to food waste by stage: Surplus unserved food left at the end of service (tonnes/year, or percentage of total food waste)
- Rough contributions to food waste by stage: Plate scrapings from food customers took, but didn't finish (tonnes/year, or percentage of total food waste)
- Charity surplus food donation: Does the canteen send surplus food to charity? (yes, or no)
- Charity surplus food donation: If yes, how much (tonnes/year, or percentage of total food waste)
- Charity surplus food donation: If not, would it be possible to start?

4) **Which of the following information on self-catered food waste management would it be it be it be difficult, or not possible for you to provide?**

- Self-catered residences: Are there self-catered residences, at the university? (yes, or no)
- Self-catered residences: If so, how many? (number of residences/proportion of residences)
- Self-catered students: Are there self-catered students at the University? (yes, or no)
- Self-catered students: If so, how many self-catered residents are there? (number of students/proportion of total students at the university)
- Self-catered students: If so, what is the recycling rate for students (proportion of self-catered students, or flats that recycle their food waste)
- Self-catered recycling: If there is a food waste recycling strategy for self-catered students, what is the current recycling strategy (optional opt-in, optional opt-out, compulsory, other)
- Self-catered recycling: If there is not a food waste recycling strategy for self-catered students, what would be the feasibility to have FW recycling (possible easy, possible difficult, not possible/unviable)

<u>Additional comments</u>

1) Is there anything else anyone else would like to add about anything that we discussed, or that didn't come up, but you think may be relevant concerning the creation of the decision-making tool?

Appendix C3: Decision-making tool input questions proposed

University location

1. Which country is the University based in? _____.
2. What state, or province is the University based in?_____.

FW generation

1. What is the approximate annual food waste generation across your university? _____Tonnes
2. If known, what is the monthly food waste generation across your university?
    a. January _____Tonnes
    b. February _____Tonnes
    c. March _____Tonnes
    d. April _____Tonnes
    e. May _____Tonnes
    f. June _____Tonnes
    g. July _____Tonnes
    h. August _____Tonnes
    i. September _____Tonnes
    j. October _____Tonnes
    k. November _____Tonnes
    l. December _____Tonnes
3. If known, what proportion of food waste comes from the catering sector at your university? _____Tonnes

Current food waste treatment

1. What is the current food waste treatment technology used to treat food waste generated at your university? _____.
2. If known, what is the cost of food waste treatment at your university? _____sterling per tonne collected.
3. If known, what is the transport distances involved in transporting the food waste from your university to the food waste treatment site? _____Km
4. If known, what is the mode of transport, or modes of transport involved in transporting the food waste from your university to the food waste treatment site (i.e. diesel truck, biodiesel truck, electric truck, train, or ferry)?

Technological feasibility

5. If known, what are the space requirements for an onsite treatment plant (dimensions any treatment site would need to fit into)?
    a. Length ≤_____m
    b. Width ≤_____m
    c. Height ≤_____m
6. If known, what are the cost requirements?
    a. Initial cost ≤_____sterling
    b. Annual cost ≤_____sterling
    c. Payback time ≤_____years
7. Are there any other feasibility constraints? _____.

Current general waste treatment

8. If known, what is the current general waste treatment technology used to treat food waste generated at your university? _____.

9. If known, what is the cost of general waste treatment at your university? _____sterling per tonne collected.
10. If known, what is the transport distances involved in transporting the general waste from your university to the food waste treatment site? _____km
11. If known, what is the mode of transport, or modes of transport involved in transporting the general waste from your university to the food waste treatment site (i.e. diesel truck, biodiesel truck, electric truck, train, or ferry)?

Canteens and catering

1. What meal types are offered by the catering services at your university (i.e. all you can eat buffet, set meals, flexible build your own food)? _____.
2. What payment methods used by the catering services at your university to pay for food at the canteens (i.e. pre-paid, or pay as you go)? _____.
3. If known, what are the rough contributions to food waste by stage?
    a. Food preparation waste in kitchens_____% of total food waste
    b. Surplus unserved food left at the end of service_____% of total food waste
    c. Plate scrapings from food customers took, but didn't finish_____% of total food waste
4. If known, does the canteen send surplus food to charity (yes, or no)?_____.
    a. If yes, how much? _____Tonnes per year, or _____% of total food waste
    b. If not, would it be possible to start (yes, or no)?_____.

Self-catering and FW recycling

1. Are there self-catered residents at your university (yes, or no)?_____.
2. If so, how many self-catered students are there at your university?_____students
3. If known, is there a food waste recycling strategy at your university (yes, or no)?_____.
4. If known, what is the recycling rate for students (proportion of self-catered students, or flats that recycle their food waste)?_____%
5. If known, what is the current food waste recycling strategy for self-catered students, if there is one (optional opt-in, optional opt-out, compulsory, other) (yes, or no)?_____.
6. If known, if there is not a food waste recycling strategy for self-catered students, what would be the feasibility to have FW recycling (possible easy, possible difficult, not possible/unviable)?