Investigating Water Conservation Strategies in Kuwait: A Micro-Component Backcasting Approach

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Abstract

Household water demand has dramatically increased in Gulf Cooperation Council (GCC) countries in the last few decades, due to rapid population growth and changing lifestyles. Growing demand has been met by increasing supply capacity, largely via new desalination plants and over-abstracting groundwater. The continuous investment in water supply to avoid a supply-demand gap has been the default strategy in the GCC, yet reliance on a supply-side approach is unsustainable and associated with declining groundwater, and reliance on desalination that results in major carbon emission and environmental impact whilst also taking a large and growing share of oil revenues. This study examines the main issues associated with water scarcity in the GCC region, then determines the scale of conservation measures that will be needed to reduce water demand to a more sustainable level. In addition, to explore the wider economic and environmental benefits resulting from adopting the conservation measures, as well as, to determine the management feasibility of doing so. The state of Kuwait has been selected as a case study as it shares the hydrological characteristics of GCC countries but is the most challenging case, experiencing extreme water stress, due to its very high per capita consumption (PCC), but lowest per capita freshwater availability in the world. The research focuses on the household sector which represents 60% of total water demand in Kuwait. Based on the initial '*Business As Usual'* demand forecast of 664 MCM in 2050, annual demand must reduce to 456 Million Cubic Metre (MCM) under a no new water target '*Light* scenario' (1% saving per annum; 32% in total), to 345 MCM under a moderate target '*Intermediate* scenario' (48% saving), and to 239 MCM (64% saving) to meet the most aggressive target '*Optimistic* scenario' for 2050.

To identify how to meet these targets, the study has used the backcasting approach whereby water conservation measures have been examined for their ability to reduce demand to the 2050 targets. Three backcast conservation measures have been utilised; a) technology (adoption of innovative appliances); b) economic (water pricing) and; c) education (public awareness) interventions. Backcast scenarios have been modelled using a Micro-Component (MC) demand model that has enabled addressing of specific household uses (e.g., showering, toilet flushing) linked to conservation interventions. These interventions have been manipulated in the backcast MC model in which two backcast packages have been developed for each scenario. The output of the backcast scenarios has shown that; (i) technology intervention has superior performance relative to other interventions; (ii) the *Optimistic* scenario delivered a very efficient economic and environmental performance but is hard to implement; and (iii) the *Light* scenario delivered a fair economic and environmental performance but is more feasible to implement.

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List of abbreviations

Abbreviation	**Definition**
2SLS	Two-Stage Linear Square
3SLS	Three-stage Linear Square
ACSAD	The Arab Centre for the Studies of Arid Zones and Dry Lands
AHP	Analytic Hierarchy Process
ANN	Standard Artificial Neural Networks
APE	Absolute Percentage Error
ARRES	Adaptive Response Rate Exponential Smoothing
AUF	Autocorrelation Function
BANN	Bootstrap-Based ANN
BAU	Business As Usual
BCM	Billion Cubic Meter
BHM	Bayesian Hierarchical Model
CCPI	Climate Change Performance Index
CD	Cook’s Distance
CI	Confidence Interval
CIESIN	The Centre for International Earth Science Information Network
CO	Combinatorial Optimisation
CO_2	Carbon dioxide
CSB	Central Statistical Bureau
CSC	Civil Service Commission
CSP	Concentrating Solar Power
CUT	Constant Unit Tariff
DBT	Decreasing Block Tariff
DES	Double Exponential Smoothing
DOI	Diffusion Of Innovation
DQM	Data Quality Management
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
ES	Exponential Smoothing
ESCWA	Economic and Social Commission for West Asia
EU	European Union
FAO	Food and Agriculture Organisation
FMF	Flexible Modelling Framework
GCC	Gulf Cooperation Countries
GDP	Gross Domestic Product
GHGs	Green House Gases
GREG	Generalised Regression
GWI	Global Water Intelligence
GWP	Global Water Partnership
IBT	Increasing Block Tariff
ICWE	The International Conference on Water and the Environment
IED	Income Elasticity of Demand
ILO	International Labour Organisation
ILT	Increasing Linear Tariff

IPCC	Intergovernmental Panel on Climate Change
IPF	Iterative Proportional Fitting
IWRM	Integrated Water Resource Management
KFAS	Kuwait Foundation for the advancement of science
KISR	Kuwait Institute for Scientific Research
Km^2	Square kilometre
KPTC	Kuwait Public Transportation Company
KSA	Kingdom of Saudi Arabia
KWA	Kuwait Water Association
l/d	Litre per day
LEAP	Long-Range Energy Alternatives Planning
m^3	Cubic meter
MAD	Mean Absolute Deviation
MAE	Mean Absolute Error
MAPD	Mean Absolute Percentage Deviation
MAPE	Mean Absolute Percentage Error
MC	Micro-component
MCA	Multi-criteria assessment
MCM	Million Cubic Meter
MD	Mahalanobis distance
ME	Middle East
MENA	Middle East and North Africa
MEW	The Ministry of Electricity and Water
MLR	Multiple Linear Regression
MOI	Ministry of Interior
MPE	Mean Percentage Error
MSAL	Ministry of Social Affairs and Labour
MSE	Mean Squared Error
MSF	Multi-Stage Flash
MSMA	Ministry of State for Municipal Affairs
NGOs	non-governmental organisations
NSE	Nash-Sutcliffe Efficiency
OECD	The Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
OVF	Ownership-Volume-Frequency
PAAFR	Public Authority of Agriculture Affairs and Fish Resources
PACI	Public Authority for Civil Information
PAE	Public Authority of Environment
PCC	Per capita consumption
PDF	Probability Density Function
PED	Price Elasticity of Demand
PHC	Per Household Consumption
ppm	Particles per million
PPT	Parts Per Thousand
PRV	Pressure Reducing Valve
PSI	Pound per Square Inch
R&D	Research and Development

RECT	Rational-Economic Choice Theory
RMSE	Root Mean Square Error
RO	Reverse Osmosis
SCF	Subjective Curve Fitting
SCPD	The General Secretariat of the Supreme Council for Planning and Development
SEA	Strategic Environmental Assessment
SES	Single Exponential Smoothing
SMMs	Spatial microsimulation modelling techniques
SNA	System of National Accounts
TAE	Total Absolute Error
TDS	Total Dissolved Solids
TED	Techno-Economic Division
TED/KISR	Techno-Economic Division of Scientific Institute for Scientific Research
TFR	Total Fertility Rate
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
UAE	United Arab Emirates
UFW	Unaccounted-for water
UN	United Nations
UNDP	The United Nations Development Programme
US	United States
US$	United States Dollar
UWS	United Water Strategy
WANN	Wavelet-based ANN
WEAP	Water Evaluation and Planning
WEC	Water Efficiency Calculator
WLS	Weighted Least Square linear regression
WPP	World Population Prospects
WRC/KISR	Water Research Centre of Scientific Institute for Scientific Research
WSDs	Water Saving Devices
WWT	Wastewater Treatment

List of Kuwait demographic concepts

Concept	**Definition**
Collective Household	A household that consists of members that share the same religion, race, or a similar job, or common employer
Domestic Workers Population	Domestic workers are non-Kuwaiti people who serve in Kuwaiti households and are treated as Kuwaiti household members in the household census
Total Kuwaiti Population	The Kuwaiti population excluding domestic workers
Naturalisation	A legal process by which non-citizens (expatriates) convert to citizens
Non-Kuwaiti household population	Expatriate population settled in the household sector
Non-Kuwaiti Population in other Sectors	Expatriates who settled out of the household sector
Private Household	A household consisting of relatives whether a nuclear or extended family
Total Household Population	The Kuwaiti population plus the non-Kuwaiti household population
Total Kuwaiti Population	The Kuwaiti population plus the domestic workers population
Total non-Kuwaiti Population	The total non-Kuwaiti population in all the country’s sectors including the household sector
Total Country Population	Total Kuwaiti population plus total non-Kuwaiti populations

See Figure 4.5 for inter-relationships of selected concepts

Chapter 1 Introduction: Water scarcity in the GCC

1.1 Overview

Water scarcity is a global issue that has emerged at national and international levels in the last few decades because of sharp population growth, socioeconomic development, and climate change, all of which have caused a dramatic increase in water demand. Freshwater represents 3% of the total water available on earth, and only 0.4% of freshwater can be accessed and used by the global population (Jern, 2006). Of this, only about 0.3% of the total global accessible freshwater occurs in the Middle East and North Africa (MENA) region, considered the driest region in the world (Dabour, 2006; Xie, 2006). Collectively, about one fifth of the world's population live under water scarcity conditions (Hering and Ingold, 2012). Freshwater shortage and misuse have led to serious and rising threats to the environment and sustainable development under increasing uncertainties emerging from fast-changing socioeconomic situations and climate change (Tessendorff, 1992; Pahl-Wostl, 2007a; Vörösmarty *et al.*, 2010). For example, the overexploitation of groundwater reservoirs in many areas of the world has led to falling water tables and water-quality degradation, leading to a fragile ecosystem, and jeopardising the environment (Flavin, 2008). Furthermore, excessive, and wasteful practices in the water sector threaten economic growth, putting more stress on energy consumption, and creating a heavy financial burden to produce clean water (Al-Rashed and Akber, 2015).

Observed and forecast trends indicate that future water problems will become increasingly complex, interlinked with the energy, agriculture, economic, and social sectors (Rijsberman, 2006; Biswas, 2008). Therefore, long-term planning for water conservation is critical to protect one of the most vital and vulnerable resources on the planet, particularly in those regions where water scarcity is so extreme. Because of increasing water demand and decreasing freshwater availability, a growing recognition has emerged worldwide for urgent, efficient, and effective water resources management (Rahaman *et al.*, 2004). Understanding the importance of sustainable water resources and threats to water quality and quantity, from rising agricultural production, increasing economic productivity, and rapid population growth, all associated with excessive water use has led to several international conferences regarding water. The key target of such conferences has been to shift the focus from water-supply augmentation policies to efficient water-resources management (Gleick, 2000) and to explore comprehensive or Integrated Water Resources Management (IWRM) frameworks. For instance, the International Conference on Water and the Environment (ICWE) in Dublin in 1992, the Second World Water Forum and Ministerial Conference in The Hague in 2000, the International Conference on Freshwater in Bonn in 2001, and many others were introduced as a result of escalating awareness of the necessity for complete and effective water resources management plans and policies (Rahaman and Varis, 2005).

The key role of efficient water resources management is to evaluate the status of the water resource, outline both short-term and long-term goals for the system, define the objectives and actions to attain the selected goals, assess the benefits and costs of each action, and evaluate the effects of such actions and progress to achieve the goals (Pahl-Wostl, 2007b). Effective and sustainable water resources management can significantly increase water security and productivity in the agricultural and economic sectors and promote more efficient water use. Water shortage might be a noteworthy obstacle for the expansion of many sectors, especially in Asia, Southern Africa, and the Middle East, where water demand grows rapidly (UN, 2015). Nevertheless, measures to implement effective water resources management and water governance are often absent in arid and semiarid regions, where freshwater availability rates are low but demand may be high (De Stefano *et al.*, 2014).

The MENA region has the lowest freshwater availability on earth (Bremere *et al.*, 2001; Bucknall, 2007), yet shows the highest levels of water demand compared to other international regions. MENA encompasses the Gulf Cooperation Council (GCC), a sub-region considered the most hyper-arid area in the region with the lowest natural freshwater per capita. In contrast, GCC states have the highest per capita global consumption (Al-Zubari *et al.*, 2017) but have nevertheless neglected demand side management in favour of augmenting water supply by over-pumping groundwater reservoirs and building new desalination plants. Such policies have resulted in adverse environmental impacts, low economic efficiencies, and inefficient energy use (Odhiambo, 2016). Therefore, this research intends to explore the growing discrepancy between water supply and demand, and water scarcity problems in the GCC as well as to explore past and existing policies and strategies to tackle water-shortage problems and their consequences. The remainder of this chapter therefore discusses water resources in the GCC and explains how the gap between demand and supply has grown, and its implications in the economic and environment sectors.

1.2 Water resources of the Gulf Cooperation Council

Al-Zubari *et al.* (2017) describes how GCC countries, located in the Arabian Peninsula, one of the driest regions in the world, are characterised by an extremely poor endowment of freshwater resources, high temperatures, low precipitation rates, and high evaporation rates. Thus, GCC countries are ranked amongst the least water secure countries in the world. At the turn of the 1970s, however, the GCC witnessed exceptional economic and social transformation boosted by a rapid population growth rate of about 3.5% (Al-Zubari, 2002a; Dawoud, 2005) and changing lifestyle practices. In addition, accelerated growth in agricultural development, industrialisation, and urbanisation occurred as a result of the sudden increase in oil revenues (Abderrahman, 2000). This transition in the Gulf region has led to a substantial increase in water demand (Table 1.1), which in turn has led to great exploitation of groundwater aquifers, the only source of freshwater in the region (Dawoud, 2017). Al-Zubari (2002b) notes that continuously increasing demand has been met mainly by over-abstracting this limited renewable source, which has led GCC countries to develop additional supply via desalination and wastewater treatment (WWT) plants.

Table 1.1: Water consumption by sector in the GCC countries (MCM/yr)

Country	**1995**			**2000**			**2010**		
	Dom. [a]	Agri. [b]	Ind. [c]	Dom.	Agri.	Ind.	Dom.	Agri.	Ind.
Bahrain	86	120	17	117	124	26	231	190	29
KSA	1,508	14,600	192	2,350	15,000	415	2,283	15,790	753
Kuwait	295	80	8	375	110	105	646	513	20
Oman	75	1,150	5	151	1,270	85	182	1,546	94
Qatar	76	109	9	190	185	15	370	261	22
UAE	513	950	27	750	1,400	30	983	3,140	477
Total	2,553	17,009	258	3,833	18,089	676	4,695	20,060	1,395

[a] domestic; [b] agricultural; [c] industrial; source: Dawoud (2005); Al-Zubari *et al.* (2017)

1.2.1 Conventional water resources availability

Water resources in GCC countries are scarce because of the region's largely arid climate. The region is characterised by a lack of surface water, erratic and sparse precipitation (Table 1.2), and high evaporation rates throughout the year (Al-Rashed and Sherif, 2000). Groundwater is the only conventional water resource, and consists of two types of aquifer (Al-Zubari, 2002b); renewable shallow aquifers of about 3.5 Billion Cubic Meters (BCM), recharging annually, and non-renewable or fossil aquifers of around 2,175 BCM.

The flat topography of many GCC members, including Kuwait, Qatar, and Bahrain, prevents any attempt to construct dam projects to capture the limited runoff, Al-Zubari *et al.* (2017). In contrast, the Kingdom of Saudi Arabia (KSA), United Arab Emirates (UAE), and Oman have mountainous areas where major efforts in dam construction have allowed capture of surface runoff. Al-Zubari *et al.* (2017) note nearly 2.4 BCM of surface runoff is captured annually in these states contributing to flood control, groundwater recharge, and irrigation of arable lands.

Table 1.2: Rainfall rates in GCC countries and some other countries for comparison

Country	**Annual average rainfall** (mm)
KSA	70
Qatar	75
Bahrain	80
UAE	89
Kuwait	110
Oman	125
South Africa	495
Australia	534
United States	715
India	1,083
United Kingdom	1,220

Source: Al-Zubari *et al.* (2017); World Bank (2005)

1.2.1.1 Groundwater mining

In the last four decades, GCC countries have intensively exploited their strategic freshwater resources for various reasons: modernisation, urbanisation, population growth, and agricultural expansion (Kotilaine, 2010). The agricultural sector occupies a large portion of groundwater consumption for irrigating arable lands toward achieving food self-sufficiency and improving life standards (Woertz *et al.*, 2008). For example, in efforts to achieve food security, KSA has granted land to arable farmers who have subsequently overexploited available water resources. Mining groundwater to irrigate crops is free of charge, and ultimately, the government purchases crops from farmers at high prices to motivate them to continue cultivating yields. As a result of such practices, the volume of water used for irrigation grew from 7.4 BCM in 1980 to 17.7 BCM in 1995. Accordingly, 35% of strategic fossil aquifers in KSA have been depleted in just 15 years (Al-Turbak *et al.*, 1996; Ouda, 2014). A similar trend prevails in other GCC countries that share a similar situation with KSA (Table 1.3), in which aquifers are already drained (Al-Hajri and Al-Misned, 1994; Al-Hashemi *et al.*, 2014; Aleisa and Al-Zubari, 2017).

Table 1.3: Agriculture sector groundwater consumption in the GCC

Country	**Consumption** (MCM/yr)		
	1990	**2000**	**2010**
Bahrain	120	137	190
KSA	14,600	17,765	18,826
Kuwait	80	221	513
Oman	1,150	1,124	1,546
Qatar	140	247	261
UAE	950	2,162	3,140

Source: Al-Zubari *et al.* (2017)

Arable land accounts for only 1.7% of total land area in the GCC (NCB, 2010), yet groundwater exploitation to satisfy water demand of the agricultural sector has exceeded the annual recharge capacity. The annual overexploitation has reached 307% in Kuwait, 93% in Bahrain, 496% in Qatar, 1,210% in UAE, 321% in KSA, and 135% in Oman. Therefore, the annual per capita freshwater availability in the region has dropped sharply from 678 m^3 in the 1970s to less than 103 m^3 in 2012 (Al-Zubari *et al.*, 2017). All of the GCC countries are ranked amongst the lowest water index value of renewable freshwater per capita, as defined by the World Health Organisation (WHO) and the Falkenmark indicator, the most widely used ‘‘water stress index'' (Worldbank, 2005; Ruess, 2015). The Falkenmark indicator categorises countries based on renewable water resource availability per capita per year. The First category; "no water stress", is where availability exceeds 1,700 m^3 /cap/yr^{-1}; between 1,000 and 1,700 m^3 cap/yr^{-1} is "water stressed"; "water scarce" countries have below 1,000 m^3 cap/yr^{-1}, a whilst "absolute water scarcity" has below 500 m^3 cap/yr^{-1}, a condition that is now common throughout the GCC countries (Figure 1.1).

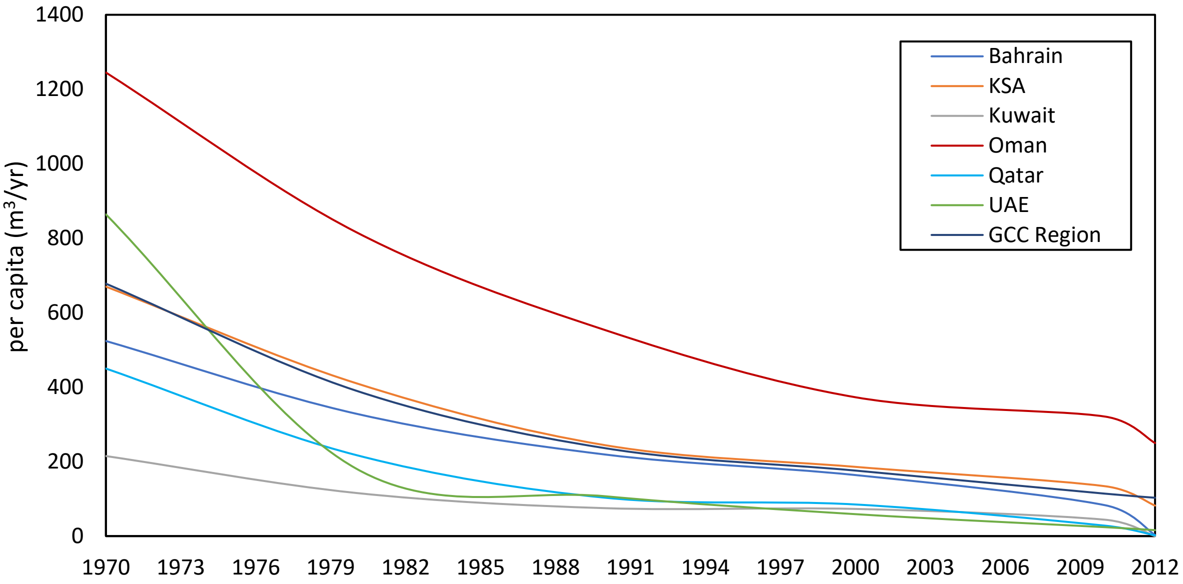

Figure 1.1: Renewable water resources per capita in GCC (m^3/yr)
Source: World Bank (2005); GCC Supreme Council (2016)

The underlying reasons for such a drastic decline in the availability of freshwater resources in the GCC countries consist of two pressing drivers. The first is an internal driver presented by the excessive groundwater mining of renewable and non-renewable resources. The agricultural sector in the GCC takes 77% of total water production from planting cereals, fodder, vegetables, fruits, and dates in open fields that consume massive amounts of water using traditional irrigation systems (NCB, 2010). For example, flood irrigation is used on 72% of agricultural lands in Bahrain, 63% in Kuwait, 60% in Oman, and 75% in Qatar. The use of these traditional irrigation techniques causes high evaporative water losses, of between 25% and 40%, resulting in low irrigation efficiencies (Al-Zubari *et al.*, 2017). However, whilst agriculture comprises 77% of total water demand in the GCC, it represents only 2% of the region's Gross Domestic Product (GDP), whereas the cost of production is much higher than the revenue (NCB, 2010). The second is an external driver presented in accelerated population growth, which is higher than the international average. At the beginning of the 1980s, the regional population was about 10 million people but increased to around 49 million in 2012, due to high birth and immigration rates (Al-Zubari *et al.*, 2017). GCC countries recognised the need for alternative sources to satisfy the resultant water demand and have relied on desalination technology since the early 1950s.

1.2.2 Desalination technology

The severe deficiency of natural water resources has led to GCC countries with sufficient oil resources investing greatly in desalination plants (Al-Hashemi *et al.*, 2014; Shomar and Hawari, 2017). Desalination technology addressed the immediate water scarcity in the GCC (Mohamed, 2009; Dawoud, 2012) and now meets more than 90% of the domestic and industrial needs in most GCC countries (Darwish *et al.*, 2009; Al-Rashed and Akber, 2015). Economic and social transformation from the 1970s (Saif *et al.*, 2014), and the resulting rise in water demand led to a strong growth in desalination capacity (El Sayed and Ayoub, 2014), (Figure 1.2). According to a 2009 water-development report by the Economic and Social Commission for West Asia (ESCWA), GCC states feature strongly in the top ten of countries that desalinate water. KSA tops the list with 17% of the world’s daily desalination production, followed by the UAE with 14%, whilst Kuwait and Qatar are sixth (4%) and seventh (3%), respectively. This is compared to other countries, such as the United States, which equals the UAE with 14%, and China at 4%. KSA, UAE, and Kuwait are responsible for more than one third of the global desalination capacity (ADNEC, 2018). Globally, the GCC has 65% of all desalination plants in the world, and more than 57% of total global desalination capacity (Saif, 2012; Saif *et al.*, 2014; Ramadan, 2015; Shomar and Hawari, 2017).

This growth in desalination capacity follows the growth in water demand. Total demand in Kuwait increased from 30 MCM in 1970 to 716 MCM in 2016 (Al-Humoud and Al-Ghusain, 2003; MEW, 2017). Growth in demand, is strongly driven by population with desalination used as a supply side response. For example, UAE increased desalination capacity 220% in the 10 years to 2013, whilst population grew by 300% (Srouji, 2017). The GCC have adopted such supply-side policies to overcome escalating demand which is also a function of rapid growth in per capita consumption (PCC), reaching the highest rates in the world. The PCC in the domestic sector in GCC countries is very high; 350 litres per day (l/d) in Bahrain, 500 in Kuwait, 512 in Qatar, 240 in Oman, 338 in the KSA, and 520 in the UAE (Al-Ansari, 2013;

Al-Zubari *et al.*, 2017). In comparison, average domestic PCC in Germany and France is about 120 l/d and about 150 l/d in England (Biswas and Kirchherr, 2012; Parmigiani, 2015).

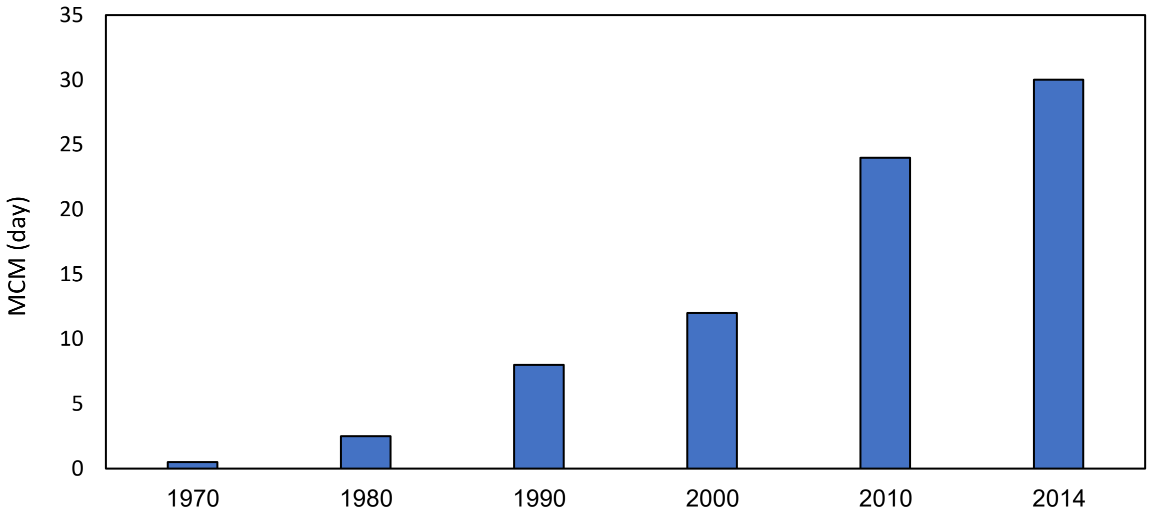

Figure 1.2: Cumulative capacity of desalination plants in the GCC
Source: Saif *et al.* (2014)

1.2.3 Treated wastewater

Wastewater reuse has also increased rapidly over the last four decades in all GCC countries (Saif *et al.*, 2014). The main uses are for municipal landscaping irrigation and also agricultural purposes, where treated wastewater is blended with groundwater (Al-Anzi *et al.*, 2012), and used for some other non-potable activities. Wastewater treatment plant (WWTP) technologies used in the GCC differ from one country to another, and include primary-level, secondary-level, tertiary-level, and Reverse Osmosis (RO) treatment technologies. Some GCC's countries use primary-level treatment and other mainly secondary-level treatment, but all use tertiary-level treatment with those treatment technologies (Table 1.4). The underlying reason of the construction WWTP tertiary-level treatment is because of its efficiency in land irrigation. The primary-level treatment is designed to separate solid waste from water, while secondary-level treatment uses anaerobic microorganisms and retention time to remove the remaining waste and other small particles (Tillman, 1991; Lin *et al.*, 2009). Tertiary treatment is the last cleaning process that enhance wastewater quality before reusing or discharging it. It is removes remaining inorganic compounds, and substances, such as the nitrogen and phosphorus, as well as, bacteria and parasites, which are harmful to health (Klamerth *et al.*, 2012).

Table 1.4: Wastewater treatment (WWT) facilities in GCC in 2015

Country	**WWT plant**	**Treatment capacity** (MCM/yr)	**Treatment level**
Bahrain	11	81.5	Tertiary
Kuwait	5	239	Tertiary – Reverse Osmosis (RO)
Oman	73	69	Secondary–Tertiary
Qatar	18	123	Secondary–Tertiary
KSA	81	1,730	Primary–Tertiary
UAE	53	556	Secondary–Tertiary
Total	241	2,798	

Source: Aleisa and Al-Zubari (2017)

Wastewater recycling is one of the growing water sources in the GCC where dependence on it has grown, especially over the last few years (Al-Rashed and Akber, 2015). The reuse of treated wastewater has financial and environment benefits and is considered a means to alleviate pressure on expensive desalinated water production and groundwater withdrawal. Moreover, it is an economic option with greater influence on future usable water sources than any other accessible technological solution for increasing water supply (Hamoda, 2004; Aleisa and Al-Zubari, 2017). Nevertheless, wastewater recycling in the GCC is in the initial stages (Al-Zubari, 2015), with wastewater reuse below 30%, which contributes only 1.8% to total water supply (Cronin and Pandya, 2009). In most GCC countries, most wastewater is still lost to sea (Worldbank, 2005).

The cost of collection and treatment of wastewater is about (1 US$) per cubic meter ($m^3$), making it cheaper than desalination. Nevertheless, most GCC countries do not charge users to consume treated wastewater, except in Oman, which charges for treated water at a level of recovery cost. Such subsidies represent a financial barrier to encouragement of water conservation.

1.3 Economic and environmental impacts

The reliance on supply side policies to tackle increasing water scarcity in the last four decades has led to unsustainable water use in GCC countries. Faced with growing water demand, GCC governments have built numerous desalination plants and over exploited limited natural water resources. This focus on supply augmentation has had significant environmental and economic effects (Al-Zubari, 2017).

1.3.1 Seawater desalination and wastewater treatment impacts

1.3.1.1 Environmental impacts

The routine discharge of effluents into the sea from desalination and wastewater plants negatively impacts the marine ecosystem. Discharged effluents are often a combination of saline concentrate, thermal and chemically added pollutants (Von Medeazza, 2005). The salinity of ambient seawater in the GCC is around 45 Parts Per Thousand (PPT) (Lattemann and Höpner, 2008), an increase in salinity level of 5 – 10 PPT in the ambient seawater as a result of saline discharge from desalination plants. Moreover, desalination plants increase the temperature in their vicinity by about 7 – 8°C (Mohamed, 2009). Consequently, dissolved oxygen will decrease in the plant vicinity, whilst chemical disposal will add chlorine and un-ionized ammonia. This continuous discharge of chemicals, together with high salinity and temperature levels can thus be fatal for marine life (Mezher *et al.*, 2011).

With dependence on desalination technology, Greenhouse Gases (GHGs) emissions have been increased in all GCC countries, as the plants are operated using fossil fuel (Al-Hashemi *et al.*, 2014). Consequently, the GCC are amongst the world’s fourteen worst countries in terms of CO_2 emissions per capita (Alotabi, 2004). Per capita CO_2 emissions of GCC members are higher than those of the European Union (EU) (Reiche, 2010) and the Organisation for Economic Cooperation and Development (OECD) (Doukas et al., 2006), (Figure 1.3). Moreover, according to the Climate Change Performance Index (CCPI), KSA has the highest per capita CO_2 emissions, and is the worst-performing of 60 countries tackling gaseous emissions (Burck *et al.*, 2018). GCC countries contribute approximately 4.6% of the total CO_2 emissions in the world (Uddin, 2014).

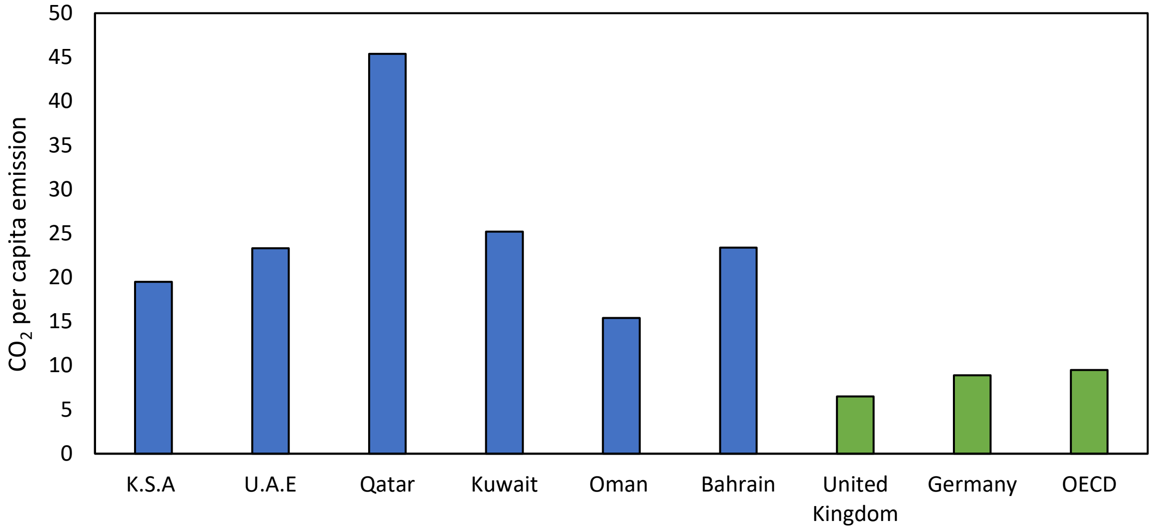

Figure 1.3: Carbon dioxide emissions (metric tonnes per capita per annum)
Source: World Bank (2014)

1.3.1.2 Economic impacts

Oil-production revenues constitute the backbone of GCC countries' economy and account for more than 90% of GDP of most GCC members (El Hag and El Shazly, 2012). Thus, these countries are directly impacted economically by rising water demand, as desalination plants rely on oil that could otherwise be used to generate revenue. Accordingly, GCC countries experience extremely high capital, maintenance, and operational costs from desalination plants, which represent high opportunity costs of oil wealth. Furthermore, freshwater production costs are not matched by revenue because of the heavy water subsidies granted by GCC governments. By way of comparison to Table 1.5, UK water utilities average charges are about 1.8 US$ per m^3.

The high subsidies for water in the GCC have led the water revenues to cover only 8% of production costs (El Sayed and Ayoub, 2014). The government of Kuwait spends more than 4.55 billion US$ per annum to operate and maintain desalination plants, yet the net revenue covers only 6% of total production costs, whilst only 25% of total water bills are collected (Darwish *et al.*, 2009). Kuwait uses around 12% of its oil production to fuel desalination plants, a share predicted to rise to about 50% by 2050 (Al-Rashed and Akber, 2015), yet GCC countries are expected to invest further in desalination plant construction and expansion to meet growing water demand. In addition, environmental maintenance costs are an important aspect in the management of desalination brine discharge and gaseous emissions (Elimelech and Phillip, 2011; Dawoud, 2012).

Table 1.5: Desalination production costs and tariff costs in GCC

Country	**Production cost** (US$/m^3)	**Tariff cost** (US$/m^3)
Bahrain[1]	1.92	0.07*- 0.53**
KSA[1]	1.35	0.027*- 1.6**
Kuwait[2]	2	0.58
Oman[1]	1.34	1.07*- 1.43**
Qatar	2.74	Free
UAE[1]	2.07	0.46*- 0.51**

Source: Supreme Council of GCC (2016); [1] Increasing rate tariff applied; [2] uniform tariff applied; * initial block; ** highest block

1.3.2 Groundwater

1.3.2.1 Environmental impacts

The continuous long-term withdrawal and overexploitation of scarce groundwater aquifers have resulted in environmental impacts in all GCC states, as well as a sharp decline in groundwater levels and quality. The excessive use of aquifers and the continuous decline of water levels leads to the intrusion of seawater into reservoirs, increasing the Total Dissolved Solids (TDS) content and making water too saline for direct use Al-Ibrahim (1991). In Kuwait, the TDS ranges between 2,250 and 5,500 Particles Per Million (ppm), which account for poor water quality of abstracted groundwater (Al-Damkhi *et al.*, 2009). Traditional irrigation methods such as flood irrigation have resulted in waterlogging and polluting of arable lands, increasing their salinity and eventually reducing soil fertility and shrinking of the agricultural areas (Worldbank, 2005).

1.3.2.2 Economic impacts

Investments in the agricultural sector have resulted in the excessive extraction of groundwater, depleting aquifers, and yet the agricultural sector adds only 2% of total GDP in GCC countries and has failed to achieve the goals of self-sufficient food policies. The strategic resource of natural water in the GCC has not been employed well economically, resulting in a drastic decline in per capita freshwater.

GCC countries face a critical issue of high and increasing water scarcity because of prevailing aridity, and rapid population growth and development. Rapid groundwater depletion and deterioration of quality, because of overexploitation and inefficient water use in traditional irrigation practices, with multiple impacts on agricultural productivity and ecosystems has occurred (Al-Zubari, 2017). The very low availability of natural water resources and very high-water demands have resulted in the GCC having the lowest per capita conventional water resources globally, yet the highest per capita water consumption in the world, contributing to their highest per capita CO_2 emissions in the world. The GCC have escalating water demand but lack appropriate conservation measures and management. These circumstances result from weak water institutions, characterised by fragmented water authorities, with a lack of coordination, and inadequate capacity development, Al-Zubari *et al.* (2017).

If current trends of water consumption and management continue, annual water demand will continue to increase sharply. Additionally, increasing the capacity of desalination plants to meet growing demand will be needed to supplement declining fossil groundwater. In effect, GCC countries are converting much of their oil to water, and environmentally unsustainable and economically wasteful practice. Thus, implementing an Integrated Water Resources Management (IWRM) strategy that adopts a holistic approach that includes demand side management is a key need. Such an integrated approach can link the water sector to the economic, energy, environment, and social sectors, and so deliver more sustainable water management, and hence sustainability. The extent to which this more sustainable management is being implemented in the GCC countries is addressed in the literature review chapter, which reviews GCC countries' water management programmes and strategies. Through reviewing the literature in water resources management in the GCC region, the gaps in knowledge have been identified from which the research fundamental question has been formed and aims and objectives have been defined.

1.4 Research question

Based on the knowledge gaps identified in the literature review chapter (section 2.5) from an in-depth literature reviewing; the research question has been formed, which is:

"To what extent can water conservation initiatives and regulations targeted at the household sector help transition Kuwait towards a more water secure future, and what are the wider economic, and environmental benefits of these interventions?"

The research attempts to understand the potential of various instruments to tackle increasing water demand in Kuwait (as a case study of the wider GCC region, see section 1.6 for further details). Furthermore, the research extends beyond how water demand reduction might be achieved, to consider the wider benefits (economic and environmental) for Kuwait of doing so. The research thus considers the potential of demand conservation measures and the advantage to Kuwait of delivering a successful conservation programme.

1.5 Aims and objectives

Given the research questions above, we can state that the study has two related aims, as follows:

(a) To determine what water conservation interventions in the household sector could transition household water demand in Kuwait to a more sustainable pathway;

(b) To evaluate identified conservation interventions in terms of wider economic and environmental benefits, feasibility, and acceptability.

The research has employed the backcasting modelling approach (see section 6.2) as a framework to identify more sustainable water conservation strategies. It first seeks to define a desirable future goal of household water consumption to 2050 (section 6.2.1), and then determine plausible transition pathways to reach that goal. The backcasting modelling proposed has used a micro-component model of household water demand to maximise the range of possible water conservation interventions that can be addressed. With a water use target(s) defined, the model parameters for the interventions (e.g., water pricing, technology adoption, see section 6.3) have been manipulated to identify packages of interventions (type, mix, intensity, and timing) that could reach the 2050 household demand target. The measures identified for these transition pathways have been a subject to further evaluation in terms of wider potential benefits (e.g., reductions in desalination energy demand) relative to household demand Business As Usual (BAU) forecasts. Finally, feasibility and acceptability of measures in the generated backcast scenarios will be discussed qualitatively and quantitatively (e.g., the feasibility of a rapid adoption of efficient appliances in the household sector). Unfortunately, the feasibility and acceptability appraisal couldn't be in place as a result of the Covid-19 pandemic outbreak, for further details see section 7.2.3.3.

The specific objectives related to the two research aims above, are shown below, with these objectives also shown in the research framework in Table 1.6 which gives an additional overview of methods and data associated with these objectives. Furthermore, Figure 1.4 summarises the research methodology applied in the study.

First aim: To determine what water conservation interventions in the household sector could transition household water demand in Kuwait to a more sustainable pathway;

- **Objective 1.1.** To build and validate a BAU model of household water demand for Kuwait to generate a baseline annual water demand forecast to 2050, recognising demographic projections. (Chapters three and four)

- **Objective 1.2.** To develop a micro-component model to model PHCs/PCCs of Kuwait's household population, and which is able to represent a range of water conservation management interventions in terms of Ownership-Volume-Frequency (OVF) elements. (Chapter five)

- **Objective 1.3.** To establish backcast model targets for total household water demand in Kuwait for 2050 and apply the model in a backcasting manner to identify water conservation interventions (type, mix, intensity, and timing) that could transition Kuwait to the backcast target(s) for 2050. (Chapters six and seven)

Second aim: To evaluate identified conservation interventions in terms of wider economic and environmental benefits, and management feasibility.

- **Objective 2.1.** To compare backcast demand to BAU demand forecast to 2050 and apply the economic and environmental evaluation analysis to quantify wider benefits of demand management packages associated with transition pathways. (Chapter seven)

- **Objective 2.2.** To evaluate feasibility and acceptability of backcast interventions through dialogue with professional stakeholders in Kuwait (see section 7.2.3.3).

Table 1.6: Research framework

First aim: To determine what water conservation interventions in the household sector could transition household water demand in Kuwait to a more sustainable pathway.		
Objective	**Method**	**Data**
(1.1) To build and validate a BAU model of household water demand for Kuwait.	(i) Model construction for baseline demand estimation; (ii) Forecast accuracy test of estimated baseline demand, and; (iii) Linking baseline demand estimate to household population projection and develop a BAU forecast through spatial microsimulation approach application.	(i) Time series data for past observations of aggregate and disaggregate household water demand (dependant variable) plus data on observed aggregate household population and disaggregate household attributes (independent variable), and; (ii) Household population projection to 2050.
(1.2) To develop a micro-component model that fits the PHCs/PCCs of Kuwait's household population and which is able to represent a range of water conservation management interventions in terms of Ownership-Volume-Frequency (OVF) elements.	Application of OVF methodology to PHCs/PPCs of BAU forecast associated with quantitative and qualitative calculations and justifications, comprising; (i) Proportional redistribution function; (ii) Calibration fitting exercise; (iii) Intuitive judgment; and (iv) Literature survey.	Data on disaggregated level (PHC/PCC) that comprises household's end-use appliances specification which represents appliance ownership, volume (litre per minute/ load per cycle); and frequency of use per day for each household member (e.g., having a shower per day) or for the household (e.g., using dishwasher per day).
(1.3) To establish backcast model targets for total household water demand in Kuwait to 2050 and apply the model in a backcasting manner to identify water conservation interventions (type, mix, intensity, and timing) that could transition Kuwait towards the backcast target(s) for 2050.	(i) Literature surveying to define backcast targets, and; (ii) Deterministic backcast Micro-Component (MC) model manipulation (a mix of interventions, intervention adoption extent and intensity, and timing/uptake rate of intervention) by applying Water Efficiency Calculator (WEC); a backcast MC-WEC model.	(i) Targets for aggregate household demand from countries that have a similar situation to Kuwait, based on a national policy and/or achievable target; (ii) Observed price elasticity and education effect for water demand in the household sector from countries similar in the context to Kuwait, and; (iii) Efficient and high-efficient appliances' flowrate (litre per minute) and volume (load per cycle).

Second aim: To evaluate identified conservation interventions in terms of wider economic and environmental benefits, feasibility and acceptability.		
Objective	**Method**	**Data**
(2.1) To compare backcast demand to BAU demand forecast to 2050 and apply the economic and environmental evaluation analysis to quantify wider benefits of demand management packages associated with transition pathways.	Statistical analysis for the economic and environmental impact of BAU forecast against backcast scenarios.	(i) Data on freshwater production cost/price from desalination plants, including; (a) cost per unit production and delivery, US$ per m^3; (b) price per unit sold for customers (water tariff), US$ per m^3 , and (ii) Data on carbon dioxide emission per unit produced from desalination plants, kilogram per m^3 (kg/m^3).
(2.2) To evaluate feasibility and acceptability of backcast interventions through dialogue with professional stakeholders in Kuwait.	A participatory approach, semi-structured interviews using Delphi technique and content analysis approach.	A full report containing assessment and a comparison between BAU and backcast scenarios.

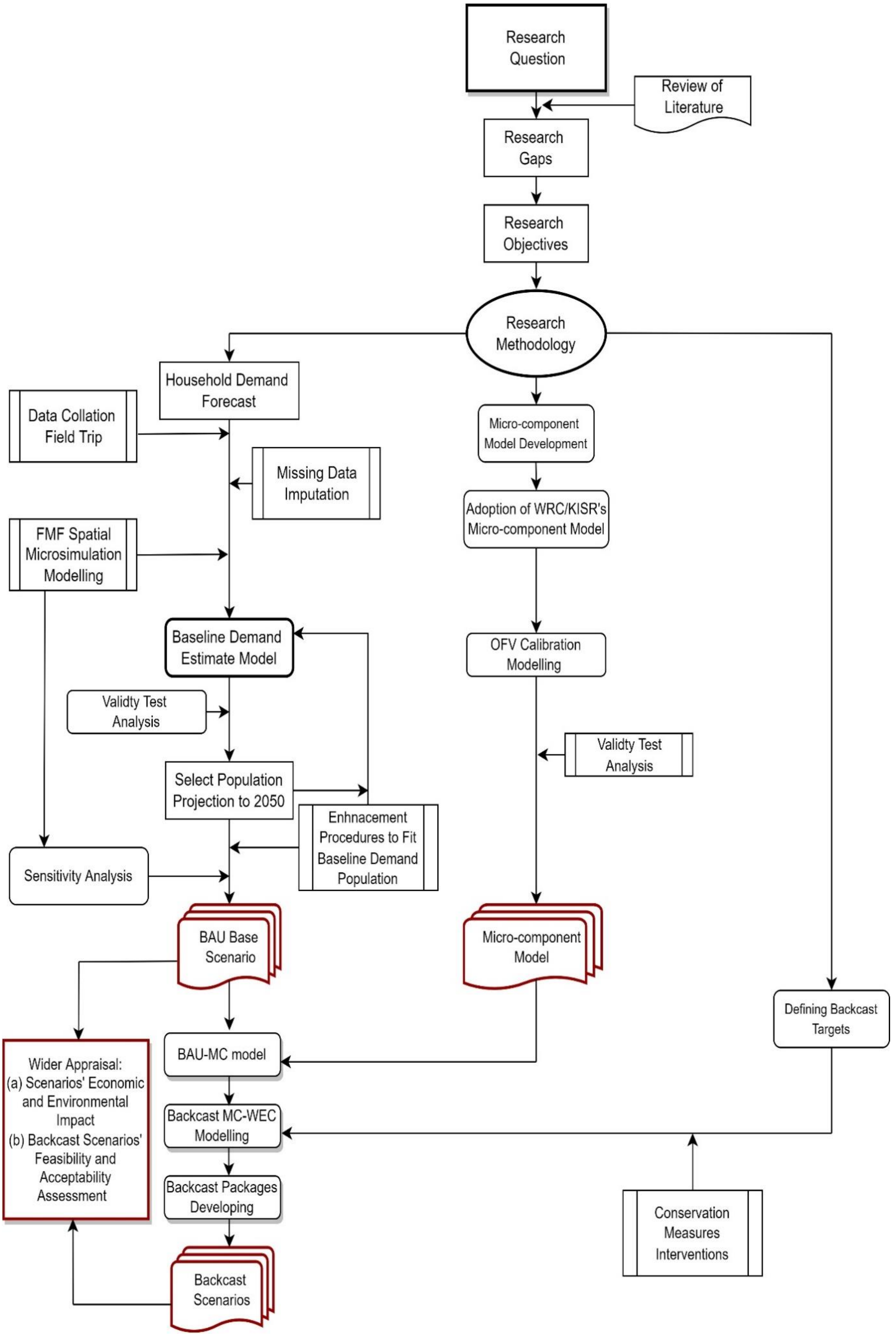

Figure 1.4: Overview of the research frame developed for the study

1.6 Research approach

This research adopts a quantitative case study methodology approach. A quantitative analysis has been presented through backcasting and micro-component modelling to quantify the household water demand in the backcasting target year (2050), and the economic and environmental implications of doing so, in which the backcast scenarios are developed. The modelling process comprises the application of the conservation measures represented in; (i) economic; (ii) technology; and (iii) education interventions (see chapter six and seven). A case study methodology has been used in this research where a holistic approach is needed to achieve study aims. It should be taken into consideration that a qualitative analysis was in the research plan (objective 2.2), but as result of Covid-19 pandemic outbreak this analysis couldn't be in place (see section 7.2.3.3 for further details)

A case study methodology can examine the phenomena (water scarcity and high PHC/PCC) within its wider context. It enables the exploration and understanding of complicated issues and is considered a sound research method when a holistic in-depth investigation is needed (Zainal, 2007). For instance, addressing all GCC countries in the research would be very challenging due to the difficulties faced in collating sufficient datasets on household demand and its drivers. Such data, even where available, is often hard to access (usually requiring official permissions and personal visits) and is not reported against a standard format (i.e., data varies widely in terms of variables, measurement and recording processes, and time and space).

Case study research can adopt an exploratory, descriptive, or explanatory approach (Yin, 1984). This case study is exploratory, with the aim to explore (via modelling) measures that could reduce household water consumption to more sustainable levels. This research focuses on Kuwait for two key reasons: first, although the annual increase in domestic water demand in Kuwait is about 8% there are very few studies of water demand in the country, and only two have addressed the household sector. Second, Kuwait has the lowest per capita freshwater availability in the GCC (and indeed in the world) yet its PCC is amongst the highest in the GCC (and world). Therefore, knowledge gained about Kuwait will be of high relevance to the rest of the GCC, not just Kuwait.

1.7 Novelty and impacts of a Kuwait case study

The case study investigates to what extent conservation measures can reduce extreme water demand to a more sustainable level and assesses some of the wider economic and environmental benefits of doing so (this wider appraisal is presented in chapter seven and discussed in chapter eight). The research thus has potential impact with respect to Kuwait itself, with results likely to be broadly transferable to the remainder of the GCC. Novelty arises as the potential of water demand management in a hyper arid country experiencing atypically high-water demand is examined. This has rarely been attempted before, and the focus on household demand addresses a less researched area still in GCC countries. Additionally, the fundamental approach (backcasting) has never been applied in the GCC before.

1.8 Thesis structure

This thesis consists of eight chapters. The first chapter is an introduction to the freshwater crisis (problem statement) in the MENA region with a focus on the GCC sub-region. The second chapter is the literature review of water resources management in the MENA and GCC regions, where the gaps in knowledge have been recognised. From chapter three through chapter eight is the development of the backcasting and micro-component model. Where chapter three is assigned to construct the baseline of water demand estimation which is the structure to forecast and then backcast water demand in the household sector. Chapter four is assigned to develop water demand forecasts in the household sector through different population projections, from which the base scenario of the household water demand is selected. Chapter five is the development of the micro-component model in which the Ownership-Volume-Frequency (OVF) methodology has been developed. Chapter six has been assigned to develop the backcast model structure and chapter seven is the application of the backcast micro-component model in which backcast scenarios have been generated and the environmental and economic implications have been investigated. Chapter eight is the concluding chapter where the novelty and originality of the research have been discussed, stating the potential publication and the limitations of the research and the recommendations for Kuwait's institutes and policymakers. Furthermore, conclusion chapter comprises a suggestion for future research needs.

Chapter 2 Literature review: Practices to tackle water shortage crisis

This chapter introduces and describes the key features and principles of Integrated Water Resources Management (IWRM), presenting its concept and approach. It then outlines water resources management in the MENA region to give a broad sense of the water situation there. Then, it focuses on the GCC region to elucidate the main obstacles that hinder delivering effective water resource management and to explore what has been done with respect to tackling water scarcity.

2.1 Integrated water resources management

There is global recognition of the necessity for efficient and integrated water resources management due to several pressing factors (ICWE, 1992; Rahaman *et al.*, 2004). These factors include the scarcity and misuse of water resources, overconsumption, water pollution, rising threats from drought and floods, uncertainties of climate change and socioeconomic development, and inefficient water resources management. As a result, the International Conference on Water and the Environment (ICWE) in Dublin in 1992, involving multidisciplinary governmental institutions, Non-Governmental Organisations (NGOs), and various agencies from around the world, was convened to develop and recommend general structures for water management (Xie, 2006). The conference introduced the Dublin statement and IWRM principles for the purpose of protecting the world's water environment. In doing so it sought to achieve sustainable development and management of water resources, comprising protection of safe supplies for drinking and irrigation water, reliable sanitation networks, protection of aquatic ecosystems, flood management, and other issues that related to water (Hering and Ingold, 2012).

There are several definitions for IWRM but the most common one is presented by the Global Water Partnership (GWP):

> *''A process which promotes the coordinated development and*
> *management of water, land and related resources, in order to*
> *maximise the resultant economic and social welfare in an equitable*
> *manner without compromising the sustainability of vital ecosystems.''*

Through this definition, it can be recognised that IWRM is an interlinked process and a holistic approach which comprises and involves cross-sectoral efforts which work together to deliver sustainability and integration (Mitchell, 2005). Biswas (2008) describes IWRM as an approach that integrates many different sectors including economic, environment, energy, social, and agriculture, to improve the management of water resources. The four principles of IWRM (Table 2.1), the so-called Dublin-Rio principles, were agreed as a framework that brings water efficiency and water sustainable management and development (Savenije and Van der Zaag, 2008). The 1992 Rio Earth Summit adopted these principles (GWP, 2000). Since then, the Dublin conference was the spark for launching international conferences concerning water resources management, including the Second World Water Forum and Ministerial Conference, International Conference on Freshwater, and many others (Rahaman *et al.*, 2004).

Table 2.1: IWRM principles

No.	Principle	Definition
1	*Environmental Sustainability*	Freshwater is a finite and vulnerable resource, essential to sustain life, development, and the environment.
2	*Participation*	Water development and management should be based on a participatory approach, involving users, planners, and policymakers at all levels.
3	*Social Equity*	Women play a central part in the provision, management, and safeguarding of water.
4	*Economic Efficiency*	Water has an economic value in all its competing uses and should be recognised as an economic good.

Source: ICWE (1992)

IWRM water management frameworks are based on these four principles. Implementation of IWRM, however, varies from country to country and depends on preference and relative importance of economic, environmental, and social impacts. For example, South Africa and the Netherlands emphasise social and environmental targets respectively, while Chile focuses on the importance of economic efficiency (White, 2013).

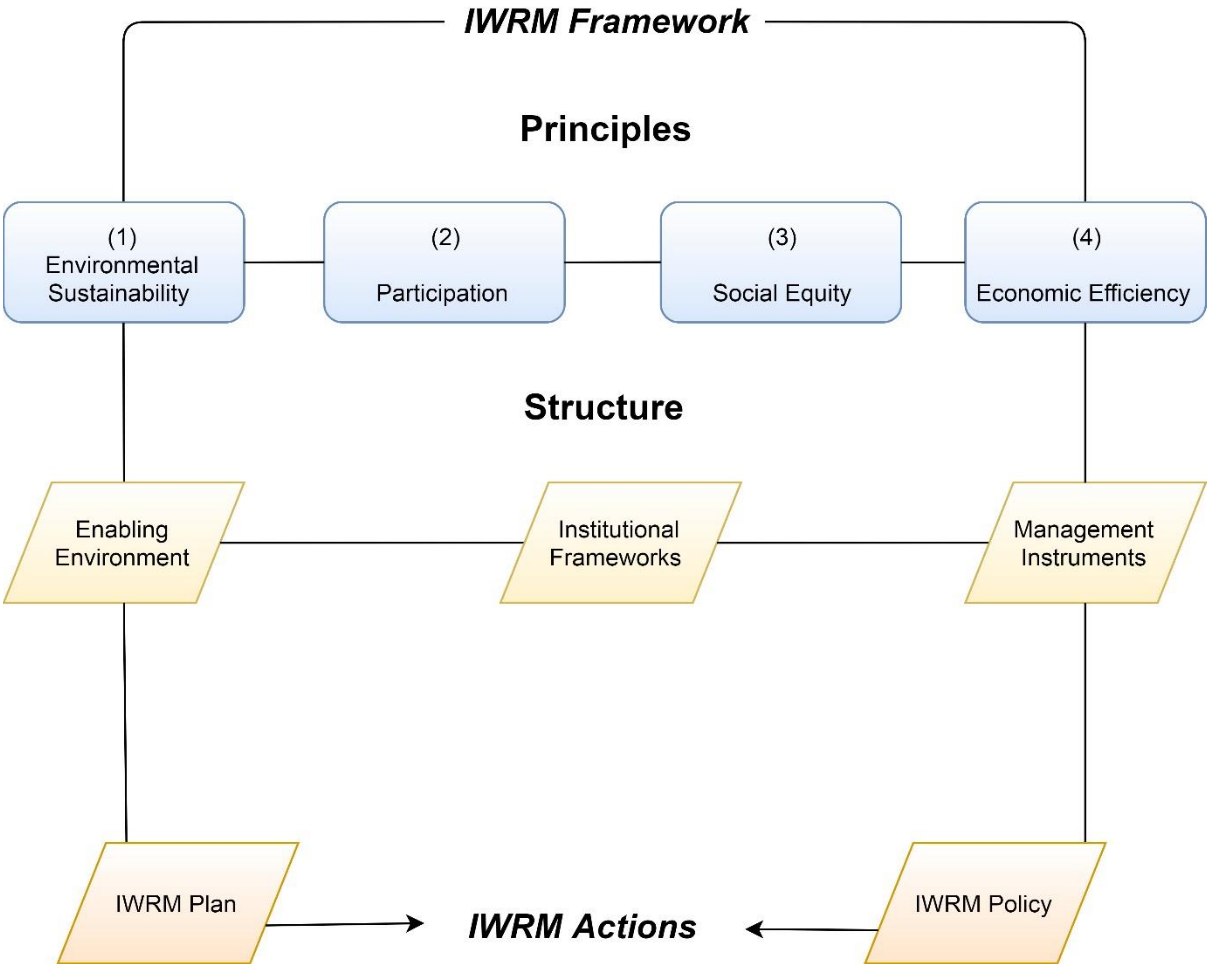

Figure 2.1: IWRM structure
Modified after Global Water Partnership (GWP)

The key purpose of IWRM is to bring water security and efficiency as well as to ensure sustainable development through implementation of several instruments within its principles (Pahl-Wostl *et al.*, 2008). It can be achieved through water supply side management and/or demand side management (Al-Radif, 1999). For example, a well-designed water pricing scheme can decrease water demand and alleviate wasteful practices, which in turn underpins economic efficiency, and creates environmental benefits. Furthermore, it can deliver social benefits by employing water charges to support low-income households and/or expand water provision programmes (White, 2013). Similarly, public participation in decision-making, can raise awareness of the importance of water to sustain life, which in turn can change people's behaviour to use water wisely and reduce demand (Inman and Jeffrey, 2006). On the other hand, water supply management programmes can regulate and enhance availability of water resources for households, industries, and other consumers (Nielsen, 2002). For example, reclamation and reuse of wastewater is an option that can augment water supply and decrease municipal effluent discharge (Council, 2012). Moreover, leakage control can increase water supply and achieve many benefits, for example, reducing energy used to treat and distribute water (Xu *et al.*, 2014). Successful IWRM can thus be achieved when an integrated approach is adopted based on the country's situation, needs and priorities (Lenton and Muller, 2012). However, there are several challenges that hinder the implementation of IWRM, particularity the difficulty and complexity posed by the need to address multiple sectors in IWRM programmes (Hassing, 2009).

2.1.1 Challenging issues of IWRM

IWRM has been criticised for the implementation challenge it poses; it can be developed in a theoretical sense, but it is not an easy task to deliver in practice due to the challenges of integration (GWP, 2009). Challenges vary based on the nature of IWRM approach being adopted. For example, dealing with uncertainties could be one challenge (e.g., climate change and socioeconomic development uncertainties), or it could be technical challenges such as data accuracy and error propagation (McDonnell, 2008). Challenges that hamper delivering IWRM, however, are common when dealing with complex systems and combined approaches (Anderson *et al.*, 2008).

Uncertainties might emerge in different stages of IWRM processes and vary depending on the type, nature, and source of each process of IWRM implementation (Pahl-Wostl, 2007b). There are two fundamental types of uncertainty, the first is ontological uncertainty or inherited uncertainty, and relates to differences in perception, for example, of climate change or socioeconomic condition (Van Der Keur *et al.*, 2010); the second, epistemic uncertainty occurs because of imperfect knowledge of the system, such as limitations in data and models. With respect to water resources management, Van der Keur *et al.*, (2008) develop these to identify four main sources of uncertainty. The first, data uncertainty is a common source of uncertainty in water resources management. The second is conceptual or model uncertainty, such as an incomplete understanding and explanation of how a system function. The third is multiple frames uncertainty, which arises where multiple stakeholders are involved, and uncertainty occurs due to different perceptions amongst them. A fourth source of uncertainty occurs as water resources management engages with multiple sectors, and deals with many aspects, making a very complex system. This uncertainty is increased as future regulatory, economic, and technological developments, which are routine in the water sector, occur, but often not be possible to account for explicitly in a water management.

Weak and missing coordination amongst institutional sectors is one of the common obstacles to IWRM (Varis *et al.*, 2014). Unsuitable and overlapping roles and functions of institutions related to water issues within the context of IWRM, and absence of coordination and integration, means concerned stakeholders impede the implementation of IWRM plans. For instance, in the Economic and Social Commission for West Asia (ESCWA) region, most of the current coordination measures relate to short-term projects and lack sustainability and empowerment (ESCWA, 2006). Centralisation in sectors relevant to water resources management, often ministries responsible for water policies and regulation, mean that other relevant institutions are not consulted early enough in development of IWRM policy. Furthermore, stakeholder participation processes are commonly practiced through technical committees that are typically inefficient and inactive following the completion of these policies.

Insufficient and poor governance is a critical hurdle facing several countries and entities seeking to implement IWRM policies. Inadequate legislation and unclear responsibilities amongst ministries and/or regional water resources management bodies is common in developing countries (Agyenim and Gupta, 2012). For example, a lack of regulatory framework to employ economic measures such as polluter pays principles and fines for excess pollution loads (Fulazzaky, 2014). However, governance tools and measures, such as policies and plans, have the ability to overcome water challenges in an integrated and affordable manner if treated as part of an IWRM framework (WCCE, 2015). Water governance is a significant element of the framework of water plans and policies, and good governance has broader tools and principles that enable delivery on IWRM targets and has the flexibility to adopt new measures (OECD, 2015). However, there is global recognition and agreement that most water issues and crises are governance crises (Akhmouch and Correia, 2016).

A lack of understanding of the concept of IWRM is amongst the greatest challenges to its implementation (Hübschen, 2011; Sukereman and Suratman, 2014). Various definitions of IWRM, alongside flexibility of employing IWRM in several paradigms, have led to misunderstanding of how IWRM instruments work and fit collectively in order to design an integrated water policy (Funke *et al.*, 2007). It is increasingly obvious amongst decision-makers and scholars that the integrated management approaches of the past have failed to engage sufficiently with the challenges created by complex and rapidly changing water environments. However, to overcome challenges to IWRM as a complex system, it is critical to understand linkages amongst IWRM components and their multiple drivers as well as understanding how to deal with unpredictable outcomes (Pollard and Du Toit, 2008).

IWRM is an interdisciplinary approach to water resources management in which efforts from many disciplines must be pooled in order to understand challenges and so construct an effective IWRM policy (Soppe *et al.*, 2005). IWRM is about developing an enabling environment where water professionals are able to collaborate meaningfully with professionals from other disciplines, functions, and sectors (Clausen, 2004), and where capacity of stakeholders and institutions is built to plan and implement policies. It is about developing a set of skills which will ultimately enable the water sector to adapt, transform, and to play a vital role in attaining water integration aspects (Mostert *et al.*, 2008). The implementation of IWRM needs joint efforts in order to promote water efficiency and conservation, economic efficiency, and environmental sustainability. IWRM tries to attain the best performance for the water sector with interlinked sectors, looking beyond water efficiency to bring about productivity and profitability. Therefore, the IWRM approach needs regulations that underpin productivity and ultimately promote efficiency.

2.2 Arid countries

Through relevant review of the IWRM approach and its principles, it is critical to explore how GCC countries tackle the challenges related to water: what policies and water resources programmes have been introduced and what are the constraints that could hamper implementation procedures? Thus, the following section will highlight water resources management programmes in the GCC region. But before engaging further with the literature regarding the GCC region specifically, I will expand and extend an understanding of issues related to water shortage and strategies that have emerged to tackle this problem. The focus is on the wider Middle East and North Africa (MENA) region with its geographical and demographical similarities to the GCC, where water resources are scarce and demand for water is relatively high. The MENA region is within the driest regions in the world, and its countries share similar climate condition to the GCC in which 85% of the area is desert. Droogers *et al.* (2012) attributes water shortage issues in the MENA region to population growth, climate change, economic development, and environmental considerations. Its countries have only 0.3% of total freshwater in the world so the MENA region is the driest region, with the GCC countries the driest in that region (Droogers *et al.*, 2012). Therefore, the MENA discussion below addresses water scarcity issues and proposed solutions in this wider region, as a precursor to developing a deeper understanding of water scarcity issues in the hyper arid GCC.

2.2.1 MENA region

Droogers *et al.* (2012) made long-term forecasts for MENA countries using a hydrological model to determine available external and internal renewable water resources under climate and socioeconomic trends. A water allocation model was used to link renewable water resource supplies (principally groundwater, surface water, and reservoirs) to demand for different sectors (i.e., urban, industry, and irrigation) while recognising population growth and socioeconomic change. The results address all MENA countries up to 2050, with water demand forecasts addressing a series of climate change scenarios, namely, those that: (i) ignore climate change effects; (ii) include average climate change; and (iii) address 'dry climate' change. Table 2.2 reports water shortage by 2050 under the climate change scenarios relative to the current shortage for selected MENA countries. For the region, results show an increase in water shortage (ranging from 85 km^3 yr^{-1} to 283 km^3 yr^{-1} in 2050) from a 50% increase in demand and 12% a decrease in supply. Some 22% of the water shortage is due to climate change and 78% to changes in socioeconomic factors. A limitation of the study is that forecast water demand does not recognise that rising water scarcity may incentivise action to mitigate against the forecast shortages.

Table 2.2: Annual water shortage in the MENA under climate change scenarios

Country	**Current water shortage** (MCM)	**Forecast water shortage in 2050** (MCM)			
		No climate change	*Average climate change*	*Dry climate change*	*Wet climate change*
Egypt	2,858	31,332	31,648	61,867	0
Iraq	11,001	48,748	54,860	68,529	38,181
Morocco	2,092	7,369	15,414	19,554	8,219
Kuwait	0	835	801	977	510
KSA	9,467	20,045	20,208	22,717	17,136
Bahrain	195	379	383	389	378
Malta	0	14	36	51	16

Source: Droogers *et al.* (2012)

Addams *et al.* (2009) forecast that water shortage would increase in the MENA region to 99 BCM by 2030, and also reported rising demand as the principal cause of the increasing water demand-supply gap in the region. Trieb and Müller-Steinhagen (2008) develop a long-term forecast where water deficit would increase from 50 BCM to 150 BCM yr^{-1} by 2050. Their study, using numerical modelling based on statistical data of the Food and Agriculture Organisation (FAO), suggested that investments in solar powered desalination would mitigate pressure on renewable water resources gradually to 2050 and ultimately overcome forecast water shortages. The research emphasises an urgent need for immediate decisions of the MENA governments to create the required political and technological conditions for efficient water management, including rapid development of the Concentrating Solar Power (CSP) plant market to increase desalination to tackle a looming water crisis. Assafa and Mohsenb (2017) also emphasised the use of CSP plants, supported by effective water governance in the MENA region, to overcome extreme water scarcity. Using principal component analysis, Jemmali and Sullivan (2014) analysed water scarcity challenges in the region and concluded that greater efforts and new strategies to manage water resources were urgently needed, including investing in solar and wind energy to support increased desalination plants capacity, whilst attaining environmental and economic benefits.

De Stefano *et al.* (2014) and Rached and Brooks (2010) attribute the region’s water crisis to water governance structures and practices. De Stefano *et al.* (2014) discussed the water crisis as a crisis of governance, not a crisis of water, as demand management is a political issue in which governments and citizens should work together to make improvements, but often do not. In their view, water governance is an important issue that determines a country’s ability to deal with future water challenges. They distinguish between concepts of governance, the exercise of economic, political and administrative authority to manage a country’s affairs at all levels, with that of water governance, which refers to a full range of decisions made in managing water, from policy-setting to service delivery. They developed an approach for benchmarking water governance, with data gathered from analysis of official policy and institutional documents and a sample of (25) experts from MENA countries (Egypt, Jordan, Morocco, Oman, Turkey, and Yemen), who in a workshop evaluated water governance using content analysis of policy and legal documents. The study indicated how water governance was connected with the effectiveness of the water system across a range of countries within the region, delivered a baseline for investigating how water governance changes over time for further application, and concluded that increased emphasis on improved water governance is key to tackling the current and future water crisis. The study suggests the need to have instruments to determine how effective water governance is now, and where performance can be improved, and whether or not investment in improvements pays off over time in terms of better water futures.

Varis (2007) and Varis and Abu-Zeid (2009) also emphasise the importance of adopting a regional plan for water governance in the MENA region, based on analysis of World Bank, United Nations (UN), Centre for International Earth Science Information Network (CIESIN), and United Nations Development Programme (UNDP) statistics. These statistics include, for example, population growth rate for MENA region against world population growth rate, the share of irrigation water used in agriculture related to agriculture’s contribution to total GDP in MENA countries, urban and rural population projections in the MENA countries from 2000 to 2030 and data related to GHGs emissions, and economic growth compared to global trends. The study predicts that if current tendencies related to the water sector (e.g., low water productivity, uncontrolled urbanisation, and environmental degradation) continue to 2030, the region will face massive problems and challenges in the water sector. Therefore, Varis and Abu-Zeid (2009) concluded that the MENA countries would struggle with serious water issues by 2030 unless action water conservation policies are adopted at national and regional levels.

In a similar context, Tortajada (2007) and Haddad and Lindner (2001) attribute water scarcity problems to water governance constraints, and support further water legislation and effective water governance, with emphasis on promoting public participation through stakeholder involvement. The key element of effective water governance in the region is referred to as effective stakeholder involvement, whereas in reality, stakeholders in the region almost have never taken part in the decision-making processes. Seeking improved patterns of governance require exceptional coordination between governments of MENA countries and stakeholders and societies in drawing future policies, as well as an implementation of programmes for regional strategy and policies (Haddad and Lindner, 2001; Tortajada, 2007). Furthermore, UNDP (2013) addresses water scarcity in the Middle East (ME) promoting adoption of good water governance to meet escalating demand (UNDP, 2013). ME countries should develop a responsive governance framework to preserve their vulnerable water resources in both conventional and non-conventional resources. The study attributes water crisis problems in the region to a governance crisis represented by the failure to provide sufficient water for marginalised areas, inadequate attention to water legislation and infrastructure, and unsustainable management. The study predicts that the water crisis would be more complex in the future under conditions of climate change, population growth, and continuing unsustainable management. Therefore, the research concludes by emphasising the need to adopt an effective water governance alongside cost-effectiveness analysis that can guide governance by establishing water's proper value and identifying the best socially, economically, and environmentally cost-effective policy decisions.

Zyadin (2013) considers MENA water sources (groundwater, treated wastewater, and surface water) and influences on water availability and allocation, including climate change, population growth, agricultural technologies, and regional transboundary water conflicts (e.g., countries share Nile river water, and other countries share the Jordan river). He concludes under current trajectories that per capita water availability will continue to plummet, and that conventional engineering responses proposed to date have been insufficient, hence measures drawing on social psychology are needed. A resulting synthesis analysis of cross-sectional bottlenecks argues that political instability and a clash of ideologies constrains MENA governments from closing the water-supply gap using large capital projects. As well, innovative approaches are needed drawing on supply side, e.g., rainwater harvesting, maximising storage capacities of built dams, groundwater recharge, desalination via clean energy technologies, and demand side management via privatising drinking water utilities and pricing strategies. Water awareness programmes and stakeholder participation are also neeed to raise public awareness of the value of water. The study concludes that effective water governance and water demand management would solve the MENA water crisis.

From the above we can conclude that the MENA region as a whole has a significant water shortage driven by population growth, climate change, and unsustainable management practices. Numerous studies predict rising water shortage where the gap between supply and demand grows, particularly due to demand increase, exacerbating the water crisis. MENA literature variously emphasises the importance of water governance and stakeholder participation; the need for supply side investment in renewable energy fuelled desalination plants; and the environmental, economic, and social benefits of developing a more sustainable water supply. Much of the literature focuses on scope for supply side augmentation to meet increasing demand, with surprisingly little attention given to scope for demand side controls which are largely absent. This anomaly is likely a reflection of considerable variability in per capita supply and demand across the region as a whole, where countries can be considered as hyper-arid, arid, and those with access to transboundary water. The GCC countries are classified as hyper-arid (Bucknall, 2007) with the lowest renewable freshwater per capita in the region and the world (Abdel Khaleq and Dziegielewski, 2006; Al-Ansari *et al.*, 2014). GCC countries are the most water stressed in the wider region yet have the highest water use PCC, and hence demand side controls are an obvious approach to dealing with the water crisis here. The general absence of such measures is surprising, and it is then necessary to review how the GCC countries manage their water resources under severe conditions, including, for example, drought and very high population growth.

2.3 Hyper-arid countries of the GCC

Many studies explore water management programmes for the GCC using scenario forecasting. For example, Dawoud (2017) developed five scenarios that estimate the demand for water using the WEAP (Water Evaluation and Planning) model for water supply and water demand under population growth, and the LEAP (Long-Range Energy Alternatives Planning) model for energy and electricity demand and supply, and carbon dioxide emission. A coupled WEAP-LEAP model is then used to evaluate future performance for water and energy under climate change to 2060. Results show that current management (Business As Usual (BAU) scenario) would lead to increasing groundwater over-abstraction, increasing desalinated water production, intensive use of energy, and high CO_2 emissions. The main drivers of such inefficient use are high subsidies that GCC governments apply in the water sector which do not match actual water production cost, and high population growth. The study concludes that the current system of water resources management in the GCC states has reached its limits and led to unanticipated consequences, and it is expected to be more complex under climate change conditions. Therefore, there is an urgent need to change current ineffective trends to adopt more efficient management.

In 2016, the GCC Supreme Council launched a Unified Water Strategy, 2016 – 2035 (GCC UWS) in an attempt to reduce water demand, set targets for water use, and to eliminate environmental and economic impacts (Al-Zubari *et al.*, 2017). The strategy emerged as a result of several pressing problems, the first, supply networks leakage ranging from 20% to 40% (except Kuwait at 5%), second is rising municipal demand (which accounts for more than 50% of total consumption for Bahrain, Kuwait, and Qatar) due to high demographic growth and ineffective institutional regulation that does not encourage water savings. The third driver is the environmental and economic impacts of water demands such as increasing CO_2 emissions and high fiscal burden on GCC economies, and the fourth driver is the impact of climate change under an uncertain future. The project utilised the WEAP modelling system and developed two scenarios, business as usual, and GCC United Water Strategy (UWS) for each country and each sector (i.e., wastewater, domestic, industrial, and agricultural sectors). The main target of the project is to reduce total per capita consumption to reach less than 250 l/d through several instruments and techniques, such as reduction of leakage to less than 10% by 2035. This project constitutes a milestone project for the GCC, covering water issues in all aspects, from water governance to the nexus amongst water, food, and energy.

Saif (2012) uses an Analytic Hierarchy Process-Multi-Criteria Assessment (AHP-MCA) approach to find solutions that could curb the environmental impacts such as, increasing GHGs in the atmosphere and to control water demand and supply. The analysis uses primary qualitative data drawn from interviews with officials in Qatar and UAE, and secondary data regarding forecast water demand and projected desalination in those countries to 2020. Saif (2012) concludes that it is necessary to enforce effective policy in the main sectors (i.e., energy, water, environmental, and institutional sectors), and recommends governments in the region place greater emphasis on demand management strategies as opposed to the usual supply management response.

Al-Zubari (2002b) attributes the water deficit in the GCC to population growth (the highest in the world at 3.5%) and accelerated agricultural, industrial and social developments. Furthermore, due to the rapid increase in population and urbanisation, municipal water needs have increased at rates that the allocated available water resources can’t keep pace with. These needs are as the result of the lack of effective conservation programmes, insufficient tariffs and charges for water use, and extreme leakage from municipal supply networks, which have led to high per capita water consumption rates in the domestic sector. Therefore, Al-Zubari proposes three scenarios up to 2025, investigated via mathematical modelling. These are: Baseline (business as usual); Supply Augmentation; and Supply Augmentation and Policy Remedies scenarios, based on projected population growth in 2025 by UNDP 1997. Results show all these scenarios will have deficits, but to varying degrees. In BAU scenario, deficit will reach 72.53 BCM with no change of consumption in the domestic and industrial sectors, and improvement in the agricultural sector only to achieve 20% of water saving by 2025. Under the Supply Augmentation scenario, there is an increase in desalination capacity and a gradual increase in recycled wastewater, but nevertheless, the deficit reaches 56.74 BCM. For the Supply Augmentation and Policy Remedies scenario, there is a gradual decrease in per capita water use in the municipal sector to 300 l/d through review of water pricing and awareness programmes. A decrease in the agricultural sector water consumption is also attained by efficient irrigation technology and changing crop pattern, yet the water deficit is still substantial at 43.50 BCM. The author recommended that to maximise a policy's efficiency and for it to be fully beneficial, it must be monitored continuously.

The World Bank (2005) attributed escalating water demand in all GCC countries to supply policies in the agricultural and domestic sectors which have led to increased PCC and decreasing natural freshwater availability. In the domestic sector, high water demand is attributed to a lack of conservation measures (e.g., price signalling mechanism). The research forecast water supply and demand to 2025 for Kuwait and UAE and included the forecasts of Al-Zubari (2002a). For Kuwait, the projections employed water pricing and population growth as parameters and developed four scenarios. In the first scenario, water consumption for daily per capita use is 785 litres where the assumption is based on historical trends (total consumption growth on of the period 1993-2002). In the second scenario, per capita consumption is 830 l/d where the water tariff is unchanged and population growth increases by 5% per annum. In the third scenario, per capita consumption peaks at 928 l/d, based on an increase of population growth at 3% per annum. In the final scenario, a block tariff would be applied, and per capita consumption would drop to 397 l/d. In the case of the UAE, supply would increase from 1,222 MCM in 2002 to 7,134 MCM in 2025, and demand would increase from 3,504 MCM to 14,379 MCM, driven by domestic and agricultural sectors. The study concludes that there is an urgent need for a review of the water resources sector, with a view to providing an enabling environment for implementation of comprehensive and sustainable water resources management strategies. Therefore, the study recommends adopting integrated water resources management, enhancing domestic water demand management, and enhancing water supply management. Several related studies emphasise a focus on supply management with the aim of enhancing water efficiency (Bushnak, 1990; Al-Hajri and Al-Misned, 1994).

Al-Zubari (1998) emphasised use of treated wastewater to compensate for shortage in domestic, agricultural and industrial sectors in the GCC as a result of a forecast that predicts increasing deficit in all GCC's water sectors (Al-Zubari, 1998). Use of treated wastewater is considered a significant supply side addition with environmental and financially benefits (Aleisa and Al-Zubari, 2017). Recommendations to the GCC countries are to support politically and legally the reuse of wastewater and to raise awareness of its benefits through education programmes and investment in wastewater treatment plants. Similarly, Al-Rashed and Sherif (2000) emphasise the need to adopt an efficient and integrated policy for wastewater use alongside the application of relevant conservation techniques in various water consumption sectors.

Odhiambo (2016) concludes that the GCC countries should develop integrated management approaches, water conservations measures and effective management plans, otherwise it will be necessary to increase desalination plant capacity and extend mining of fossil aquifers. This is as a result of forecasts to 2025 (World Bank 2005) for agriculture, industry, and domestic sectors in the GCC and an estimation of population growth to 2050 from the United Nations 2012 (Odhiambo, 2016). Odhiambo emphasises the need for conservation measures for domestic water uses (e.g., price signalling) due to accelerated population growth, the main driver of water demand. El Sayed and Ayoub (2014) conclude that 70% of total desalination production that goes to the domestic sector is wasted due to water leakage in municipal networks and ineffective water tariff systems, as most water policies focus on supply management. Therefore, similar to Parmigiani (2015) and Abderrahman (2000), they propose a strict water tariff and IWRM programmes, including demand and supply side management, with the aim of reducing environmental and economic impacts. Saif *et al.* (2014) recommends that the GCC governments develop new water resources based on desalination using non-fossil fuels, including renewables and nuclear power. The barriers to do so are recognised, including renewable energy availability, affordability, and political and security issues related to using nuclear energy.

In the view of Al-Hashemi (2014), population growth is the main reason for persisting water problems and its adverse consequences. The leading sector which consumes a lot of water per nation, is the municipal sector. For example, population growth in the UAE increased over 300% between 2003 and 2013, where desalination capacity increased by more than 220%. Through analysing time series data for both population growth and increasing desalination capacity for all GCC countries, Al-Hashemi concludes that the GCC countries are the world’s leaders in desalination technology but that they should also be leaders in demand management too. He identifies an urgent need to implement new laws to alleviate unsustainable water use by increasing the level of public awareness of water scarcity, installation of water saving devices (WSDs) in households and implementing measures to protect available water sources from environmental degradation, including a comprehensive policy that involves public participation.

From analysis of population and water demand in the GCC region to 2025 (using UNDP and Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) data), Dawoud (2005) recognised high population growth as a key in the GCC water problems, but also pointed to deficient institutional arrangements and poor management practices, and in particular an over-reliance on new desalination water. He emphasised the need for research and development to reduce desalinated water production costs and raise efficiency. Other studies also encourage enhancement of desalination plant performance, including energy use reduction, through more efficient water use (Darwish *et al.*, 2009; Fath *et al.*, 2013).

Al-Senafy *et al.* (2003) concluded that GCC countries need to implement water resources conservation programme measures consisting of public awareness, use of WSDs, and leakage reduction as well as water billing. Public awareness campaigns can reduce water by 5% of total demand, and with water conservation devices alongside leakage reduction, these would save 10-20% of total demand. In addition, effective water tariffs could deliver a 20% water demand reduction (Al-Senafy *et al.*, 2003). Al-Senafy believes these instruments should be employed in GCC region as a policy, due to the high water resources deficit and rapidly escalating demand in the domestic sector, the high cost of construction and operation desalination plants, the high cost of subsidies, and the excessive use groundwater.

The review of GCC water literature shows that the domestic sector is the largest user of water, with the highest per capita consumptions in the world. Numerous studies forecast substantial increases in domestic demand over the long term. Whilst there is much interest in IWRM and a discussion of a wide range of management measures, the emphasis remains on supply side solutions, including continued fossil water mining, wastewater reuse, and in particularly increasing desalination capacity. There is interest in fuelling the latter using renewable technology, and even nuclear power, but these technological fixes come with substantial costs and risk. Water use remains highly subsidised in the GCC and whilst there is some interest in demand side controls, its use remains in its infancy. To date there has been relatively little active implementation of demand management in GCC countries despite the increasing water gap, and largest per capita consumption rates in the world. Therefore, it is important to investigate what has been achieved to date in individual GCC countries to tackle the problem of high and increasing domestic water demand.

2.3.1.1 Kingdom of Saudi Arabia (KSA)

The Kingdom of Saudi Arabia is a large desert country (2,150,000 km^2), the largest in the GCC region. Domestic water (and sanitation) is very costly because the central area of the kingdom, including the capital Riyadh, relies on pipeline transmission from desalination plants in the Arabian (Persian) Gulf to the east and Red Sea to the west. Elhadj (2004) concluded that the growth in Saudi cities' demand for household water in the central KSA, such as Riyadh and Qassim should be sourced from groundwater aquifers rather than desalination water because it is much less expensive. It is also inefficient to plant water-intensive crops such as alfalfa and wheat, when importing them from the international market is much cheaper. The study recommended diverting groundwater from the agricultural sector to the household sector, and more fundamentally, that KSA's water governance should be based on a participatory approach rather than an absolute monarchy. Abdulrazzak and Khan (1990) attributed increasing water demand in the domestic sector to population growth, changing lifestyle patterns and people moving from Beduin dwellings to cities. They forecast a rapidly increasing PCC in the domestic sector and suggested a comprehensive water plan focussed on consumer-oriented domestic water conservation practices was needed. The plan consists of education programmes and public awareness campaigns, use of conservation water devices and building codes, metering, billing, and an excess water use penalty, as well as wastewater reuse. These instruments were considered able to reduce PCC from 260 l/d in 1990 to less than 117 l/d. A study of public awareness of water issues and related policies in the domestic sector, using a questionnaire survey of 197 householders in eastern KSA showed low public awareness of water shortage (Ouda *et al.*, 2013). Few respondents have water conservation devices at home, but a high percentage expressed readiness to purchase and install conservation appliances, whilst the majority consider that the water price is low and are willing to pay more for water.

Ouda (2013) examined water tariffs for domestic use and found that the block rate tariff only covers 5% of production cost and so doesn't reflect the real price of water and so does not encourage consumers to consume water efficiently. The subsidies which the Saudi government provide for domestic use reached 2,596 million US$ in 2010 and are estimated to reach 6,472 million US$ in 2020, driven by high population growth. Ouda (2013) proposed a new rising block tariff consisting of five blocks, with the first block charge at (1.3 US$) for less than 50 m^3, and the fifth block rising to (4.3 US$) for more than 300 m^3 a month. The study recommends that the KSA government implements urgent demand management measures in order to increase the economic efficiency. The measures include water bill payments collection improvement, replace old meters with smart meters, reduce Unaccounted for Water (UFW), awareness campaigns, and a subsidised programme to adopt WSDs.

2.3.1.2 State of Qatar

In Qatar, domestic water is fully subsidised for local people and partly subsidised for foreign residents (Al-Mohannadi *et al.*, 2003). Al-Mohhanadi (2003) used a questionnaire distributed amongst 724 respondents to investigate public awareness of water shortage and its consequences, and to assess attitudes to the importance of water and to water laws and tariffs. The results showed that efforts to control water demand in Qatar using awareness campaigns, legal restrictions and tariffs have been ineffectual. The study concludes that the government should develop tighter legislation for the water industry, introduce an effective water tariff that motivates consumers, and focus on renewable sources to operate desalination plants such as solar energy. Baalousha and Ouda (2017) note that domestic water demand is mainly met by desalination (99%) making rising domestic demand the biggest water challenge. The second challenge is leakage of supply networks which has reached 30% of water supplied. The authors developed three forecast scenarios to 2040 to forecast domestic demand under pessimistic, moderate, and optimistic scenarios that are based on demand-supply management. In the optimistic scenario, demand falls 2% per annum to 2040, driven by leakage controls; in the moderate scenario, demand falls 0.5% per annum, and under the pessimistic scenario, demand is not reduced. The study recommends implementing measures to control demand, else substantial investment will be required to increase desalination capacity and water supply infrastructure (Baalousha and Ouda, 2017).

2.3.1.3 Kingdom of Bahrain

In Bahrain, literature related to water management in the domestic sector is scare. Al-Zubari *et al.* (2018) used the WEAP model to assess vulnerability of the municipal water system to climate change. The model is used to forecast domestic water demand and associated costs, with and without climate change for 2012 – 2030, under five scenarios: business as usual, reduce leakage rate, raise water awareness, use water saving devices, and a comprehensive scenario of all previous options. The results show that climate changes increase water demand, but that the additional demand can be alleviated by the conservation measures. Although there are high uncertainties in the model, the author concludes that climate change would add particular pressure on the domestic sector (e.g., household members having longer and more frequent shower) which would present further challenges to water management in the future; therefore, the government should review the water resources management system and raise its efficiency. Also using the WEAP model, Al-Zubari (2014) shows escalating water demand to 2030 and estimated rising CO_2 emissions from increasing fossil fuel use in water production. Al-Zubari recommends revising the current tariff structure to conserve water, increase cost recovery, achieve social equity amongst water users, and so alleviate the negative environmental impacts of rising demand.

2.3.1.4 United Arab Emirates (UAE)

Giwa and Dindi (2017) proposed reducing UAE total water demand through the implementation of several options in the household, including water conservative devices, cost-reflective water pricing, and building codes. Moreover, Srouji (2017) and Qdais and Al-Nassay (2001) concluded water price is the main instrument to control water demand efficiently in the household sector in UAE. DeFelice and Gibson (2013) used a probabilistic model to examine whether water pricing could reduce GHGs emissions and reduce high water demand. Their result showed that water pricing could reduce air pollutant and greenhouse gas emissions by 1% to 5%, depending on assumptions about how households respond to the incentives. Demand side management plans curbing per capita consumption to levels typical of Singapore or the United Kingdom would curb emissions by 10% or 11%, respectively. They conclude that the reduction in water demand will play a key role in the progress of UAE over the following 20 years.

2.3.1.5 The Sultanate of Oman

The situation in Oman is similar to Bahrain in which there are few studies in the domestic sector. However, Rahman *et al.* (2018) attempted to explore the importance of water saving devices (WSDs) in the domestic sector through a survey of consumers. Results show WSDs were effective in restaurants, mosques, hotels, and government buildings, but not in households. They suggested retrofitting plans that include replacement of current plumbing equipment, plus a residential water audit program.

2.3.1.6 State of Kuwait

The domestic sector is the largest water consumer in Kuwait, accounting for an estimated 60% of total demand. Nevertheless, there are very few studies that have investigated the reasons for such high demand and very few studies have addressed the problem. Fadlelmawla (2009) highlights that in Kuwait average Per Household Consumption (PHC) was about 814 l/d in 2001, amongst the highest rates in the world, and concludes that the government of Kuwait should impose tighter regulation, such as mandating WSDs, restructuring the water tariff, penalising wasteful practices, and implementing public awareness campaigns. The author emphasises the use of WSDs, due to an experimental result in governmental facilities which used WSDs for four weeks which resulted in a 30% reduction in water consumption.

The most recent study for the household sector is by Water Research Centre of Kuwait Institute for Scientific Research (WRC/KISR), who investigated which components of household demand consumes most water, using real-time ultra-sonic flow monitoring of domestic water consumption amongst 153 household volunteers (Aliewi and Alayyadhi, 2018). The result shows that total household use, broken-down into micro-components, has a PCC of 245 l/d in comparison to total PCC equivalent for the country, from all demands, of 475 l/d (hence the estimate that households accounts for 60% of total demand). Water supply and consumption have received significant attention in the last few years due to increasing water scarcity and decreasing availability of renewable water per capita. The old solutions which were dependent on increasing water supplies have reached their limit and are no longer considered effective and sustainable solutions, and the government are encouraged to implement tighter demand management to balance demand and supply. Aliewi and

Alayyadhi (2018) recommends concentrating on demand management, including use of water pricing, which will help stakeholders to take initiatives in decreasing their use. They also suggest finding ways to invest in alternative technologies, for example media networks should be used to broadcast televised shows or advertisements on the status of water resources and supply in Kuwait as well as using schools to educate young people on the water scarcity and its issues in Kuwait.

Al-Humoud and Al-Ghusain (2003) surveyed 3,000 members of the public selected randomly, to explore water awareness and management options. The survey was stratified by living conditions (e.g., household size, income level) to estimate water consumption of respondents. Of the participants, 24% of households had more than four family members, 68% of citizens lived in two-story houses, 86% of houses have gardens, and 44% of these gardens are watered three times a week. Regarding households' income level, 27% of them had incomes ranging from 3,343 to 5,010 US$ per month, whilst 22% made more than 6,680 US$, whereas 21% made between 2,341 and 3,340 US$, and 14% and 13% of them made 1,670 – 2,338 and 5,010 – 6,680 US$, respectively. The average monthly water bill payments ranged from 67 to 234 US$, noting that 1,000 Imperial gallons (4.545 m^3) cost the MEW supplier 8.85 US$, yet consumers pay only 2.65 US$.

The study found that Kuwaiti households use 44% of their water consumption to wash their clothes daily, 23% four times a week, 12% three times a week, and 5% once a week. Furthermore, floor scrubbing, especially as dust covers the floor most of the summertime, consumes much of their water supply: 44% wash their floors daily, 23% twice a week, and 13% four times a week. The forecasting approach was applied in this study, and the autocorrelation function (AUF) model was used. A time series methodology was also used to forecast water consumption. In the model, 30 observations were conducted from 1970 until 2000 to generate an estimated short-term forecast of household water consumption. The series indicates that the demand will grow by 8% per annum. Therefore, the research emphasised the shift of the government's supply and expansion in its water production policy, to seek alternative policies that control water demand. Earlier literature focuses on future forecast by time series extrapolation over 30 years of observations and then generating estimations. These ignore many behavioural components such as population growth and changing lifestyles, which are influential variable in water demand consumption.

According to Milutinovic (2006) multiple factors lead to the high demand in Kuwait, including temperature and pipeline leakage, but there is one factor that has a massive effect on consumption: water pricing. Milutinovic (2006) therefore investigated the influence of a rising water block tariff (free water up to 150 l/d, after which the price is 1 US$ per m^3) compared with a flat tariff (also called volumetric uniform rate), using price elasticities from studies in other arid regions (California, Spain, KSA, Tunis, and Australia). Results showed how this pricing water would decrease the demand 20 to 40 percent above the 150 l/capita/day free water allowance and would deliver a revenue to the government of about 420 million US$ yr^{-1}. The research also stated that paying for water in the state of Kuwait is not common behaviour – water is charged for, but most payments are not collected due to weak governance and legislation (e.g., that mandates a maximum period after which unpaid bills are written off; some customers have not paid their bills for years), which leads to wasteful use. Therefore, water bills might not affect customers, and would instead be treated as unnecessary fees and would not be accepted by the public. In contrast, a free initial water allowance would be more acceptable among consumers and might address the water problem in the country. The results were assumed applicable to other GCC countries, as they have similar characteristics and water is generally under-priced. The author recommends further demand management studies in the domestic sector.

Nevertheless, the major obstacle remains that there is not a culture of paying for water in Kuwait. The government shoulders most of the water production cost (an old regulation which has not changed) which is high compared to international costs. In the domestic sector, the government subsidises water use by more than 1 billion US$ yr^{-1} and only about 25% of water charges due are collected (Darwish *et al.*, 2009). Undoubtedly, subsidies have led to high and excessive consumption. On the other hand, a flat rate subsidy is enforced for both high- and low-income households, so those with lower income may be more heavily penalised by stronger enforcement of the flat rate tariff, which is arguably against the Dublin principle relating to equity. Restructuring the water tariff towards an increasing block tariff may therefore be preferable.

Table 2.3: Literature addressing water scarcity and insecurity in MENA and GCC

Author	Region/Country	Method	Outputs
Assafa and Mohsenb (2017)	MENA	Descriptive analysis	The transition to CSP plants technologies needs effective water governance.
Jemmali and Sullivan (2014)	MENA	Principal component analysis	The renewable-based energy to operate desalination plants is a strategic option to MENA.
De Stefano *et al.* (2014)	MENA	Content analysis (professional stakeholders)	Enhance the current water governance performance and set plans to improve future governance performance to create better water futures.
Droogers *et al.* (2012)	MENA	Hydrological modelling (GIS)	Five future scenarios projections (2050) to water demand under climate change conditions.
Varis and Abu-Zeid (2009)	MENA	Descriptive analysis	Action towards achieving water conservation policies and convert from national policies to regional policies basis.
Trieb and Müller-Steinhagen (2008)	MENA	Numerical modelling	Recommend immediate and urgent decisions should be taken by MENA governments to create the political and technological conditions for efficient water management and a quick market introduction and extension of CSP to tackle water crisis.
Dawoud (2017)	GCC	WEAP-LEAP modelling	Developed five scenarios to estimate the demand for water and energy under various conditions by 2060.
Al-Zubari *et al.* (2017)	GCC	WEAP modelling	Set targets to the year 2035 (PCC less than 250 l/d, and supply networks losses less than 10%).
Odhiambo (2016)	GCC	Descriptive analysis	Implementing water conservation measures to the domestic sector.

Author	Region/Country	Method	Outputs
Al-Hashemi (2014)	GCC	Descriptive Statistical Analysis	Shifting from supply management to demand management (implement a new set of legislation).
Saif (2012)	GCC	AHP-MCA/Field survey	Place greater emphasis on demand management strategies opposed to the usual supply management response.
World Bank (2005)	GCC	Literature survey	Scenarios for future prediction (2025) to Kuwait and UAE, summarising to adopt IWRM in GCC.
Al-Zubari (2002b)	GCC	Mathematical modelling	Three scenarios predict future situation (2025), summarising to a deficit in all the scenarios.
Al-Zubari *et al.* (2018)	Bahrain	WEAP modelling	Five scenarios to predict future (2030) in the domestic sector under climate change conditions.
Abdulrazzak and Khan (1990)	KSA	Scenario analysis	Examined the effects of demand measures in the domestic sector.
Aliewi and Alayyadhi (2018)	Kuwait	Experimental (real-time ultra-sonic flow monitoring)	Experimental examination to measure the consumption of the household components in 153 households.
Milutinovic (2006)	Kuwait	Regression modelling	Examine the effect of price signalling in reducing water demand in the household sector.
Rahman *et al.* (2018)	Oman	Field survey (questionnaires to stakeholders)	Examine the effect of WSDs in the domestic sector.
Baalousha and Ouda (2017)	Qatar	Scenario analysis	Three scenarios to predict future demand (2040) under different situations in the domestic sector.
DeFelice and Gibson (2013)	UAE	Probabilistic model	Examine the effect of water pricing in the household sector in reducing GHGs emissions.

2.4 Discussion

From the review of water resources management in the GCC, it is evident that the water crisis is amongst the most crucial issues for governments of these countries over recent decades. The key attention of the GCC has been to augment supply, to tackle severe water shortage, and this remains the dominant focus. However, most literature observes that the supply side focus has resulted in unsustainable water management practices, represented by over-abstraction of groundwater, increasing fossil fuelled desalination capacity, and very high subsidies for the domestic, agricultural, and industrial sectors. Over-abstracting groundwater to meet agricultural policies has resulted in groundwater depletion, water quality degradation (increases in water salinity and dissolved substances), declining soil fertility, and loss of arable lands as a result of irrigation with brackish and saline water. The rapid depletion of groundwater is a result of unsustainable and uncontrolled use (most GCC members do not charge for groundwater), using low-efficient irrigation technologies, planting water-intensive crops, and traditional irrigation systems, such as flood irrigation, which is jeopardising this strategic source of water. Nevertheless, the agricultural sector only adds about 2% of the total region's GDP budget, whereas the cost of production is much higher than the revenues.

GCC countries have heavily invested in desalination technologies in order to meet high and increasing demand in the domestic sector (from very high population growth and unsustainable management). Desalination technologies constitute the backbone source of water for the domestic sector in the region (e.g., 99% of domestic supply in Qatar, 97% in Kuwait 97%, and 100% in UAE). Unsustainable and weak management for water use in the domestic sector represented through ineffectively low-tariffs (highly subsidised and under collected), uncontrolled network leakage, and increasing-supply policy have adversely affected the economy and the environment and represent wasteful use of desalination resources. Economically, revenues from water bills never exceed 8% of total production cost, far below full cost recovery, which means that under current demand trajectories, subsidies will place an even heavier burden on the fiscal budget. For the environment, relying on fossil fuels to operate desalination plants has led to increasing GHGs emissions and to the highest CO_2 per capita emissions in the world, as well as increasing brine discharge to the sea which adversely impacts the marine ecosystem.

Furthermore, GCC countries have not efficiently invested in wastewater treatment. Wastewater treatment and reuse have potential to be a significant source of water, with production costs and environmental impacts less than for desalination. However, reuse of treated wastewater currently constitutes only 1.8% of the total water supply in the GCC. Wastewater treatment management is of limited effectiveness – about 56% of wastewater is treated, but only 30% of treated wastewater is reused. Thus, the region has lost a key opportunity to mitigate against scarcity as efficiency of wastewater recovery is low with a large mismatch between treatment levels and reuse.

Achieving water sustainability in the region is not easy due to the multiple challenges that constrain delivery. A high population growth rate, high per capita consumption and very low per capita availability represent major challenges. The percentage of UFW (water supply network losses) is at high levels, between 20% and 40% in GCC countries (except Kuwait 5%). Climate change and fast-changing socioeconomic development further put the region's countries under water stress, increasing the gap between supply and demand. High water production costs and severe environmental impacts of desalination add further high economic and environmental stress. Weak governance is also one of the greatest challenges, represented by inadequate legislation to manage water resources, absence of actor coordination, conflicting responsibilities amongst institutions, a lack of stakeholder participation, and weak mechanisms for implementing those regulations that exist.

Much of the available literature (Bushnak, 1990; Al-Hajri and Al-Misned, 1994; Al-Zubari, 1998;2002b; Al-Rashed and Sherif, 2000; Worldbank, 2005; Dawoud, 2005; Saif *et al.*, 2014; Aleisa and Al-Zubari, 2017; Fath *et al.*, 2013; Darwish *et al.*, 2009) focuses on supply side management options for meeting increasing demand and tackling water scarcity. However, a substantial body of literature (Abderrahman, 2000; Al-Senafy *et al.*, 2003; Saif, 2012; El Sayed and Ayoub, 2014; Al-Hashemi *et al.*, 2014; Parmigiani, 2015; Odhiambo, 2016; Ramadan, 2015; Al-Rashed and Akber, 2015) attribute the current water stress to supply side strategies, and recommends shifting to water demand management (or IWRM in which demand management is addressed). Surprisingly, very few studies develop water management forecasts with a focus on demand management (Al-Zubari *et al.*, 2017; Dawoud, 2017).

Most literature on the region's water resources concludes that demand in the domestic sector is increasing rapidly, increasing the complexity of the crisis, and representing a key challenge for the future. However, few studies address the domestic sector specifically, and most that do are based on descriptive analysis which reflect on current trends (e.g., high demand, poor management, unsustainable practices), before advocating demand management via a packages of measures (Qdais and Al Nassay, 2001; Al-Mohannadi *et al.*, 2003; Al-Humoud and Al-Ghusain, 2003; Elhadj, 2004; Darwish *et al.*, 2009; Fadlelmawla, 2009; Zaharani *et al.*, 2011; Ouda, 2013; Ouda *et al.*, 2013; Srouji, 2017; Giwa and Dindi, 2017; Rahman *et al.*, 2018; Aliewi and Alayyadhi, 2018; Al-Zubari, 2014). Very few studies have addressed the regions water scarcity crisis with respect to water demand management (Abdulrazzak and Khan, 1990; Milutinovic, 2006; DeFelice and Gibson, 2013; Baalousha and Ouda, 2017; Al-Zubari *et al.*, 2018), with little consideration of the domestic sector specifically.

2.5 Gaps in knowledge

From the review, we can identify three clear gaps in the literature relating to resolution of the water crisis in GCC countries:

(1) A lack of knowledge on water demand management in the GCC region, as most studies have concentrated on supply side management. For demand management, only two studies (Al-Zubari *et al.*, 2017; Dawoud, 2017) have explored the role of water demand management on future demand and scarcity.

(2) A general lack of research on the domestic sector, and very little research addressing demand management in that sector. Available studies tend to be rather outdated, for example, Abdulrazzak and Khan (1990), and Milutinovic (2006).

(3) Also, largely missing in the literature is an evaluation of the wider benefits of demand management (e.g., revenue, reduction in desalination costs and impacts), which if recognised could incentivise more water efficient management.

Chapter 3 Baseline water demand forecast: Model development

3.1 Overview

The research has three main objectives, of which the first is to forecast household water demand under a Business as Usual scenario to 2050. In this chapter household demand is modelled for the early base years (2013-2018) to produce estimates of demand by household characteristics. Relevant datasets for the BAU forecast are investigated, and where necessary further developed. In chapter four, these BAU water demand estimates are projected to 2050 to reflect a series of demographic projections, thus providing a disaggregated BAU forecast to 2050. A baseline demand forecast begins with an analysis of the current situation that identifies the starting point for modelling and/or forecasting the future (Hogg *et al.*, 2005). Thus, chapter three addresses the early baseline demand of the household BAU demand forecast (objective 1.1). It delivers a critical reference point for the chapter four BAU projections, and so creates a basis for comparing demand with and without water conservation interventions.

The chapter starts by discussing the search for potentially suitable data sets, and then presents those used in baseline (2013-2018) development; these include data from the Ministry of Electricity and Water on aggregate demand, and demographic and other data sets used to disaggregate this demand. Moreover, this chapter specifies the procedures that have been applied to the collated datasets to ensure its readability for further modelling. These procedures include; first, data organising and classifying; this includes work to categorise and define data types (e.g., category: water demand; type: aggregate, disaggregate demand by type – e.g., PHC, PCC and micro-component). Second is data cleansing; this procedure comprised omitting unwanted and incomplete data. Third, statistical procedures, including assumption and simulation processes were applied to address data insufficiency. After applying these procedures, the household BAU baseline demand was built, then, accuracy and validation tests have been applied to ensure the model is well enough for BAU future forecast and subsequent backcast modelling.

3.2 Data collection field trip

This research adopts a model building process to determine potential transition pathways. In doing so it must first build a BAU forecast of future water demand, which in turn requires model construction. Many models of water demand exist, and collectively represent understanding of the many factors that influence water demand. As no suitable household water demand model for Kuwait exists, it must first be constructed. This model building exercise is informed by prior water demand research from which the main drivers of water demand can be determined and included in the model. This then is neither an extreme induction nor extreme deduction approach but is arguably closest to what Overmars *et al.* (2007) refer to as 'theory guided factors induction'. This position is one where existing theory suggests a short list of variables which informs model building.

This approach therefore relies on an understanding of the likely drivers of water demand, plus awareness of associated data from which a model can be built and validated (which in our case is partially achieved via simulating water demand in a spatially disaggregate manner). Collecting substantial data to accomplish the research is thus a significant step and a crucial phase of the research. For Kuwait, little of the relevant data is available online, and an in-person data audit and collation field trip to Kuwait was required, with numerous visits made to relevant departments in the country to understand what data exists, and to gain access as required (Table 3.1). The focus is on the household sector and hence the variables of key interest were population, household size, household status (Kuwaiti or non-Kuwaiti), and dwelling type (see review of drivers in chapter two). The field trip established that the MEW constitutes the sole authority responsible for water supply, distribution, support, and administers a centre for water research. However, the ministry and its agencies (i.e., Kuwait Institute for Scientific Research (KISR); Kuwait Foundation for Advancement of Science (KFAS); and the Kuwait Water Association (KWA)) have no complete statistics regarding disaggregate household water demand (e.g., PHC by household size, household status, and spatial distribution by governorate), neither historical nor recent reports. The only governmental entity that holds any such statistics is the Central Statistical Bureau (CSB). Their statistics are based on household expenditure survey (on food, fuel, water, etc.) from which household consumption of water is inferred. However, these statistics are limited to one-year only

(2013) due to the cost (overseas surveying experts, recruitment of surveyors, and issues with participant consent, see section 3.3.2 for more detail).

Following the fieldwork trip, the collected data was examined, organised, and classified to be ready for further data analysis and modelling (Table 3.2). As a result of the previous action, an insufficiency of data was revealed, that constrains the development of an observed disaggregated baseline (2013; the current situation) and for BAU forecasting. Therefore, further work on the datasets was required, comprising cleansing (e.g., removal of unwanted values), and modification employing several assumptions and estimations.

Table 3.1: List of visited institutions in Kuwait during data field trip

Institution	Department	Aqcuried datasets
Ministry of Electricity and Water (MEW)	1. Consumer's Affairs 2. Research and Studies 3. Desalination Plants	- Water Book 2018 - Datasets related to Greenhouse Gases (GHGs) emissions from desalination plants and some article of water demand in household sector
Central Statistical Bureau (CSB)	1. Information Technology 2. Census Division	- A sample survey of 2,961 households with household water demand by various demographic variables (household size, household status, and households' spatial distribution by governorates); it is based on a 2013 survey of demand inferred from household expenditure. - Annual Statistical Abstract (2015-2016).
Public Authority of Civil Information (PACI)	Census Division	- Tables of the household sector (residential) census from 1998 to 2018; these include household size, household status, and the spatial distribution of the households over the country's governorates.
Kuwait Institute for Scientific Research (KISR)	1. Water Research Centre (WRC/KISR) 2. Techno-Economic Division (TED/KISR)	- A report on micro-component use of water in the household sector (TED/KISR: 2017). - A report on micro-component use of water for Kuwaitis in villas, plus the associated raw data (WRC/KISR: 2018).

Table 3.2: Datasets and variables for forecasting future demand

Purpose/Target	Type of datasets	Variables and source	Process of examination, classification, and organisation
- To assume missing values, i.e., household sizes that are not included in CSB matrix (see section 3.3.2). Assumption process by apply fitting-function regression (see section 3.4). - To apply this matrix with the aggregate household population in the household sector to generate the baseline year (2013) by using spatial microsimulation method (see section 3.5).	Household water demand and aggregate household population (2013)	Household size, type of dwelling, PHC demand, distribution over the country's governorates, and household status (Kuwaiti and non-Kuwaiti). Source: (i) CSB survey sample for the year 2013; (ii) PACI, population census	- Creating an equation to convert the cost of water demand (per household) to consumption by litre per household per day. - Omitting households that have zero demand (missing records) and/or households that have no specified dwelling type. - Creating tables to classify households based on; (i) household status; (ii) household size; (iii) dwelling type. - Rearranging household size range from 2 to ≥12 rather than 2-33, as 95% of households in the sample fall between 2 to 12 household sizes.
- To produce aggregate water demand for observed population from 2013 to 2018 (baseline demand) in association with the CSB dataset (see section 3.7).	Aggregate household population (2013 – 2018)	Household size, type of dwelling, PHC demand, distribution over the country's governorates, and household status; from 2013 to 2018. Source: (i) PACI, population Census; (ii) CSB survey sample for the year 2013	- Translating tables from Arabic to English. - Omitting households that have no specified household size, household status, and/or area location in the country. - Checking the aggregate population in each governorate and aggregate population in the country in each year.

Purpose/Target	**Type of datasets**	**Variables and source**	**Process of examination, classification, and organisation**
- To use population projection to forecast aggregate household demand 2050 (chapter four).	Population projection of Kuwait in the household sector	- Total population by household status until 2050. Source: KISR - Total population. Source: UN	KISR population projection has been selected (section 4.2.1.3), and further enhancement procedures have been employed to fit household population characteristics of baseline demand (section 4.3).
- To project and calibrate the micro-component model and fit it to the BAU demand forecast (chapter five).	Disaggregate (end-use) water demand in the household sector	- Micro-component water use by; (i) household size; (ii) dwelling type, (iii) household status, and; - Micro-component use by ownership, volume, and frequency of use elements. Source: TED/KISR and WRC/KISR - Volume of traditional water end-use appliances. Source: literature survey.	- Prepare tables that comprise the micro-component uses of indoor and outdoor appliances for Kuwait's households (Appendix A and Table 5.2), and; - Employ calibration test using linear combination equations, and fractional equations to project ownership, volume and frequency (section 5.4).
- To calculate the cost and revenue of freshwater production and CO_2 emissions of forecast and backcast demands (chapter seven).	Economic and environmental	- The revenue, cost, and delivery per unit (US\$/m^3) of freshwater production. - The CO_2 of desalination plants per unit emissions (kg/m^3) based on plant type (thermal and membrane). Source: MEW Water book 2018 and literature survey.	- Prepare equations to calculate the cost and revenue of freshwater production, and the amount of CO_2 release to the atmosphere (see section 7.2.3.2).

3.3 Data cleansing and preparing for demand estimation

As mentioned above, the only data available for disaggregate household demand is for 2013 (via the CBS expenditure survey), which presented a significant constraint on modelling. However, as this is the best data available it was used as the basis for building a disaggregated demand model, first with disaggregation of demand for 2013, then the development of a baseline demand for 2013 – 2018. Some validity tests (3.7.1.2) have been employed to validate this baseline demand estimation.

3.3.1 Available data

To estimate aggregate demand for the household sector for 2013, two datasets were used. First, the survey of household water demand conducted by the CSB, involving 2,961 households comprising Kuwaiti and non-Kuwaiti's (household status), household size, and dwelling type for each household, with demand recorded as per household consumption (hence, hereafter the 'PHC demand matrix'). The dwelling is recorded as a villa, floor or flat in a villa, a flat, a traditional house, or an annex[1] (illustrated in Figure 3.1). The survey also includes the number of non-Kuwaitis in Kuwaiti households and the number of Kuwaitis in non-Kuwaiti households. Second, is the household census for 2013, provided by the Public Authority and Civil Information (PACI), referred to hereafter as the 'household population matrix'. The household population matrix includes household status, and household size distributed over the country's governorates.

The data is analysed to derive water use by demographic groups that can be identified within the CSB sample, and which can also be constructed and represented within the PACI census data for the entire population. Thus, additional analysis has been employed to develop demand estimates for years (2013 to 2018) – these estimates are driven by demographic forecasts for the population as a whole (See section 3.5). Of necessity, the analysis assumes that the demand coefficients derived from the CSB water survey are fixed through time – this issue is discussed further in section 3.7.1.3.

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[1] Floor or flat in a villa and annex dwellings are part of villa dwelling.

Figure 3.1: Dwelling types in Kuwait
Source: Aljarida (2018)

3.3.2 CSB household survey and water expenditure

Before turning to the derivation of water demand coefficients from the CSB sample, it is important to understand the nature of that sample. Sampling is the process of selecting a specific group or segment of a population to reflect and represent the entire population from which it is drawn. Sampling is an essential step in the research process because it informs the quality of conclusions made that stem from the underlying findings (Onwuegbuzie and Collins, 2007). Sampling design methods are classified into: (i) probability sampling; (ii) non-probability sampling. Each of these categories includes a number of different techniques, and each technique has its proprieties. In general, probability sampling techniques use random selection where each unit in the population has an equal chance of being picked. Participants "samples" are thus selected without missing characteristics in the entire population. Non-probability sampling is non-random, so persons in the population do not have an equal chance of being selected (Schreuder *et al.*, 2001). The opportunity for selection in probability sampling is fixed and known, whilst in nonprobability sampling it is unfixed and unknown. The final result of probability sampling is unbiased, and the inferences are statistical, while the nonprobability result is biased, and inferences are analytical. Probability sampling comprises four techniques – simple random, stratified, cluster, and systematic sampling; in contrast the nonprobability techniques consist of convenience, quota, purposive, and snowball sampling (Howard, 2018).

The 2013 CSB household income and expenditure survey includes expenditure on water, from which demand can be estimated in the absence of any other observed data (see further below). The CSB survey followed the international agreed classification of household expenditure on goods and services in the "System of National Accounts (SNA)" of 1993 (Jackson, 2000). To gauge the seasonal effects on household expenditure, consumption, and income, the survey ran from the first of January to the thirty-first of December, with water and electricity consumption readings taken quarterly. The survey is designed according to a statistical methodology and international recommendation, so that data collection is reliable and reflects the required variables to achieve the objectives of the survey. The CSB hired sampling design experts to develop and design samples to satisfy survey objectives and represent all population units. The expert sampling panel adopted probability sampling, with a combination of cluster and stratified sampling techniques. Four thousand Kuwaiti and non-

Kuwaiti households were selected by applying the stratified cluster sampling to obtain the best possible homogeneity between population units[2]. In the sampling process, each stratum[3] has a group of clusters, which include Kuwaiti and non-Kuwaiti samples. A variance in the percentage of Kuwaiti households in the country's governorates has been observed through the distribution of the sample within the clusters, as well as a disparity in the level of the household expenditure between Kuwaiti and non-Kuwaiti households. Consequently, the Kuwaiti nationality has been treated as a variable for each stratum. Based on that, four strata have been established in which every strata has a certain percentage of Kuwaiti households, see Table 3.3. Twenty-four strata have been created to represent the entire population in the household sector, consisting of four strata for each of the six governorates. In sum, all of the stratums, including 250 clusters, are equally distributed over the governorates. The advantage of this survey is the application of Data Quality Management (DQM) and the principles of data management to ensure comprehensive coverage and accuracy in the final results of the survey. A disadvantage occurs in the omission of households with a single individual; the rationale is that the consumption and expenditure patterns of individuals are different to those of families, hence outside the scope of the CSB survey, despite individuals representing 33.1% of all households (in 2013), as PACI reported.

Table 3.3: The Kuwaiti household distribution over the stratums

Strata	The percentage of Kuwaiti households
First	Less than 25%
Second	Between 25% to 49%
Third	Between 50% to 74%
Fourth	Between75% to 100%

Source: CSB (2013)

In the survey, 2,961 households agreed to have water expenditure recorded. Those households consist of 41.4% of Kuwaiti households and 58.6% non-Kuwaiti households. The full year survey recorded quarterly water use from household meters, from which expenditure data is then reported (the average expenditure of quarters has been calculated for each household by CSB). The expenditure data on water has been used in the research to

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[2] The whole survey comprises four thousand participants; of this, 2,961 participants gave consent to participate in the water and electricity survey.

[3] In stratified sampling, stratum is a homogenous subpopulation group within a population; it is a technique to enhance the precision of the sample by reducing sampling error.

back-calculate the daily average water use of the actual household water demand (PHC – l/d) for each category of household size, dwelling type, and household status. Kuwait has a uniform water tariff where the cost of a thousand imperial gallons is 0.8 Kuwaiti Dinar (2.63 US$), equivalent to 0.58 US$ per m^3. Such a tariff system enables measurement of water demand precisely as expenditure is based wholly on actual use, with no other charges (e.g., fixed fees or wastewater disposal). Thus, the following equation can be used to determine water use from the recorded water expenditure:

$$PHC = (\{k/p * 1000\}/\{q/d * 4.546\}) \tag{1}$$

Where PHC is average daily consumption in litres for each household group; k is the water expenditure in Kuwaiti Dinar; p is the unit of water price (0.8 Dinar for 1000 imperial gallons); 1000 represents a thousand Imperial gallons as the consumption tariff; q is a quarterly (three month) period where the meter readings have been obtained; d is factor to convert months to days (90 days) to get daily consumption; and 4.546 is for conversion of imperial gallons to litres. Table 3.10 shows the average PHC l/d after calculation (using equation 1) and the output of PHC missing values assumption processes (section 3.4).

3.3.3 Data cleaning and missing values defined

3.3.3.1 PHC demand matrix

Before proceeding with any statistical analysis some data cleaning was necessary. In the PHC demand matrix, 85 of the 2,961 households had no dwelling type specified and/or zero expenditure (missing records) and were removed (Table 3.6). Additionally, the PHC demand matrix omits some household size categories, most notably those for one person (Table 3.5), where household sizes in the matrix start at 2 and end at 33 people although there are few such very large households. Consequently, household size categories have been modified so sizes between 12 and 33 people are merged to give a category of household sizes of 12 and above. 95% of the PHC demand matrix records fall in the 2-12 household size categories (Table 3.4), with the remaining 5% subsequently lumped into the household size category of above 12 people, after calculating the average water demand of the 12 to 33 household size.

Table 3.4: Observation frequency distribution by dwelling types and household size in the PHC demand matrix

Kuwaiti household size															
Household size	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Villa	11	31	40	67	87	82	98	84	78	44	35	13	22	18	
Floor or flat in villa	18	25	34	38	35	29	29	18	8	7	2	1	2	N/A[*]	
Flat	19	12	14	16	18	6	9	4	2	N/A	1	1	N/A	N/A	
Traditional house	4	7	9	12	19	12	15	13	11	4	5	6	3	1	
Total	52	75	97	133	159	129	151	119	99	55	43	21	27	19	
Household size	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**26**	**27**	**28**	**30**	**33**	**Grand total**
Villa	7	8	2	2	N/A	2	N/A	2	1	2	1	2	1	1	741
Floor or flat in villa	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	246
Flat	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	102
Traditional house	2	2	N/A	2	1	N/A	1	N/A	N/A	1	N/A	N/A	N/A	N/A	130
Total	9	10	2	4	1	2	1	2	1	3	1	2	1	1	1,219
Non-Kuwaiti household size															
Household size	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Villa	2	2	4	4	2	N/A	3	2	2	N/A	2	N/A	N/A	1	
Floor or flat in villa	N/A	5	11	10	15	7	1	4	1	1	N/A	N/A	N/A	N/A	
Flat	213	241	351	216	123	49	22	7	4	N/A	N/A	1	N/A	N/A	
Traditional house	1	1	2	2	4	7	8	11	14	2	6	5	5	5	
Annex	134	83	25	13	2	2	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Total	402	407	490	378	305	194	186	143	120	58	51	27	32	25	
Household size	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**26**	**27**	**28**	**30**	**33**	**Grand total**
Villa	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	25
Floor or flat in villa	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	56
Flat	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,228
Traditional house	3	N/A	N/A	N/A	N/A	1	1	N/A	N/A	N/A	N/A	1	N/A	N/A	88
Annex	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	260
Total	5	5	0	1	3	2	1	0	0	0	0	1	0	0	1,657

[*] Not/Available (N/A)

Table 3.5: Missing values in the CSB water expenditure survey

<table>
<tr><th colspan="2">Kuwaiti</th></tr>
<tr><td>Household size</td><td>Dwelling type</td></tr>
<tr><td>1</td><td>Villa</td></tr>
<tr><td>1</td><td>Floor or flat in a villa</td></tr>
<tr><td>1</td><td>Flat</td></tr>
<tr><td>1</td><td>Traditional house</td></tr>
<tr><td>11</td><td>Flat</td></tr>
<tr><td colspan="2">Non-Kuwaiti</td></tr>
<tr><td>Household size</td><td>Dwelling type</td></tr>
<tr><td>1</td><td>Villa</td></tr>
<tr><td>1</td><td>Floor or flat in a villa</td></tr>
<tr><td>1</td><td>Flat</td></tr>
<tr><td>1</td><td>Traditional house</td></tr>
<tr><td>1</td><td>Annex</td></tr>
<tr><td>2</td><td>Floor or flat in a villa</td></tr>
<tr><td>7</td><td>Villa</td></tr>
<tr><td>9</td><td>Annex</td></tr>
<tr><td>10</td><td>Annex</td></tr>
<tr><td>11</td><td>Villa</td></tr>
<tr><td>11</td><td>Flat</td></tr>
<tr><td>11</td><td>Annex</td></tr>
<tr><td>12</td><td>Annex</td></tr>
<tr><td>12</td><td>Floor or flat in a villa*</td></tr>
</table>

* Floor or flat in a villa category has a single value above twelve household size, but this value cannot be projected on the household size of twelve, because it is an outlier value.

Regarding dwelling types, we must take into account that the PHC demand matrix omits the annex dwelling type category for Kuwaitis but is reported for non-Kuwaitis. To understand why this is so, the cultural background of housing in Kuwait, and the government's housing policies must be explained. The country guarantees a house (generally known as a villa) for each citizen either by: (i) providing a citizen a complete built villa which should include an annex; or (ii) a grant of land and a zero-interest housing loan with capital sum repayment over forty years. Citizens may have to wait for a government housing grant, but in the meantime are provided with a subsidised housing allowance. The allowance has different requirements for guaranteed payment to a citizen, one of which is proof of a rental contract to show payment to a landlord/estate agent. The rented accommodation should be in a flat, a floor in a villa, a traditional house, or a villa excluding annexes. The reason for this is that annexes are built as accommodation for the household's domestic workers, and it is therefore rare to find a Kuwaiti family living in an annex, which has become a cultural norm.

Table 3.6: The number of the household samples through the cleaning processes

Process stage	Number of samples
Pre-cleaning	2,961
Total cleaned values, distributed as;	85
(a) Households with uncertain dwelling type	73
(b) Households with zero demand	12
Post-cleaning	2,876

3.3.3.2 Household population matrix

The household population matrix is similarly processed by removing incomplete data (i.e., household size, status, and/or location is unspecified). The household size range starts for one person and ends at 14 and above; therefore, the household size range has been reduced to 12 and above (adding those categories above 12 household size to it) in order to match the household size range in the PHC demand matrix. Unfortunately, the household population matrix does not include dwelling type, which water demand literature indicates is generally considered an important determinant of demand. This variable is not included in the data collection procedures of the PACI, the only body responsible for collecting demographic statistics in a continuous manner. Therefore, its absence creates a difficulty in readily applying the observed water use data from the CSB sample to the wider national population. Unlike the PACI, the CSB has more infrequent surveys, such as the population census every ten years, in which dwelling type is recorded.

The limitations of missing values in the CSB water demand expenditure survey, and lack of dwelling type in the PACI national population census must be addressed so as to give the best possible estimate of annual water demand to the household sector. Section 3.4 discusses how missing values in the PHC demand matrix are derived through a curve fitting approach, whilst section 3.5 describes how water use by demographic cohort in the CSB sample is applied to the national level, via a process of microsimulation, in which dwelling type categories are simulated in the national household population data.

3.4 Assumption of missing values in the PHC demand matrix

Filling gaps in the PHC demand matrix is an important part of the research in which the choice of technique used influences the accuracy of estimating aggregate demand. Curve fitting (regression trend line) analysis is an appropriate technique to assume the missing values drawing on an understanding of the relationship between variables, with demand as dependent/response variable, and household size as the independent/predictor variable (Raghunathan *et al.*, 2001; Royston, 2004). The correlation between variables in regression analysis is represented in the coefficient of determination (R squared). However, a robust R^2 correlation doesn't imply substantial causation due to the pattern of parameters that have been investigated (Cohen *et al.*, 2014). For instance, PCC in the household sector depends upon the size/members of a household in which high household size indicates lower PCC due to scale efficiencies and vice versa. Therefore, representation of the parameters will be in an inverse slope; household sizes are represented on the X-axis in an ascending order, and water demand represented on the Y-axis (Figure 3.2). Regression analysis may be linear or nonlinear. A common type is the linear regression where the equation takes the basic form, $Y = a + bx$, where x is the explanatory variable and Y is the dependent variable. This can adopt a straight line but with exponents (e.g., as polynomial, logistic, and algorithmic equations) linear regression can produce curves. Nonlinear regression such as Weibull and Fourier are represented by mathematical functions other than $Y = a + bx$ (Gunst, 2018).

Selection of a regression function relies upon the degree of fit R^2, the pattern of the presented parameters, and the residual plots (Espinheira *et al.*, 2008). The pattern of the parameter significantly influences the orientation of the regression slope; logically, PCCs should decrease as household size increases, so PCC of a one-person household must (on average) be higher than PCC of a household of greater than one person. Consequently, the slope would take an inverse line where PCCs in low household sizes are higher than high household sizes. Furthermore, PCCs can never be negative, even for values that could be very close to zero demand. Residual plots can be used to test for errors by subtracting observed from assumed values (Lee and Brooks, 2006). Low residuals indicate a good fitting line, whilst high residuals indicate either over-fitting or under-fitting. On the other hand, to guarantee the best fitting line, outlier points in scatter plots that may strongly influence the fitted line must also be considered. This curve fitting process is discussed in further detail next.

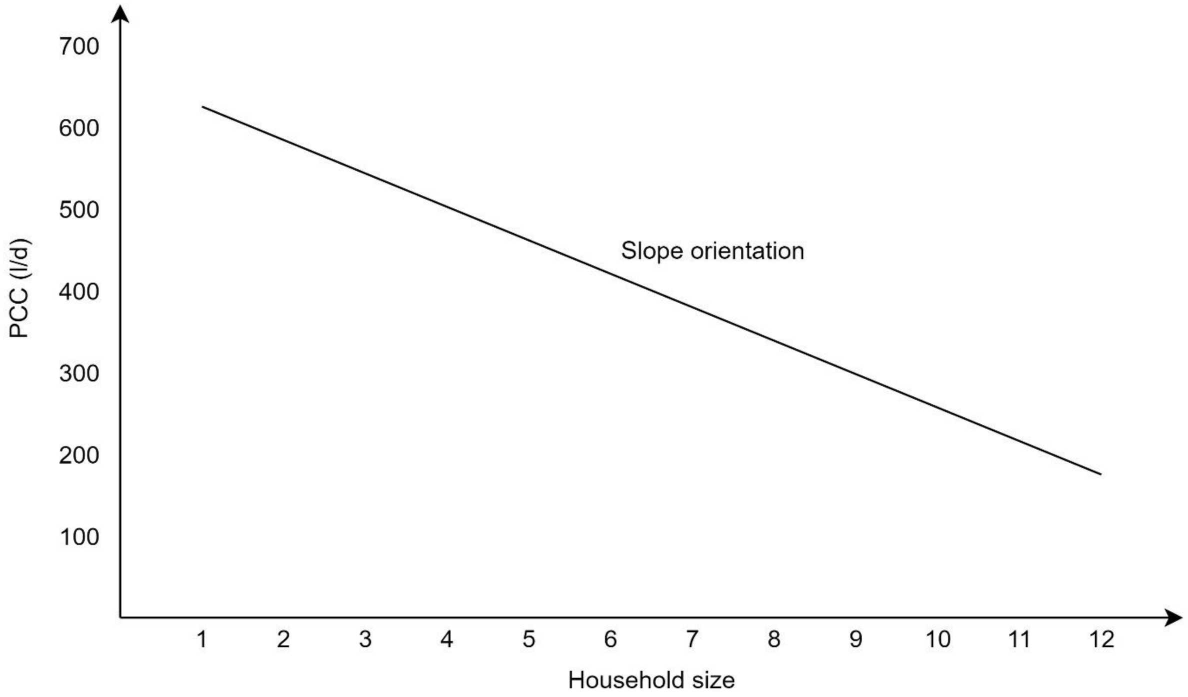

Figure 3.2: The default slope curve of PCC in the household sector

3.4.1 Assumption process

Where extrapolation or interpolation is used to assume missing values, it should not ignore the elements that could affect the assumption process. Selection of a regression function to adequately simulate the observed pattern is a vital part of the assumption process (Miller, 2002), and poor selection would negatively affect model performance (Rothermel and Harrold, 1997). Thus, after curve-fit testing exercise, the Power regression function has been selected as the best function fitted to the PHC demand matrix parameters[4], and where influential outlier points have been defined. Outlier points in the scatter plots have adversely influenced assumed values and has altered the trendline from its true orientation. The following section explains how influential outliers are addressed to correct this bias, and thus how more credible Power function can be fitted to allow missing values to be assumed.

3.4.1.1 Define the influential outliers and trendline function slope

An outlier or discordant value is a value that appears to deviate markedly from the main body of the observation points (Grubbs, 1969). Outliers can occur because of: (i)

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[4] PCC values have been used in curve fitting rather than PHC values, as PCC values have a more consistent trendline slope.

measurement error where an experimenter has taken the calculations/records incorrectly; or (ii) due to inherent or random variability in the dataset (Maddala and Lahiri, 1992). Dealing with outliers in a random observation depends upon different criteria. First, if an outlier occurs as a result of measurement error, then an experimenter should omit or replace it by taking another measurement. Second, if an outlier observation is an actual observation, in this situation, doubts emerge whether to retain or reject it. Some literature (Stevens, 1984; Rothermel and Harrold, 1997; Rousseeuw and Leroy, 2005; Motulsky and Brown, 2006) has stated that if this risks a misleading result then discarding the outlier is a clear-cut decision. In this case, outliers are considered influential observations that have a strong influence and high leverage[5] in the trendline analysis, but if it has only high leverage, then it depends on the experimenter's judgment whether to retain or omit it. Others state that even though the outliers affect the pattern of the slope and influence the assumed fit, they shouldn't be rejected because they are considered relevant evidence.

Detecting outlier points using diagnostic tests has become widely used to better reveal outlier points in trendline analysis (Stevens, 1984). There are several diagnostic tests to detect influential observation in curve fitting including Cook's Distance (CD), Mahalanobis distance (MD), and Graphical Diagnostic Procedures including Standardised Residuals and Studentised Residuals. Cook's Distance is a measure of the alteration in the trendline coefficients that would arise if this case was rejected, thus revealing which cases are most influential in affecting the trendline equation. It is used only to estimate the influence of outlier points when performing Ordinary Least Squares (OLS) regression. Mahalanobis distance is a measure of the distance between a point (X) and a distribution point in multilevel space in which far points from distribution point tends to be an outlier value (Liu *et al.*, 2018). Standardised Residuals and Studentised Residuals are diagnostic tests that assume random observations follow the normal distribution where the mean value is considered the central distribution and standard deviations represent the detectors; the more points that are far from the centre the more outliers exist. The difference between these tests is that Standardised Residuals uses z-distribution while the other uses t-distribution.

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[5] Leverage is a measure of how far the independent variable values of an observation are from those of the other observations; for instance, high leverage points are those points made at extreme or outlying values.

Unfortunately, none of these tests are applicable to the PHC demand matrix, to find the influential outlier points, for several reasons. First, Cook's Distance test is only applicable for linear slopes so restricts the choice to simple linear regression. Second, all the mentioned tests, including Cook's Distance, assume that the Y-axis has a single mean and a single standard deviation where all observation plots are deemed as one category with similar characteristics. However, the PHC demand matrix set outs the average demand of each household size in each dwelling type category. Consequently, from a statistical perspective, detecting outliers' tests can't be implemented to the PHC demand matrix. The reason for this is that each dwelling category has several household sizes (2-12), and each household size point in a graph is an average of observation points. Since the PCCs values are based on household size, then if any detecting test is applied, it will incorrectly gauge the distributed plots. Furthermore, there is a considerable number of a single observations in some dwelling type categories (Table 3.4), which constrains implementation of the previous tests.

The only test applicable to detect influential and leverage points is through a trendline fitting curve exercise where different trendline functions are applied (over several iterations) with and without extreme observations (outliers) to see how these observations affect the trendline orientation. Consequently, influential outlier points have been defined and the best fitted trendline function (Power) has been selected simultaneously. By applying this test, the influential and leverage outlier points in the PHC matrix have markedly been detected. These outlier points affect the orientation of slope and lever trendline towards its location in whatever trendline is being performed. Five outlier points have been detected, outliers between leverage and influential (Table 3.7). Figure 3.3 is an example of fitting the trendline function before omitting the influential outliers, it shows how influential outliers affect the trendline and bias the missing value assumption. Uncertainty exists as to whether these outliers occur because of measurement error or if they represent actual variability in observed demands. However, due to the high influence of the outlier points in the slope and assumption process these points have been omitted and replaced by assumed values by applying regression fitting function, where missing values have been derived as well.

Several functions were tested for their ability to simulate demand patterns by household attribute, with low residual values. Simple linear regressions performed poorly, as first, the assumed PCC values for one person households are lower than for two person or more households, in most cases, contrary to expectations of scale efficiencies. Second, the lower demand values (assumed PCC in high household sizes) reach zero demand, and in some cases go below zero, which is unrealistic. Third, the coefficient of correlation R^2 is poor. Conversely, using a Power function shows a good R^2, and a good PCC fit line compared to a simple linear regression. In addition, subtracting residual values from the observed values show better results that the simple linear regression. Therefore, Power functions are used to derive missing PCC values by household size and type, as shown in Figures 3.4 and 3.5.

Table 3.7: The leverage and influential outlier points in the PHC demand matrix

Dwelling type	Household size	Household status	PCC	Leverage	Influential
Villa	9	Non-Kuwaiti	158	✓	
Floor or flat in a villa	11	Non-Kuwaiti	344	✓	✓
Floor or flat in a villa	12	Non-Kuwaiti	361	✓	✓
Flat	10	Non-Kuwaiti	69	✓	
Flat	12	Kuwaiti	55	✓	

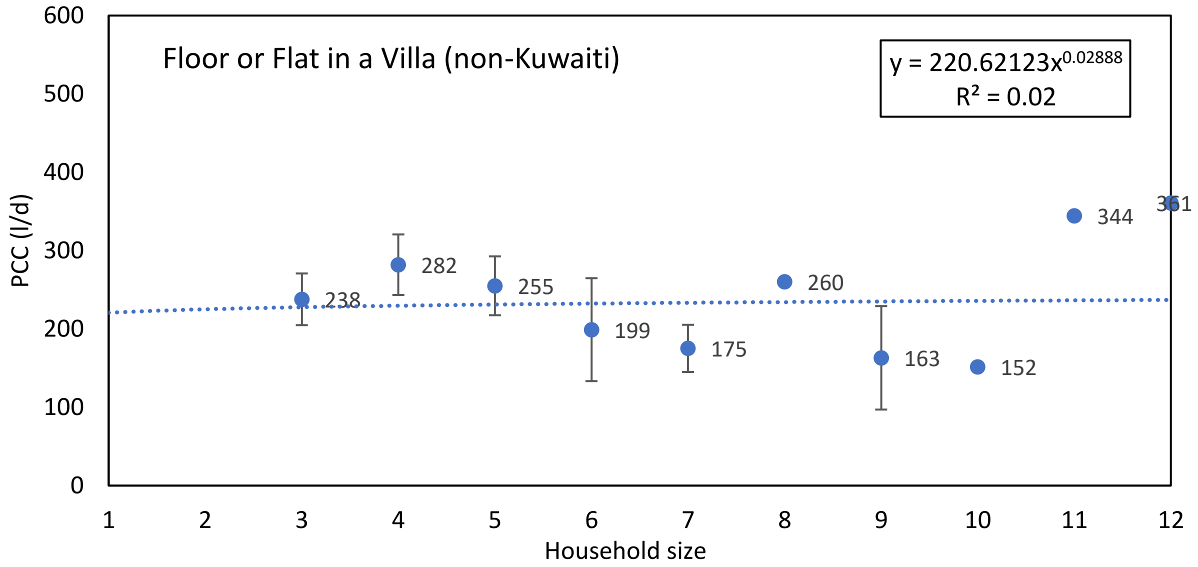


Figure 3.3: An example of applying Power trendline function with outlier observations

3.4.1.2 *Accuracy test of the assumed and observed values*

Accuracy of the assumed values is shown by R^2 degree, and the extracted residual values. The Power trendline function is superior to other forms and has strong R^2 values, low residuals between observed and assumed values, and slope orientation performance that best fits the observed values (Figure 3.4 and Figure 3.5). For observed values, accuracy tests should measure how well these observations (sample population = PHC demand Matrix) represent the entire household population. A number of statistical tests can fulfil this task to conclude whether the sample is representative and statistically significant. Null hypothesis (H_0) tests test the probability (P-value) of how frequently the observations of the sample population (n) occurs in the entire population (N) in randomness. Null hypothesis tests can be applied using Chi-squared, z, t, and F tests. The probability degree is usually selected as alpha (α) value is 0.5 (0.25 in each tail of a normal distribution), which represents 95% of the entire population. The Confidence Interval (CI) also measures the margin of error between the sample population and the entire population and gives upper and lower bounds from the mean. The alpha (α) value is usually represented as (0.05) in the CI test, where the confidence level is presented as 95% of the entire population.

The purpose of these tests is to determine how representative the sample population is of the entire population. A null hypothesis can be applied in the z-test with >30 observations; else a t-test is used (similarly with the CI test). Selecting the appropriate test depends on the number of variables (dependent and independent), and sample size. For instance, the F test tests more than one independent variable, whilst z and t-tests only test a single independent variable.

The CI test shows the margin of error and gives lower and upper bounds from the average, so shows how far lower and higher consumption is from average consumption of the sample population to the entire population. The CI test has been used, with the confidence level set at 95%, consistent with wider literature. Use of t- and z-distributions is dependent on the number of observations in a category (t-distribution where N<30 observations). The t and z-distributions follow the normal distribution, but the t-distribution has a flatter shape than the z-distribution. CI outcomes using t-distribution show outlier values in some categories that does not reflect reality (negative and close to zero) and the pattern of the parameters. The t-distribution is chosen to give more realistic outcomes that represent the entire population, and since it resulted in outlier values; t-distribution has been replaced by z-distribution to the categories that are lower than 30 observations, which markedly gives better outcomes (Figures 3.4 and 3.5, and Tables 3.8 and 3.9). Table 3.10 shows the PHC demand matrix after all missing PHC and PCC values have been imputed.

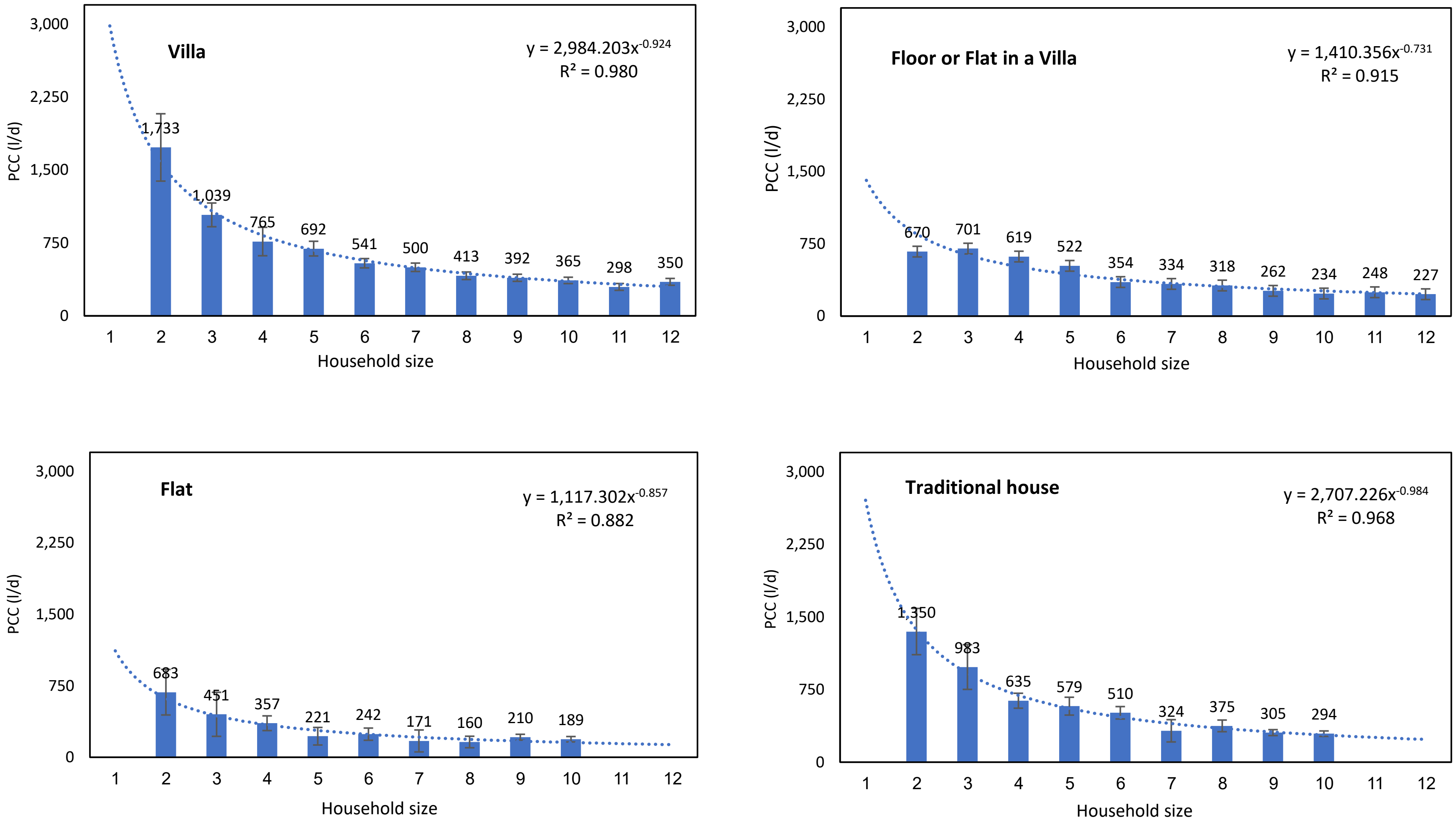


Figure 3.4: Curve fitting for missing value imputation: Kuwaiti household dwelling categories

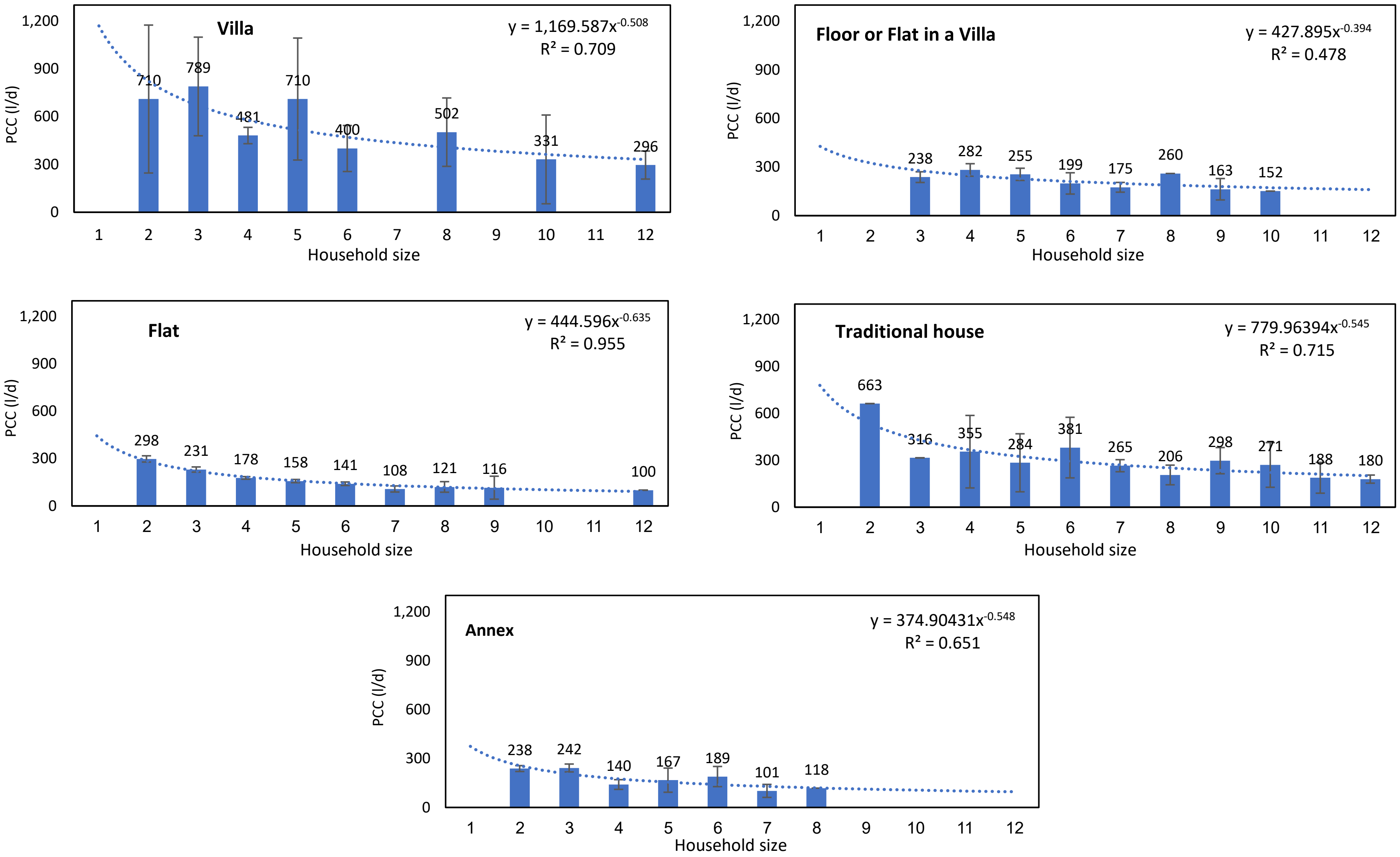


Figure 3.5: Curve fitting for missing value imputation: non-Kuwaiti household dwelling categories

Table 3.8: Confidence interval (litres PCC/day) by utilising t and z distribution of Kuwaiti households

	Kuwaiti CI (t – distribution) (α = 0.95)										
Dwelling type	*Household size*										
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**≤12**
Villa	394	127	151	77	49	44	39	37	33	36	36
Floor or flat in a villa	161	161	115	97	59	63	534	724	306	951	1,474
Flat	256	778	340	501	414	1,057	71	50	183	Imputed	Imputed
Traditional house	1,017	745	238	279	102	173	89	98	90	125	45

	Kuwaiti CI (z – distribution) (α = 0.95)										
Dwelling type	*Household size*										
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**≤12**
Villa	346	122	146	76	48	43	39	37	33	35	35
Floor or flat in a villa	149	153	111	94	57	60	64	75	25	69	87
Flat	239	231	77	92	64	115	60	31	28	Imputed	Imputed
Traditional house	627	596	203	248	95	154	81	88	79	77	42

Table 3.9: Confidence interval (litres PCC/day) by utilising t and z distribution of non-Kuwaiti households

	Non-Kuwaiti CI (t – distribution) (α = 0.95)										
Dwelling type	*Household size*										
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**≤12**
Villa	3,008	2,006	83	621	936	Imputed	471	Imputed	1,805	Imputed	143
Floor or flat in a villa	Imputed	47	44	43	72	38	Single value	107	Single value	Imputed	Imputed
Flat	20	16	8	10	11	20	35	91	Imputed	Imputed	Single value
Traditional house	Single value	Single value	1,504	1,203	315	48	76	95	158	638	27
Annex	18	24	31	82	401	258	Single value	Imputed	Imputed	Imputed	Imputed
	Non-Kuwaiti CI (z – distribution) (α = 0.95)										
Dwelling type	*Household size*										
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**≤12**
Villa	464	309	51	383	144	Imputed	215	Imputed	278	Imputed	88
Floor or flat in a villa	Imputed	33	39	38	66	30	Single value	66	Single value	Imputed	Imputed
Flat	20	16	8	10	11	19	33	73	Imputed	Imputed	Single value
Traditional house	Single value	Single value	232	186	194	39	63	84	143	98	26
Annex	18	24	30	74	62	40	Single value	Imputed	Imputed	Imputed	Imputed

Table 3.10: The final PHC demand matrix after missing values have been imputed

	(A) Kuwaiti												
Dwelling type	*Household size – PHC (l/d)*												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**≤12**	**Average**
Villa	*2,984**	3,466	3,117	3,060	3,460	3,246	3,500	3,304	3,528	3,650	3,278	4,200	**3,399**
Floor or flat in a villa	*1,410**	1,340	2,103	2,476	2,610	2,124	2,338	2,544	2,358	2,340	2,728	2,724	**2,258**
Flat	*1,117**	1,366	1,353	1,428	1,105	1,452	1,197	1,280	1,890	1,890	*1,573**	*1,596**	**1,437**
Traditional house	*2,448**	2,700	2,949	2,540	2,895	3,060	2,800	3,000	2,745	2,940	3,597	3,324	**2,917**
Average	**1,990**	**2,218**	**2,381**	**2,376**	**2,518**	**2,471**	**2,459**	**2,532**	**2,630**	**2,705**	**2,794**	**2,961**	**2,503**
	(B) Non-Kuwaiti												
Dwelling type	*Household size – PHC (l/d)*												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**≤12**	**Average**
Villa	*1,170**	1,420	2,367	1,924	3,550	2,400	*3,045**	4,016	*3,447**	3,310	*3,806**	3,552	**2,834**
Floor or flat in a villa	*428**	*652**	714	1,128	1,275	1,194	1,225	2,080	1,467	1,520	*1,826**	*1,932**	**1,287**
Flat	*445**	596	693	712	790	846	756	968	1,044	*1,030**	*1,067**	1,200	**846**
Traditional house	*780**	1326	948	1,420	1,420	2,286	1,855	1,648	2,682	2,710	2,068	2,160	**1,775**
Annex	*375**	476	726	560	835	1,134	707	944	*1,008**	*1,060**	*1,111**	*1,152**	**841**
Average	**640**	**894**	**1,090**	**1,149**	**1,574**	**1,572**	**1,518**	**1,931**	**1,930**	**1,926**	**1,976**	**1,999**	**1,516**

* Imputed values from Power trendline fitting function

3.5 Synthetic population simulation of the household population matrix

PHC water demand coefficients (based on developed PCCs, Figure 3.4 and 3.5 fit lines) must be scaled to the national population to model total national household water demand. However, this process is constrained by a lack of dwelling type data in the national population census, linked to household size and citizenship variables (the dwelling type data is an important element of the PHC/PCC sample matrix). This problem is addressed using synthetic population simulation which seeks to construct an artificial population with a distribution of characteristics that match that of the observed population. It enables estimation of variable combinations that do not exist in the census of a specific area (Hermes and Poulsen, 2012), and enables estimation of aggregate demand. A decent synthetic population simulation is needed to reflects the characteristics of a population allowing extension from a small population (e.g., survey sample) to an aggregate population (e.g., census), and to provide solutions to data limitations (Whitworth *et al.*, 2017). That is, census data tend to have fewer details (variables) over individuals and/or households (i.e., often because of difficulty and/or individual confidentiality and legal restrictions) compared with survey samples. Survey samples are thus a good source of data to simulate missing variables in census or administrative records (Smith *et al.*, 2009; Whitworth *et al.*, 2017).

In this research, two obstacles prevent estimating aggregate demand with the datasets available. First, the household population matrix is missing the “dwelling type” feature that exists in the PHC demand matrix; second, the household population matrix provides only the aggregate population of households. Thus, a disaggregated household population (individual household-based) with a projection of dwelling type to the household population matrix is needed to get an aggregate demand. This model can then provide the basis for application of water demand forecasting and testing of backcast water conservation interventions in a more functionally resolved way (e.g., adoption of interventions by dwelling type).

Small Area Estimation (SAE) is a powerful approach in interlinking the household population matrix (census “macro data”) with the PHC demand matrix (sample population “microdata”) through shared benchmarks, thus eventually simulating a synthetic population (Rao and Molina, 2015). The term small area usually refers to a small geographical district, for instance, a governorate, a county, a state, or a municipality that the population characteristics of this area will be estimated for (Datta *et al.*, 1999). It sometimes implies a small domain such as small population based on, for example, age, sex, and race groups within a large geographic area (Breidenbach and Astrup, 2012). The general notion of the SAE approach is to borrow information from related data sources to fill gaps in the small area data set of interest (e.g., census). The potential datasets that can be used and employed are classified into: (i) data gauged for the characteristics of interest in a similar area; and (ii) data gauged for characteristics of interest on previous events (Ghosh and Rao, 1994; Pfeffermann, 2002). Whitworth *et al.* (2017) note SAE is becoming key in survey sampling because of an increasing demand for reliable small area statistics. A number of user groups from different disciplines, e.g., policymakers and planners ask for more spatially detailed data in order to design plans and policies and make forecasts, but the desired data are often not available at required spatial scales. Accordingly, SAE methods have been adopted to simulate “non-available” information using survey samples that have covered these areas. Survey samples are supposed to be designed to represent the entire population of the area being surveyed. Consequently, characteristics that have been simulated for a small area census from a survey sample should reflect the entire population which supposedly constitute trustworthy outcomes (Rao, 2014; Visagie, 2019).

SAE methods are classified into: (i) direct estimation; and (ii) indirect or model-based estimation (Chandra *et al.*, 2007). Direct estimations depend on a survey sample to find a synthetic population using statistical techniques so that a survey sample is used directly (Rayer, 2015). Indirect estimations use survey samples to simulate a synthetic population from census or administrative records (Rahman *et al.*, 2010). Direct estimation statistics have three techniques. First, the Horvitz-Thompson (H-T) estimator is used to estimate a total and mean finite population when a stratified sample is selected with unequal probabilities without replacement (Cochran, 1977; Maiti, 2011). The H-T estimator technique is easy to calculate and provides unbiased results for larger samples, but is considered unreliable and unable to employ auxiliary data such as a census, because it is usually lacks disaggregate attributes (Rahman, 2009; Quatember, 2016). Second, the Generalised Regression (GREG) estimator technique represents substitutes where the sample values (from survey sample) are weighted (using Weighted Least Square (WLS) linear regression) to optimise unobserved units from the auxiliary dataset on a specific domain or unit level. It has been used to reduce the variance of estimates and to improve outcomes and to correct bias. The GREG estimator can be negative in some situations and is considered an inconsistent technique because of relatively high residuals (Pfeffermann, 2000; Rahman *et al.*, 2013; Eurostat, 2014). Third, the modified direct estimator, also known as the modified GREG has been used to increase the GREG estimator's reliability. Even though this estimator can develop unbiased estimates and uses the overall sample data at the aggregated level to get the overall regression coefficients, it doesn't raise the effective sample size, which is the distinction of indirect SAE estimators (Rao, 2003).

Indirect SAE estimation, on the other hand, is based on statistical models that generate estimates for all small areas. Indirect SAE consist of an implicit models' approach, an explicit models' approach, and a geographic approach (Rahman, 2008a). The difference between implicit and explicit small area estimation approaches is that the explicit approach imputes that the solution is performed with direct iterative calculations. In contrast, implicit algorithms mean that the solution needs to be computed by adding other equation(s) because some terms cannot be calculated explicitly at the search step (Ascher *et al.*, 1997). Implicit models include: (i) synthetic estimation; (ii) campsite estimation; and (iii) demographic estimation (Prasad and Rao, 1990). Conversely, explicit models, include; basic area level models; basic unit level models; and general linear mixed models (Rahman, 2008b). These models have not been subject to in-depth or extensive review and are noted here for comprehensiveness. Of more interest is the indirect SAE geographic approach which represents a sophisticated method compared with direct SAE. The geographic approach also shows superiority in presenting the outcomes spatially, which is entirely based on spatial modelling (Whitworth, 2013).

Spatial microsimulation modelling techniques (SMMs) are the main part of the indirect SAE geographic approach. The origin of spatial microsimulation date to 1957 when Guy Orcutt built his microeconomic simulation model (Spielauer, 2011). Afterwards, Orcutt and colleagues further developed the microsimulation methodology, when they employed behavioural dynamic microsimulation of income, housing system analysis, and demand for healthcare (Orcutt, 1961; Kennett and Orcutt, 1976). Since then, spatial microsimulation's importance has increased (Ballas *et al.*, 2005). Spatial microsimulation is a vital method for establishing small area estimates of a dataset that are inherently not available for small geographical scales. In other words, it is a technique for estimating the characteristics of a population, and permits a merging with traditional aggregate statistics over an area with a smaller scale and more detailed surveys to generate a synthetic population that covers simulated characteristics from both (Tanton and Edwards, 2012). Spatial microsimulation is a very valuable alternative means of small area estimation. Several literature (Chin and Harding, 2006; Harding and Gupta, 2007; Hermes and Poulsen, 2012; Tanton and Edwards, 2012) report that spatial microsimulation models are reliable, robust and have more advantages compared with other type of models used for SAE. Due to its efficiency and reliability; in addition, it represents a cost-effective method; thus, spatial microsimulation has received much attention and high demand. Furthermore, spatial microsimulation can be associated with other models to achieve aims, such as using spatial microsimulation to estimate aggregate water demand in the household sector (Clarke *et al.*, 1997).

Spatial microsimulation can be split into two types, dynamic and static microsimulations (Kavroudakis *et al.*, 2013). Dynamic microsimulation projects the population in the base year forward through time by simulating transitions of life events (e.g., mortality and fertility at an individual-based level). It takes a base dataset and ages this dataset over time. Dynamic microsimulation can be presented in two main types; (i) dynamic population models, where the aging process of a sample over time is taken for the entire population; and (ii) cohorts component models, which involve an aging process for only one cohort (splitting the population into cohort components) rather than an entire population (Li and O'Donoghue, 2013; Tanton, 2014). Dynamic microsimulation models usually employ probabilities to model life events of an individual, in which the base file or original sample data (microdata) is progressed through time in accordance with probabilities (Van Imhoff and Post, 1998). In contrast, static microsimulation models restrict the spatial microsimulation to a single point in time without any change of individuals attributes (Gupta and Harding, 2007). A static microsimulation is able to create microdata in order to fit future population projections and has been used to measure the effect of interventions and so shape policies (Harding, 2007). The main difference between dynamic and static microsimulation is that dynamic simulation uses time explicitly in which individuals' characteristics change as interventions are introduced over time. Static simulations represent individuals characteristics over time to give a vision of the current situation of the future (Zaidi and Rake, 2001; Cassells *et al.*, 2006). In sum, the selection process of which spatial microsimulation is most suitable, depends on the research aim, targets, data availability and representation of time required. For these reasons, static spatial microsimulation modelling has been most widely used in the household synthetic population simulation and is considered appropriate for our purposes. External sources of population projections of the relevant area will be selected to extend the single static simulation to produce a synthetic population for future years (see chapter four).

Static spatial microsimulation employs two major methods, reweighting and synthetic reconstruction, each of which has subcategories (Hermes and Poulsen, 2012). Reweighting essentially adjusts the sampling design weights to a set of new weights by utilising the available data (e.g., census) at a spatial scale. This method has different techniques which are categorised based on the statistical approach; (i) a probabilistic approach, represented in the Combinatorial Optimisation (CO); and (ii) a deterministic approach, represented in Generalised Regression (GREG), and Iterative Proportional Fitting (IPF)(Edwards and Clarke, 2012). Combinatorial optimisation can create a synthetic population by selecting individuals randomly from sample data (microdata) to fill the small area (census) by simulating and adjusting weights, in order to get as close as possible to microdata weights. Combinatorial optimisation has two models, first, the hill-climbing model which selects a combination of observations to be replaced, and then selects one observation to replace an observation in the combination. This model reduces the number of combinations to be measured and, thus, delivers sub-optimal solutions (Mühlenbein, 1989).

Unlike hill-climbing, the simulated annealing process selects random observations from the microdata and allows changes of combination to be optimised to deliver better solutions by applying intelligence algorithm. A deterministic approach, in contrast, employs a modest (fractional) equation to compute new weights iteratively for the obtained microdata to match recognised small area distributions which generate the same outcome every time the model is run. Much literature (Ballas *et al.*, 2003; Hynes *et al.*, 2009; Tanton, 2014) have tested static spatial microsimulation models to distinguish which model has more reliable and trusted outcomes, and concluded that the combinatorial optimisation simulated annealing approach is more effective; thus, this model has been adopted in this study. Furthermore, the Flexible Modelling Framework (FMF) software (Harland, 2013) has been selected in which to implement this spatial microsimulation modelling.

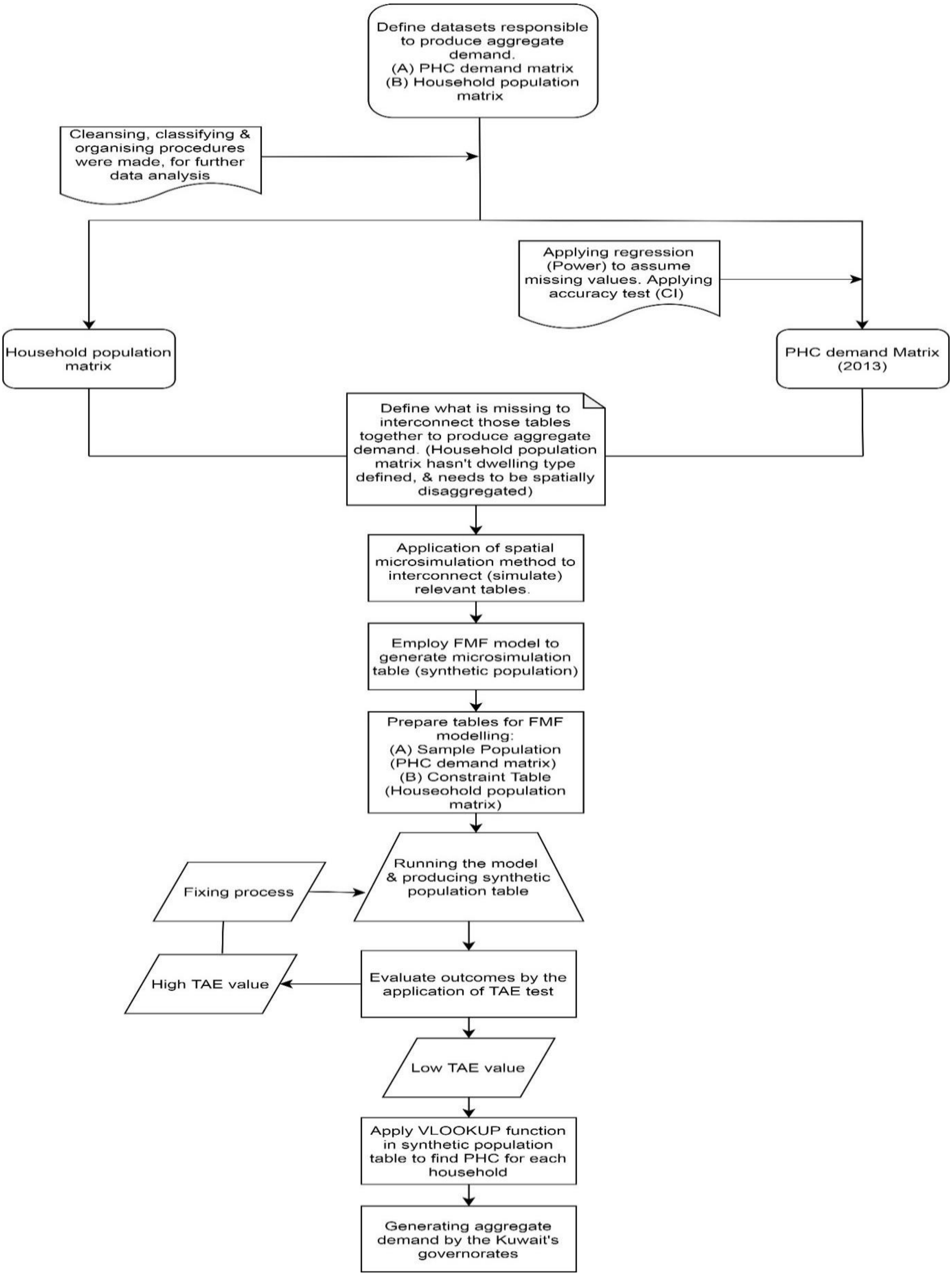


Figure 3.6: Workflow for estimating aggregate demand, showing role of population microsimulation

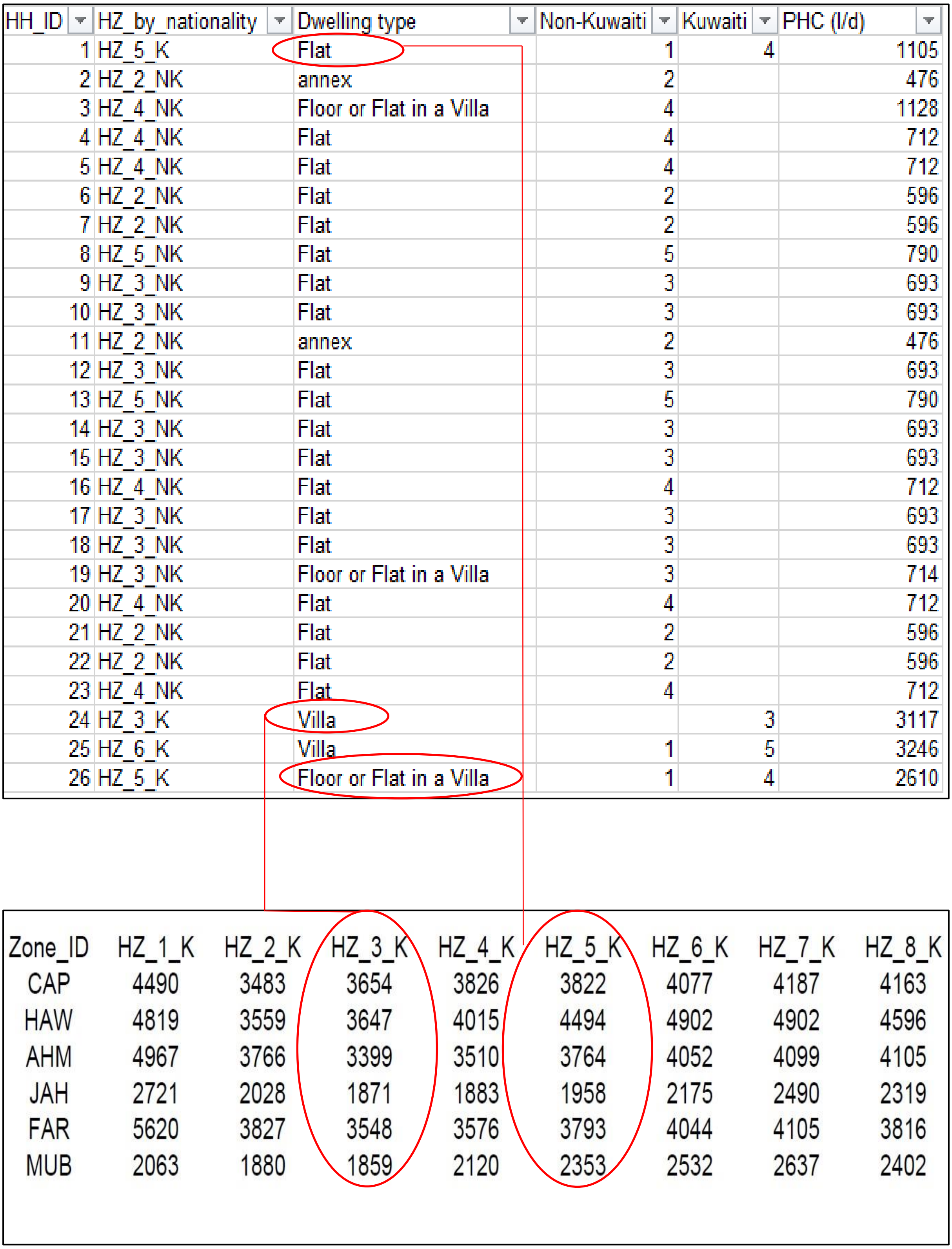
3.5.1 FMF spatial microsimulation

In the FMF software, the constraint table (the household population matrix in our case) has spatial references or zone codes (the country's governorates are represented by the zone codes) to the sample population table which is the PHC demand matrix. Each sample or value in the PHC demand matrix has a unique identifier; thus, a field (column) has been added to the relevant table named (HH_ID), which is a shortcut of "Household Identifier". Accordingly, we have produced 2,894 unique household identities. Furthermore, the household size field has been merged with the nationality (household status) field to make sure the modelling process fits well. The necessity of merging those two fields lies behind matching the field in the sample population table with the fields in the constraint table to get the best outputs. The point here is that the FMF model is not able to match more than one field in the sample population table to the constraint table fields. In other words, the FMF matches fields in the constraint table with a field in the sample population table and the field headers in the constraint should match the values in the selected field in the sample population (Figure 3.7).

For the constraint table, a cross-tabulated constraint table has been generated from the household population matrix. The cross-tabulated table combines household size with the household status column into a single column to match the sample population table. The labelling convention adopted is as follows. For the constraint table, the governorates are denoted as in Table 3.11. Shortcuts for the merged fields (household size and household status) are used for both tables; here, for instance, a household of a single Kuwaiti only is denoted as HZ_1_K while a household of ten non-Kuwaiti is HZ_10_NK (Table 3.12). After tables are prepared in this way, modelled and synthetic population simulation can proceed.

Table 3.11: Abbreviations of the country's governorates

Governorate zone	**Abbreviation**
Capital	CAP
Hawalli	HAW
Al-Ahmadi	AHM
Al-jahra	JAH
Al-Farwaniya	FAR
Mubarak Al-Kabeer	MUB



HH_ID	HZ_by_nationality	Dwelling type	Non-Kuwaiti	Kuwaiti	PHC (l/d)
1	HZ_5_K	Flat	1	4	1105
2	HZ_2_NK	annex	2		476
3	HZ_4_NK	Floor or Flat in a Villa	4		1128
4	HZ_4_NK	Flat	4		712
5	HZ_4_NK	Flat	4		712
6	HZ_2_NK	Flat	2		596
7	HZ_2_NK	Flat	2		596
8	HZ_5_NK	Flat	5		790
9	HZ_3_NK	Flat	3		693
10	HZ_3_NK	Flat	3		693
11	HZ_2_NK	annex	2		476
12	HZ_3_NK	Flat	3		693
13	HZ_5_NK	Flat	5		790
14	HZ_3_NK	Flat	3		693
15	HZ_3_NK	Flat	3		693
16	HZ_4_NK	Flat	4		712
17	HZ_3_NK	Flat	3		693
18	HZ_3_NK	Flat	3		693
19	HZ_3_NK	Floor or Flat in a Villa	3		714
20	HZ_4_NK	Flat	4		712
21	HZ_2_NK	Flat	2		596
22	HZ_2_NK	Flat	2		596
23	HZ_4_NK	Flat	4		712
24	HZ_3_K	Villa		3	3117
25	HZ_6_K	Villa	1	5	3246
26	HZ_5_K	Floor or Flat in a Villa	1	4	2610

Zone_ID	HZ_1_K	HZ_2_K	HZ_3_K	HZ_4_K	HZ_5_K	HZ_6_K	HZ_7_K	HZ_8_K
CAP	4490	3483	3654	3826	3822	4077	4187	4163
HAW	4819	3559	3647	4015	4494	4902	4902	4596
AHM	4967	3766	3399	3510	3764	4052	4099	4105
JAH	2721	2028	1871	1883	1958	2175	2490	2319
FAR	5620	3827	3548	3576	3793	4044	4105	3816
MUB	2063	1880	1859	2120	2353	2532	2637	2402

Figure 3.7: An example of how sample population table matches the constraint tables

Table 3.12: The cross-tabulated constraint table (number of households) derived from the household population table (2013)

<table>
<tr><td colspan="13">Kuwaiti</td></tr>
<tr><td>Zone_ID</td><td>HZ_1_K</td><td>HZ_2_K</td><td>HZ_3_K</td><td>HZ_4_K</td><td>HZ_5_K</td><td>HZ_6_K</td><td>HZ_7_K</td><td>HZ_8_K</td><td>HZ_9_K</td><td>HZ_10_K</td><td>HZ_11_K</td><td>HZ_12_K</td></tr>
<tr><td>CAP</td><td>4,490</td><td>3,483</td><td>3,654</td><td>3,826</td><td>3,822</td><td>4,077</td><td>4,187</td><td>4163</td><td>3,711</td><td>3,118</td><td>2,471</td><td>8,064</td></tr>
<tr><td>HAW</td><td>4,819</td><td>3,559</td><td>3,647</td><td>4,015</td><td>4,494</td><td>4,902</td><td>4,902</td><td>4,596</td><td>3,635</td><td>2,751</td><td>2,052</td><td>4,601</td></tr>
<tr><td>AHM</td><td>4,967</td><td>3,766</td><td>3,399</td><td>3,510</td><td>3,764</td><td>4,052</td><td>4,099</td><td>4,105</td><td>3,614</td><td>3,220</td><td>2,719</td><td>8,036</td></tr>
<tr><td>JAH</td><td>2,721</td><td>2,028</td><td>1,871</td><td>1,883</td><td>1,958</td><td>2,175</td><td>2,490</td><td>2,319</td><td>2,310</td><td>2,157</td><td>1,788</td><td>5,853</td></tr>
<tr><td>FAR</td><td>5,620</td><td>3,827</td><td>3,548</td><td>3,576</td><td>3,793</td><td>4,044</td><td>4,105</td><td>3,816</td><td>3,430</td><td>2,937</td><td>2,295</td><td>6,519</td></tr>
<tr><td>MUB</td><td>2,063</td><td>1,880</td><td>1,859</td><td>2,120</td><td>2,353</td><td>2,532</td><td>2,637</td><td>2,402</td><td>2,120</td><td>1,755</td><td>1,366</td><td>4,136</td></tr>
<tr><td colspan="13">Non-Kuwaiti</td></tr>
<tr><td>Zone_ID</td><td>HZ_1_NK</td><td>HZ_2_NK</td><td>HZ_3_NK</td><td>HZ_4_NK</td><td>HZ_5_NK</td><td>HZ_6_NK</td><td>HZ_7_NK</td><td>HZ_8_NK</td><td>HZ_9_NK</td><td>HZ_10_NK</td><td>HZ_11_NK</td><td>HZ_12_NK</td></tr>
<tr><td>CAP</td><td>21,481</td><td>3,739</td><td>2,884</td><td>2,491</td><td>1,829</td><td>1,062</td><td>678</td><td>392</td><td>320</td><td>204</td><td>131</td><td>358</td></tr>
<tr><td>HAW</td><td>55,820</td><td>20,033</td><td>18,344</td><td>18,756</td><td>12,922</td><td>7,091</td><td>3,428</td><td>1,687</td><td>873</td><td>464</td><td>278</td><td>516</td></tr>
<tr><td>AHM</td><td>36,608</td><td>9,061</td><td>8,139</td><td>7,368</td><td>4,298</td><td>2,322</td><td>1,222</td><td>705</td><td>471</td><td>338</td><td>237</td><td>619</td></tr>
<tr><td>JAH</td><td>17,807</td><td>3,291</td><td>2,628</td><td>2,413</td><td>2,139</td><td>1,761</td><td>1,505</td><td>1,526</td><td>1,372</td><td>1,336</td><td>1,194</td><td>4,494</td></tr>
<tr><td>FAR</td><td>61,517</td><td>16,305</td><td>14,456</td><td>14,023</td><td>8,887</td><td>4,966</td><td>2,671</td><td>1,486</td><td>967</td><td>669</td><td>461</td><td>1,274</td></tr>
<tr><td>MUB</td><td>4,623</td><td>4,48</td><td>385</td><td>353</td><td>283</td><td>222</td><td>139</td><td>112</td><td>64</td><td>45</td><td>40</td><td>75</td></tr>
</table>

The sample population table is missing the one person household size in all dwelling types for Kuwaiti and non-Kuwaiti, and the household size of two persons for non-Kuwaiti in the “floor or flat in a villa” category. The FMF can simulate the demographic data for these missing categories drawing on other categories, and total observed data, which is known. For example, the FMF can simulate a population for the missing household size of nine persons in the annex category because it has eight categories enumerated before it. To obtain a reliable output, average increase/decrease of the sample’s numbers to each dwelling type category has been calculated and applied to estimate the missing values. The equation to balance the FMF simulation is:

$$S = (\{k/100\} * j) \tag{2}$$

Where S is the sample size of a household size category to be extracted; k is the number of samples in the following household size category to S, divided by 100%. The calculated result is multiplied by j, the average increase of a dwelling type's category which includes all the household size categories. 363 samples have been extracted plus 8 samples that are located in the middle or at the end of the matrix. In sum, 371 samples (unique household identifiers) have been added to the household population matrix to address a full complement of 3,247 household identifiers in total (Table 3.13).

Table 3.13: The number of samples of the missing values for dwelling type categories

Kuwaiti			
Dwelling type	Household size	The average of increasing rate (%)	Number of dwelling after calculating the average
Villa	1	9	10
Floor or fat in villa	1	9	16
Flat	1	10	17
Traditional house	1	9	4
Non-Kuwaiti			
Dwelling type	Household size	The average of increasing rate (%)	Number of dwelling after calculating the average
Villa	1	11	2
Floor or flat in villa	1	11	4
Floor or flat in villa	2	11	4
Flat	1	11	190
Traditional house	1	9	1
Annex	1	14	115

3.5.2 FMF model outcomes

Initially, the constraint and sample population tables are uploaded to the FMF model. Fields are then selected that match each other in the tables and the model is run. The FMF model produces a new file with a table of two columns. The first is the cloned or copied zone codes over the number of the household fields in the constraint table. The second is the clone of the unique household identity against the zone column. The outcome of the model is generation of a 673,682 synthetic population samples (for 2013). To add the attributes (dwelling type and water demand) for every household identity in the generated synthetic table a VLOOKUP function in Excel has been employed, transferring those attributes from the sample population table to the synthetic population table. This procedure has been applied to a household population matrix between for 2013- 2018 (observed populations – to prepare for aggregate household demand estimations) to produce synthetic population tables that have all the needed categories.

3.5.3 FMF outcomes evaluation test

Evaluation and assessment tests in SAE and especially in spatial microsimulation models vary, with no agreed statistical tests amongst demographers to test the reliability and credibility of a simulated synthetic population. Furthermore, very little literature extends discussion and explanation of the obstacles and difficulties of validation methods for synthetic population estimation. For example, a difficulty may occur in validity testing when a simulated synthetic population of a small area has no other data at the same level/area available. However, several statistical techniques have been introduced to test validity and accuracy for outcomes being extracted, using external and internal evaluation methods. These use: (i) scaling up a synthetic population of a small area to a level where data is available, then a goodness of fit test can be applied; (ii) comparison of the simulated synthetic population with other data that is similar or closely related; and (iii) comparison between the simulated synthetic population and census data (constraint table) through the application of forecast error tests such as Total Absolute Error (TAE), Standard Absolute Error (SAE), and Percentage Error (PE). Variables selected as common (conductors) between the constraint table and sample population table should be selected carefully, as their choice influences the quality of synthetic population simulation - its representation and goodness of fit.

Due to the lack of complementary data from Kuwait to evaluate the population simulation, either on a national level or similar international level, the simulated annealing – combinatorial optimisation process (Kirkpatrick *et al.*, 1983), is evaluated using the TAE metric. In evaluating the reliability of the simulated annealing – combinatorial optimisation process, Huang and Williamson (2001) and subsequently others (Smith *et al.*, 2009; Melanie, 2014) concluded that the TAE test is a good test of outcomes. In the TAE test the simulated synthetic population is compared with the constraint table (census). The FMF software includes a fitting test function which evaluates the outputs under several statistical fitting tests, including TAE. Application of the TAE test in this study returns a TAE value of zero, which indicates the synthetic table fits very well. An error of zero is usually considered spurious in statistical tests, but Lomax (*pers. comm*) explains that this is a credible TAE result as only one constraint table is being simulated with the sample population table; that is the synthetic population is simulation is quite simple (one constraint table for the sample population table), and so all individuals in the population can be simulated completely with the sample population table. The results of the population microsimulation are thus a credible total population, sub-divided by all the variables (including dwelling type) in the PHC sample household matrix. This allow the water use coefficients in the matrix to be applied to the wider population with confidence.

3.6 Baseline demand estimation and BAU forecasting

Forecasting is the process of predicting future events and situations (Bowerman and O'Connell, 1979). It is the activity of generating predictions of the future based on past and present data, implementation of trend analysis, and methodologies that seek to represent system understanding (Chatfield, 2000). Forecasting is a vital process in economics, commerce, and various branches of science, and is important for many types of organisations since predictions of future events must be incorporated to pursue decision-making procedures (Bunn and Salo, 1993). Bowerman and O'Connell (1979) state that the government of a country needs to make forecasts, across a wide range of decision domains, in order to formulate effective policies. A forecasting approach is based on representation of dominant trends and processes with past trends or better system understanding, used to make estimates of future conditions or the impact of interventions (Kok *et al.*, 2011).

Forecast techniques vary by time horizon addressed and may be qualitative or quantitative, with many techniques in use (Brockwell and Davis, 2016); Table 3.14 shows the widely used forecasting/estimation techniques. Very short-term forecasting is often considered anything less than a month; short term one to three months, medium term three months to two years, and whilst long-term forecasting is for two years and more (Veeramachaneni, 2012). Qualitative forecasting makes prediction on the basis of expert judgment (Bragg, 2019) and so predicts the future in a subjective manner, and is often used when historical data is either not available or scarce (Lawrence *et al.*, 2006). Qualitative forecast techniques include Delphi analysis, Subjective Curve Fitting (SCF) or scenario forecasting, and forecast by analogy (Batyrshin and Sheremetov, 2007).

Quantitative (model-based) forecasting is based on analysis of a variable of interest in an attempt to predict (extrapolate) future values (Stanton, 1989). It consists of two approaches, univariate and multivariate (causal) forecasting. Univariate forecasting relies on past and present data of a single variable only, which changes as a function of time (e.g., extrapolation or time-series forecasting). Univariate forecasting models have many uses (Stock and Watson, 1998) but are ineffective at analysing changes outside the historical precedence (e.g., a policy intervention). Multivariate forecasting is causal forecasting between a dependent (response) variable and other independent variables (predictors) that are related to the variable to be forecasted. Multivariate methods better represent system behaviour (Chambers *et al.*, 1971; Law, 2016) and represent a more powerful means to measure and predict change in future conditions, including those from policy and management interventions. Multivariate forecasting can also be used to predict the future without such interventions, for instant, future food demand (dependent variable) under population growth (independent variable), or temperature change with atmospheric CO_2 increase, or indeed water demand with population growth (Köne and Büke, 2010; FAO, 2017).

Forecasting has been widely used in the water industry, where water demand forecasting is essential for water resource planning (Herrera *et al.*, 2010). There are several purposes of forecasting water demand, such as planning for new development, water distribution system expansion, estimation of water demand, identifying supply-demand imbalances, and supporting decisions-making (Jain *et al.*, 2001; Bougadis *et al.*, 2005; Donkor *et al.*, 2012). Planning for the future is the core of the water business since it serves and provides the basis for making operational, tactical, and strategic planning, as well as understanding spatial and temporal patterns of water demand (Mitchell and White, 2003). Forecasting demand in the household sector has increasingly been used as a result of population growth, expansion of residential areas, and change of consumption pattern (Gato *et al.*, 2007; Peña-Guzmán *et al.*, 2016).

Forecasting of residential demand uses the averaging techniques as a deterministic technique that can help define the end use demand of each facility (e.g., taps and showers). The key to the application of the averaging forecasting is to define the PCC and PHC demand in which gives more insight of how these demands in different levels (e.g., by dwelling type, and household size) can be controlled. Therefore, the averaging forecasting technique has been selected to estimate and forecast demand in disaggregate and aggregate levels, through the application of the micro-component model (see chapter five for in-depth discussion).

Table 3.14: Forecasting approaches, methods, and techniques

<table>
<tr><th colspan="3">Quantitative</th></tr>
<tr><th>Method</th><th>Purpose/definition</th><th>Techniques</th></tr>
<tr><td rowspan="5">Univariate</td><td rowspan="5">It is a quantitative analysis of only one variable, which is a modelling of time series that represent changes in a single variable over time. It useful when a forecaster needs to predict business as usual situation.</td><td>Average</td></tr>
<tr><td>Naïve, consisting of Drift, and seasonal naïve forecasting</td></tr>
<tr><td>Time series regression; including single and multiple linear regressions and nonlinear regressions.</td></tr>
<tr><td>Exponential smoothing; including SES, DES, Holt’s (Brown) ES, and ARRES.</td></tr>
<tr><td rowspan="2">Time series decomposition; including moving average, classical decomposition, SEATS decomposition, and STL decomposition.</td></tr>
<tr><td>Multivariate (causal forecasting)</td><td>It is time series modelling which has more than one time-dependent variable. Each variable depends not only on its past values but also has some dependency on other variables. This dependency is used for forecasting future values, especially when intervention measurements have been applied.</td></tr>
<tr><th colspan="3">Qualitative</th></tr>
<tr><th>Method</th><th>Purpose/definition</th><th>Techniques</th></tr>
<tr><td rowspan="3">Judgmental forecasting</td><td rowspan="3">It represents the opinion of experts and consultants to predict the future, and the prediction process is subjectively achieved; hence, it depends on logical intuition.</td><td>Delphi</td></tr>
<tr><td>Forecast by Analogy</td></tr>
<tr><td>Subjective Curve Fitting (SCF) or Scenario forecasting.</td></tr>
</table>

Source: Chambers *et al.* (1971); Stanton (1989); Veeramachaneni (2012)

3.7 Results

3.7.1 Estimation of household water demand

Through literature review of water demand and supply management in Kuwait (chapter one and two), it is evident that the water demand in the household sector has not been addressed deeply or widely. Therefore, it is necessary to explore and address the issue in a more broad and profound sense given the per capita consumption is amongst the highest in the world, and the per capita of freshwater resources is the lowest. Furthermore, posing future scenarios of how the demand might be in different situations can stimulate officials and policymakers to take actions towards sustainability, water demand and supply efficiency. Accordingly, the backacast micro-component model has been utilised to achieve this mission. First, the baseline year (2013) has been estimated, followed by the estimation of the baseline demand (2013 – 2018) which has been compared and validated against the observed demand (second). Third, BAU demand forecast (2050) has been built on the baseline demand estimation (chapter four). Which has enabled us to project and calibrate the micro-component model to the BAU forecast (fourth), developed in chapter five. Eventually (fifth), is the establishment of the backcast micro-component model to develop the backcast scenarios where conservation interventions have been applied, and backcast scenario implication appraisal has been achieved (chapters six and seven).

Setting a baseline year and estimating aggregate water demand in the household sector to compare with observed aggregate household demand, available from the Water Yearbook (MEW, 2018)[6], is a primary task that provides a base for building forecast scenarios of household demand. Observed household demand data is available, at the aggregate level only, for 2014 – 2017, so our approach is to apply our model to 2013 and judge the validity of the model against the remaining years (2014 – 2017) (see section 3.7.1.1). Subsequently longer-term projections of future demand are made by manipulating the key input data, the demographic forecasts, to produce the best forecasts that we can (chapter four), to act as a Business As Usual, baseline scenario. We recognise that other drivers are likely to operate,

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[6] The observed aggregate household demand is only available from 2014 to 2018; the demand figures are obtained from district meter records.

causing a shift in PHC/PCC over time, but available data prevents any credible analysis of this issue, which thus represents a model limitation (section 3.7.1.3).

3.7.1.1 Generating the baseline (2013 – 2018) demand estimate

To establish a base period that reflects the 'current' situation of water demand in our case study, water use coefficients from the PHC demand matrix are used to represent the primary driver of water demand and linked to association population data (the simulated population from the household population matrix, see section 3.5.2), this is presented in the following equation:

$$BLDE = \sum_{t=i} (\{cgj^{-d}_{(h)} + egj^{-d}_{(h)} / 10^{-9} * yr^{-1}) \tag{3}$$

Where $BLDE$ refers to the baseline demand estimate; cgj is the Kuwaiti demand (PHC – l/d) by spatial distribution g and dwelling type j for each household size h in a daily basis d; egj is the non-Kuwaiti demand (PHC – l/d) by spatial distribution g and dwelling type j, divided by a billion (litres in one MCM), then, multiplied by a yearlong at time t (e.g., 2015) to get the aggregate demand for a certain year (2013 – 2018).

The equation has been applied for each year of the baseline demand estimated period, where the results show an expected increase in demand with household population increase. Table 3.15 shows the observed aggregate demand, estimated aggregate demand, and the observed-estimated residuals for each year. On aggregate demand, the average increase rate of estimated demands is 4.3%, the highest rate is 9.7% in 2014, and the lowest is 2.5% in 2018. The substantial increase in demand in 2014 (9.7%) is driven by the substantial increased growth rate of non-Kuwaiti household population. In contrast, the lowest increase rate in 2018 (2.5%) is driven by the decrease of increase growth rate of non-Kuwaiti household population (see section 4.3.2 and 4.3.3 for in-depth discussion). Of aggregate demand; on average, Kuwaiti household population is responsible for about 74% of total demand, whilst non-Kuwaiti household population is responsible for about 26% of total demand. These figures are very close to the figures of TED/KISR's survey conducted in 2017 that estimated Kuwaiti demand is about 73% of total demand and non-Kuwaiti demand is about 27% (Burney *et al.*, 2017).

Table 3.15: Estimated household water demand, 2013-2018 (MCM/yr)

Year	**Household population** [a]			**Million Cubic Metre** (MCM)		
	Kuwaiti [b]	Non-Kuwaiti [c]	Total	Observed	Estimated	Residual
2013	1,422,220	1,559,531	2,981,751	N/A*	366.18	N/A
2014	1,680,403	1,912,602	3,593,005	421.66	405.59	16.07
2015	1,733,024	1,946,934	3,679,958	423.91	419.31	4.60
2016	1,807,660	1,961,275	3,768,935	445.22	431.96	13.26
2017	1,875,202	1,984,831	3,860,033	452.38	445.29	7.09
2018	1,998,864	1,947,834	3,946,698	N/A	456.63	N/A

* Not/Available (N/A); [a] population here is the number of people in the household sector not the number of the households in the sector (see section 4.3); [b] domestic workers have been included in Kuwaiti population (see section 4.3.2); [c] the figures of non-Kuwaiti population are the total non-Kuwaiti population in the country. Source: PACI

3.7.1.2 Accuracy and validity of the estimated baseline demand

Accuracy tests play a key part in selecting a given estimation technique and decide what is best for the forecasting model (Mahmoud, 1984). The purpose of model validation/accuracy test (also known as model performance or model evaluation) is to assess whether the outcomes of the model are acceptable with respect to the actual observed data (Mitchell, 2016). In other words, model validation is a set of processes and activities (e.g., coefficient of determination R^2, and graphical residual analysis) intended to assess if models are performing as hoped.

In our study, we have modelled water demand for 2013, using the expenditure survey which addresses water use for a highly disaggregated population sample, but have no matching annual observed demand. We therefore also make forecasts for several nearby years (2014 – 2018) for which aggregate observed household water demand is recorded (excepting 2018) by the MEW, and demographic data is available. To model demand in later years, to 2050, the research applies demographic forecasting (chapter four).

Many accuracy tests are used to compare predicted and observed data to a model. The most common tests are the forecast error (residual) tests that measure accuracy for continuous variables; representing in two metrics groups; (i) scale-dependent error tests such as Mean Absolute Deviation (MAD), Mean Squared Error (MSE), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE); and (ii) scale-independent error also knowns as percentage error such as Absolute Percentage Error (APE), Mean Percentage Error (MPE), and Mean Absolute Percentage Error (MAPE), or the so-called Mean Absolute Percentage Deviation (MAPD). Those tests are used to find the difference between the actual (observed) values against the estimated (forecasted) values.

Such forecast error tests are widely used in demand forecasting including water demand forecasting. The strength of forecast error tests is its role in the selection of appropriate models and in delivering insights in recommending changes to existing models to reduce deviations in future forecasts (Donkor *et al.*, 2012). Furthermore, the coefficient of determination R^2 is commonly used to evaluate time series (regression) forecasting. Also, in time series evaluation tests, the Chi-square (X^2) test which is intended to test how likely it is that an observed distribution is due to chance. It is also called a “goodness of fit” statistic because it measures how well the observed distribution of data fits with the distribution that is expected if the variables are independent. There are a number of estimation accuracy tests such as student t-test, Theil’s and cross-validation tests which is not a subject to describe all of them; the most important act is to define and apply the appropriate tests that would evaluate the accuracy of the estimated values against the observed values.

The model used in estimating baseline demand is a deterministic model, where the average of given values (e.g., average of PHC observations of Kuwaiti households in villa of five members) is used to estimates aggregate demand in a given year (known as point estimation technique). Consequently, the forecast error tests used are best accuracy tests for aggregate values (actual against estimated values). Altunkaynak *et al.* (2005), Herrera *et al.* (2010) and Donkor *et al.* (2012) stated that MAPE, RMSE, and MAE are frequently used in water demand estimations in order to select the best-fit technique. MAE, MAPE, and RMSE share the same principle of measuring the accuracy where indicates the discrepancy between the observed and estimated values in which lower values of these metrics consider a sign of well-fitting (Adamowski *et al.*, 2012). However, MAPE is more preferable compared with the mentioned metrics because it is independent of system capacity (Bakker *et al.*, 2014). These metrics have been applied to our model for two reasons; first, because they are commonly used to evaluate accuracy of water demand forecasts; second, to find out the differences amongst those metrics, and to assure of the accuracy of estimations, see Table 3.16.

Table 3.16: The equations of MAE, MAPE, and RSME accuracy metrics

Metric	Equation
MAE	$\sum_{t=1}^{n} \frac{\lvert A_t - E_t \rvert}{N}$
$MAPE$	$\sum_{t=1}^{n} \frac{\left\lvert \frac{A_t - E_t}{A_t} \right\rvert}{N} \times 100$
$RMSE$	$\sqrt{\frac{\sum_{t=1}^{n} (A_t - E_t)^2}{N}}$

Key: A refers to the actual demand; E is the estimated demand; t refers to a certain year; and N is the number of intervals.

For our 2014 – 2017 baseline period, the calculation of MAE shows an error of 10.26, a MAPE of 2.36%, and RMSE gives an error of 11.24. The result of forecast error metrics has shown a good model fit, and one that compares favourably (higher performance) to other household water demand forecasting studies (Chen *et al.*, 2003; Gilliland and Sglavo, 2010; Bakker *et al.*, 2014; Tiwari and Adamowski, 2014). So, we conclude that our model of baseline demand estimation is well-suited to building a BAU demand forecast.

3.7.1.3 Long run change in PHC/PCC

Change in consumer's consumption patterns over time is a potentially important factor in future demand – that is, per capita consumption may not be static, and we might expect this to have risen in previous decades, as Kuwait households have adopted new water use technology, for example. As a result, attempts were made to assess long run change in patterns of consumption, a "behavioural coefficient" for the case study. The average PCC from 1993 to 2017 has been obtained from the 2018 MEW water book and the results reveal no consistent temporal pattern in PCC (Figure 3.8). However, this analysis is heavily constrained by a lack of appropriate data as household sector use is lumped into other sectors (agricultural, industrial, commercial, and governmental sectors) (MEW, 2018). Accordingly, the average coefficients in the PHC demand matrix (2013) have been kept as is (static) throughout BAU demand forecast to 2050 (chapter four).

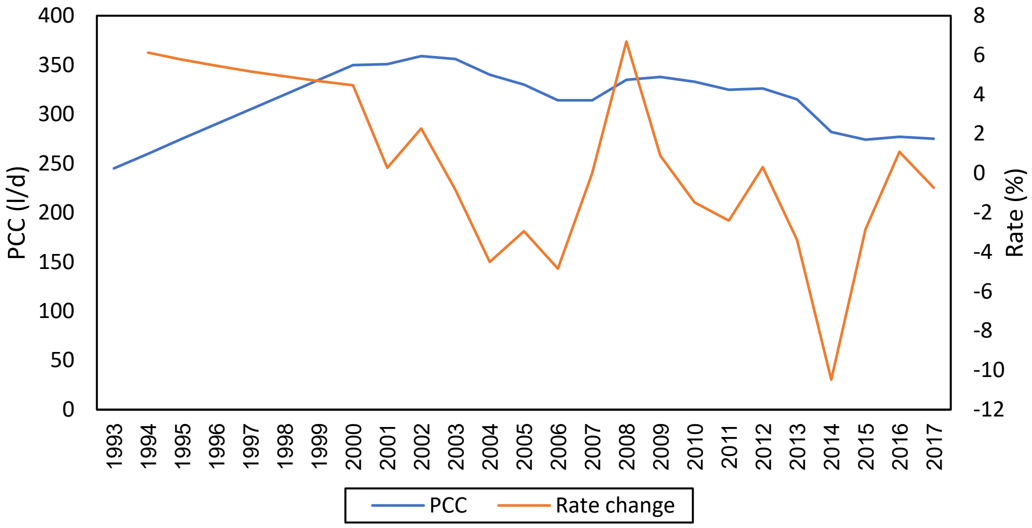

Figure 3.8: The annual rate change of PCC (l/d) from 1993 to 2017
Source: MEW (2018)

3.8 Conclusion

Data needed for household water demand model building has been investigated for Kuwait. A data investigation field campaign identified a general lack of suitable data which has proved a major constraint on model building and validation. Data that has been sourced has however enabled a model to be constructed drawing on sample of household water demand from a family expenditure survey. Missing values were imputed via a curve fitting process addressing specific household sizes, using a Power function, to develop missing PHC/PCC values. The influential and leverage points that adversely influences the trendlines have been defined and omitted. To estimate water demand, a static microsimulation method has been applied to link the available national level demographic data to the PHC demand matrix attributes (adding the dwelling type's variable). The combinatorial optimisation – simulated annealing technique was selected as it is widely considered the best available technique for this type of application. Demand estimates were then generated using an averaging forecasting technique (PHC matrix x population data) for 2013-2018 and model performance tested using forecast error metrics using the very limited observed household demand data (2014-2017; aggregate household demand). Based on these tests, the estimates have shown good performance relative to observed demand. Change in PCC use over time is expected, but it has not been able to address this in the model due to lack of suitable data, hence this remains a limitation of the demand forecasts to 2050, which are addressed in the next chapter.

Chapter 4 The BAU household water demand forecast

4.1 Introduction

Prior to micro-component model development, a forecast of household water demand under the current situation is needed. This relies on the demand model developed in chapter three, linked to demographic forecast to the 2050 target year. Business as usual demand forecasting is thus the objective of this chapter. A demand forecast produced using the disaggregate behavioural model developed in chapter three allows backcast demand scenarios that can explore conservation interventions in greater detail than with an aggregate model. Subsequently economic, environmental, and feasibility and acceptability of different intervention strategies can be evaluated.

A BAU demand forecast depends on representing changes in demographic trends (the principal predictor). Therefore, it is critical to assign a suitable, robust, and sophisticated population projection that reflects population growth trends (e.g., fertility and mortality rates), and meets the needs of the research (e.g., disaggregating population to nationals and expatriates). As the process of population projection is beyond the scope of this study, the research uses external population projections to build a BAU demand scenario. As stated in the previous chapter, 2013 is the base year for which the PHC demand matrix has been produced, and the observed population has been obtained from the PACI, then aggregate demand estimated. Observed population data for 2014 – 2018 was also available from the PACI and has been used to produce further demand estimates; a similar process will be applied to estimate aggregate demand for future years. For 2019 – 2050 population projections matrices have been sourced from the UN Population Division and from the TED division, of KISR. These projections are discussed further in section 4.2.1.

This chapter seeks to: (i) evaluate the UN and KISR population projections in terms of their use in the demand forecasting (section 4.2.1); (ii) produce BAU demand scenarios under parameters variations, then, select a preferred base scenario (sections 4.4 and 4.4.2); and (iii) test sensitivity of demand to different population projections (section 4.4.2). The selection criteria for population projections are based on research needs, including the need to address Kuwaiti and non-Kuwaiti populations separately, as well as those variables that reflect the rather specific nature of Kuwait's population (e.g., very high expatriate population, naturalisation procedure). Population scenarios will be developed from the population projections, to produce a range of BAU demand scenarios. The base scenario will be selected using judgment on past observations of demographic trends, past and ongoing policies, and social perspectives of the country. Finally, the base BAU scenario will be analytically compared with the other scenarios to gauge uncertainty and sensitivity.

4.2 Population projection

Population projections are essential inputs to the development of policies, strategies and plans across numerous sectors (Patton and Sawicki, 1993). They alert policymakers to major trends that may affect a country's development, and assist them to craft policies that can be adapted as population trends change (Population Reference Bureau, 2009). They are widely used in resource allocation and planning, including within the water sector, where demographic forecasts are a critical input to water resource planning, assessing future demand for water, and thus ensuring management of the future supply-demand balance. Population growth is a key driver of water demand and brings increasing demand and competition for water for household, municipal, and industrial uses. Many of the world's most water stressed regions are typically those with few water resources but also a high population growth rates, as in the MENA region. Such regions need accurate population projections[7] so as to develop robust and effective water management plans and policies (PAI, 2012; Chi and Wang, 2018).

A trustworthy water demand forecast is primarily based on a reliable population projection that reflects historical trends of past observations of the demographic characteristics (Billings and Jones, 2011). An advanced population projection can deliver estimates of change in the age group, sex, net migration, mortality rate, and Total Fertility Rate (TFR). It can also show the geographic distribution of a population. This supports a better understanding of population movement in the future and how this would affect water demand (e.g., which regions or areas will have higher population and thus higher demand).

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[7] Population projection accuracy depends on a set of assumptions of population components including migration, fertility, and mortality. These assumptions are built on several demographic factors including sex, age structure, household size, fertility rate, and net migration.

Population projection process differs from country to country and from one organisation to another, depending on the context, needs and objectives. For instance, in the GCC countries, expatriates represent about 50% of the total GCC population (70% in Kuwait and 89% in UAE) (Abdulrazak, 2018); therefore, projecting expatriate trends (e.g., which nationalities, their spatial distribution, and their demographic characteristics) is crucial as water consumption patterns of expatriates are different, compared with nationals (section 3.3.2).

At the household level, the basis of forecasting water demand is to understand the future distribution of population by the demographic characteristics in the PHC demand matrix (chapter three). These characteristics are; (i) population (households); (ii) household size; (iii) household status (national or expatriate) and; (iv) dwelling type. Each dwelling has its characteristics, for example, a villa may have garden that requires watering, whilst a flat does not. Additionally, villas tend to have more residents, bathrooms, and kitchens than flats and annexes, thus water consumption tends to vary from one dwelling type to another. These variables adopted to forecast demand in the case study are thus households and household size, household status, household dwelling type, and household's spatial distribution over governorates. These variables have been addressed in the base period estimates (2013 to 2018), and we seek to similarly apply them in the future demand projection (2019 to 2050).

4.2.1 Household population projections for Kuwait

The responsible government departments for demographic studies and statistics in Kuwait are PACI, CSB, and the Ministry of Social Affairs and Labour (MSAL). These departments provide demographic data specific to its tasks and responsibilities. CSB was established in 1961 to conduct general censuses every ten years. PACI was established in 1982 to develop a central databank to support delivery of government services to citizens, business, and visitors, and that can be used to inform political decisions. As part of this service, demographic statistics are regularly collected. MSAL issues statistics for foreign labour in the private sector (except labour in the household sector, i.e., domestic workers). Unfortunately, these departments do not provide any future projection of population as their main demographic remit is to issue statistical reports on past population trends, and they do not engage in forecasting.

4.2.1.1 TED/KISR population projection

The TED division in KISR published a single-variant population projection in 2010, covering a long-term horizon, 2010 - 2050. TED gathered datasets from the national-based sources (PACI, CSB, and MSAL) comprising of the fundamental demographic variables (fertility, mortality, and migration). They developed a time series of past trends of population change and age structure with 2010 fixed as the so-called 'launch year'[8] (Rayer, 2007; Alramadan and Almusallam, 2013). The key advantages of the TED/KISR projection are; (i) adding in a naturalisation coefficient to reflect expatriates becoming Kuwaiti citizens; (ii) separating the population into two groups, nationals, and expatriates. A naturalisation variable has been added to the projection parameters as a result of naturalisation decrees issued each year since 1952 by the cabinet, sustained by the 1952 naturalisation law (Al-Hadawi and Al-Anezi, 2019). The purpose of setting two population projection groups is due to the high proportion of expatriates in the population, some 70% of the total population. The projection used the cohort component methodology in which individuals within a population share a common characteristic (e.g., age) and go through a transition process (e.g., ageing). It is a powerful method that categorises a population into components based on age distribution by sex, and it is able to add variables, such as ethnicity. It is based on the population components of historical demographic trends, including births, deaths, and in/out migration in which each component is modelled through passing a different stage of life alongside its age groups and sex (UN, 1956; Shryock *et al.*, 1973).

The key advantage of the cohort component method is that it follows the pathway of past demographic changes through aging population components through time to reach a target year (Smith *et al.*, 2006). As an analytical method, it seeks to reflect understanding of the processes (birth, death, migration) that give rise to demographic change. This contrasts with less dependable mathematical projection methods (arithmetic, geometric, logistic) that rely upon trend projection. Such trendline projection depends on historical data of population growth/decline but without taking into account the underlying demographic processes (Gawatre *et al.*, 2016). The cohort component method delivers in-depth knowledge on the dynamics of a population, and it is applicable at any geographical level, such as the world,

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[8] Launch year refers to the most recent datasets employed to start a projection.

nation, province, and sub-district. It is also able to be applied with a wider range of assumptions (Pandurang *et al.*, 2018). There are disadvantages of the cohort component method, however. First, it is highly reliant on reliable fertility, mortality, and migration datasets, which are not always available. Second, it assumes that birth and death rates, and estimates of net migration will remain the same throughout the projection period. Furthermore, it does not reflect the non-demographic factors that stimulate population growth or decline, such as, for example the effect of women's education on fertility and family size. Despite these problems, the cohort component method is the most widely used demographic tool by planners as it is considered to provide superior demographic forecasts to those possible with simpler mathematical methods (Murdock, 2019). Population projections for Kuwait, provided by TED/KISR, using this approach are presented in Figure 4.1.

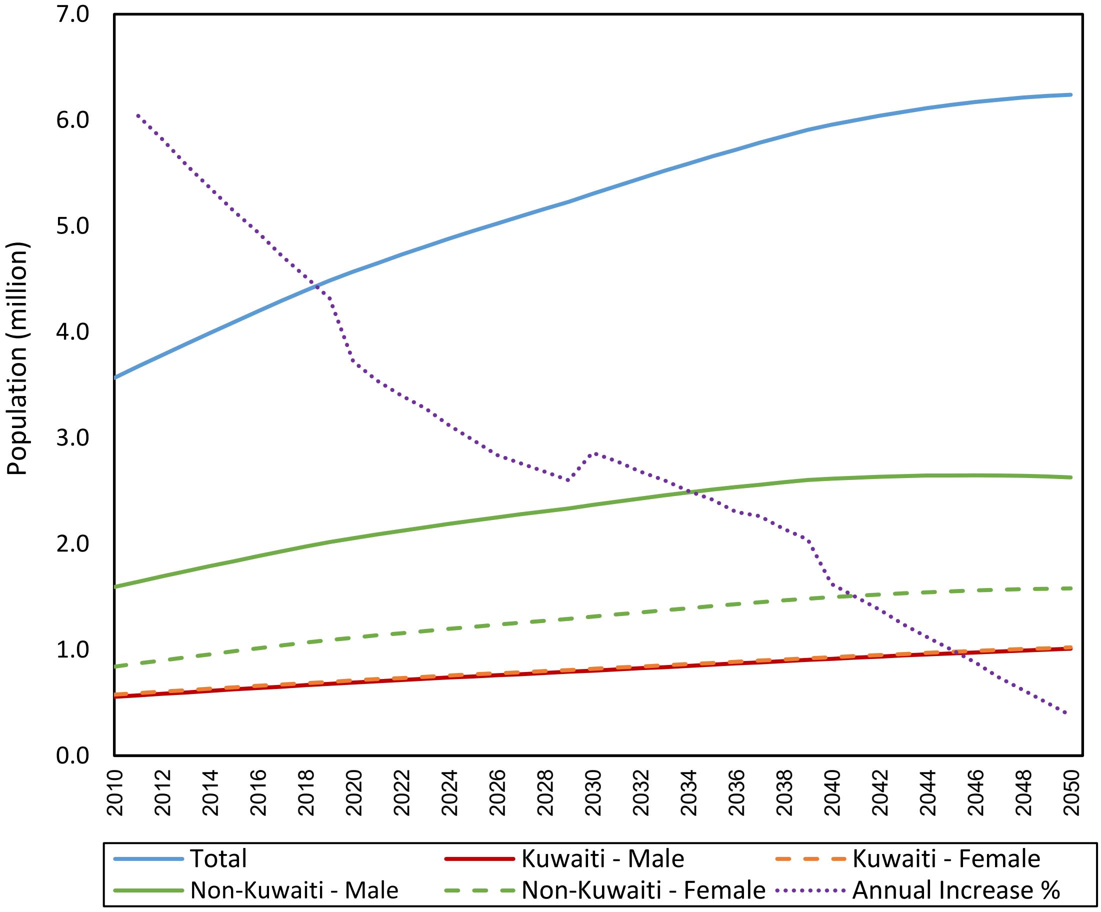

Figure 4.1: TED/KISR Kuwait population projections
Source: Alramadan and Almusallam (2013)

4.2.1.2 The UN population projection

The United Nations has also produced a projection for Kuwait following the same approach as TED/KISR, the cohort component method. The Population Division of the UN is responsible for publishing the World Population Prospects (WPP) projections. It produces a revision of projections each year as a result of receiving the latest empirical datasets of the demographic trends for countries and areas equal to or above 90,000 inhabitants. In the most recent 2019 revision, the projection addresses 235 countries (including Kuwait), based on different sources of demographic datasets (UN, 2019). The UN projection modelling has two periods. First is the estimates period, runs from 1 July 1950 to 1 July 2020. In this period, revisions to past estimations are made as new demographic datasets are gathered, and historical datasets appraised. The cohort component method is applied to estimate populations 1950 – 2020. Second is the projection period, this period has 2020 as the base year from which projection extends to 2100. A probabilistic approach has been adopted in the cohort component method. The fertility rates play the main driver of the population projections, in association with the estimates period trends. These two drivers have been employed to project populations for all WPP countries. In the forward projections, three phases of fertility have been defined for each country's population, according to the demographic transition theory:

(i) Phase I: High fertility level (pre-transition phase): six births or above per woman;
(ii) Phase II: A fertility transition phase: below six births and over two birth per woman;
(iii) Phase III: A low fertility phase (post-fertility phase): two birth per woman or below.

The demographic transition recognises a shift from high birth rates and high infant death rates in less advanced economies to low birth rates and low death rates in societies with advanced technology, education (particularly of women) and economic development. Observation has shown transition theory to be broadly accurate, but demographic forecast applying the theory are often imprecise due to context, the particular social, political and economic factors that affect populations in specific countries.

Based on recent demography datasets, all countries conducted in the WPP projection are considered in the transition period (phase II) or had already completed transition and are now in the post-transition period (phase III). Kuwait is in phase (II); for those countries in phase II, the fertility decline divides into a systematic decline and various random distortion terms, where the total fertility is modelled as a function of its level using a double-logistic decline function by a Bayesian Hierarchical Model (BHM). The future trajectories and pace of fertility of the countries that experience the fertility transition are informed by historical trends of the specific country of interest, and the variability in the historical trends of countries that have already experienced similar fertility decline. For those countries that have already reached phase III, a time series model is employed to project future fertility levels. The time series model, based on a Bayesian Hierarchical Model, has used empirical evidence from low-fertility countries that witnessed increase in fertility rates after fertility declines. Therefore, in this category (phase III), are the historical data of the country of interest and empirical evidence of countries that have experienced low-fertility levels, which then, experienced an increase after low-fertility; sub-replacement fertility levels have been used to project future natural growth and/or decline. The number of countries that have already experienced phase III has risen from 25 in 2012 to 40 in 2019. For populations in phases II and III, the BHM has generated 186,000 double-logistic curves for all countries in these phases. Each population has received hundreds of trend curves that show the uncertainty in the model, as the horizon of the projection is quite long. Then, the median of these curves has been set as the base scenario under the name medium-variant scenario. A number of scenarios have been developed to test for sensitivity and uncertainty (Table 4.1).

For Kuwait, the population is in phase II and demographic projection follows the procedure as stated above. However, whilst there are advantages to the UN projections, particularly in terms of providing harmonised statistics for every country, there are disadvantages with respect to Kuwait and the current study. First, when compared with official Kuwaiti sources (PACI) we observe significant differences in base data. The count of total population in the UN data show high residuals (difference) compared with the observed source data from PACI (Figure 4.2). In addition, the UN demographic data for Kuwait in the 2019 WPP does not match with sources of the datasets in the metadata matrix that is provided with projections tables. Thus, the best available current data for Kuwait is not represented in the UN WPP so the base year demography is considered incorrect due to the outdated data, even though the methodology used is robust. Also, projections are made on an aggregate level with no distinction between Kuwaiti and non-Kuwaitis. The UN projection does however confirm that Kuwait in transition phase II, with fertility decreasing through time to reach phase III in the forecast period. Consequently, the natural increase rate will be declining, and thus the population growth rate is expected to decrease. This fact has helped assume the population growth manner of Kuwait while using TED/KISR projection (as it has been selected to be used in forecasting BAU demand, see section 4.2.1.3 and 4.3.1).

It must consider that the transition theory would only be appropriate for the Kuwaiti population (30% of the total country population) as the population growth is natural; hence, it can act in accordance with population dynamic models. But it is inappropriate for the non-Kuwaiti population (70% of the total country population (PACI, 2022); see Kuwait's population classification in Figure 4.5) as the growth is unnatural (immigration) where the growth is uncertain. Non-Kuwaiti population can't be modelled with any certainty as this population is determined by; for example, government policy (e.g., balancing Kuwaiti and non-Kuwait populations), economic or health crises (e.g., Covid-19 pandemic), see section 8.2. This unique situation of Kuwait's population (and indeed other GCC countries) is a subject for further works in modelling population prospects, which has been recommended in section 8.4.

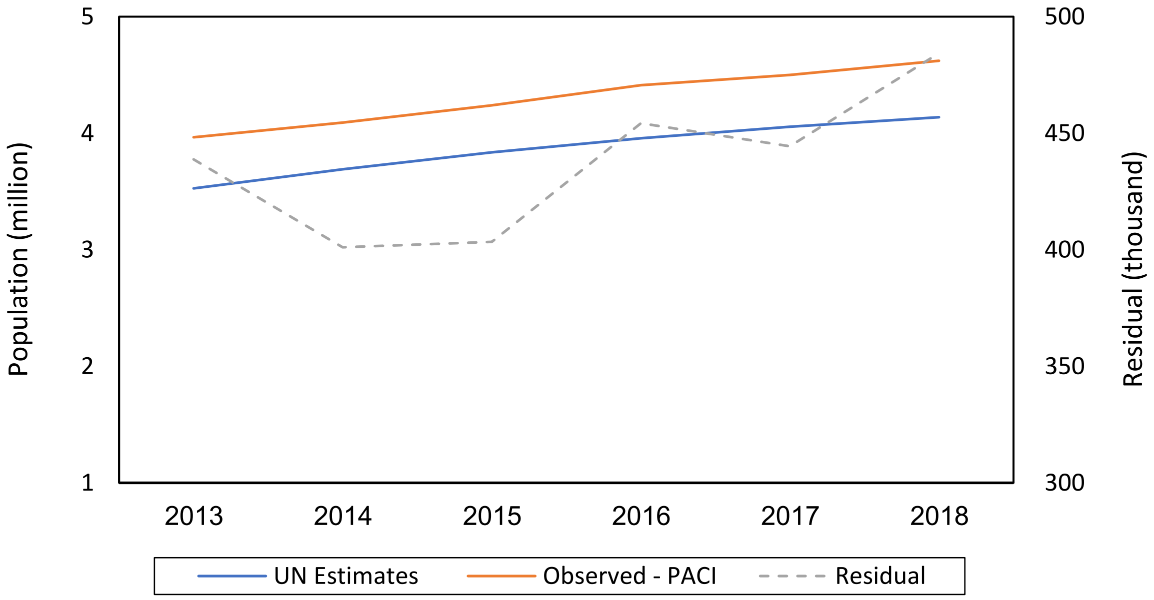

Figure 4.2: The population differenece between observed and estimated populations
Source: PACI (2018); UN (2019)

Table 4.1: UN population projection assumptions for fertility, mortality, and international migration

Projection variants	**Assumptions**		
	Fertility	**Mortality**	**International Migration**
Low fertility	Low	Normal	Normal
Medium fertility	Medium - based on median probabilistic fertility	Normal - based on median probabilistic fertility	Normal
High fertility	High	Normal	Normal
Constant fertility	Constant as of 2015 - 2025	Normal	Normal
Instant Replacement Fertility	Instant replacement as of 2020 - 2025	Normal	Normal
Momentum	Instant replacement as of 2020 - 2025	Constant as of 2015 -2020	Zero as of 2020 - 2025
Constant Mortality	Medium	Constant as of 2015 -2020	Normal
No Change	Constant as of 2015 - 2020	Constant as of 2015 -2020	Normal
Zero Migration	Medium	Normal	Zero as of 2020-2025

This table is from the official website of the Population Division of the UN, here: (https://population.un.org/wpp/DefinitionOfProjectionVariants)

4.2.1.3 Selecting a population projection for Kuwait

Differences between the UN and KISR population projections have been noted, arising from difference in observed statistics, and treatment of the population (Kuwaiti and non-Kuwaiti). As discussed earlier, household demand forecasting is primarily built on population projection hence a choice between these projections must be made, recognising their quality and suitability to the research needs.

On balance, the TED/KISR projection is considered more suitable than the UN projection, for several reasons. First, it separates the population into national and expatriate populations, which helps in forecasting Kuwaiti/non-Kuwaiti water demand, as national's consumption differs markedly to expatriates (discussed further below). Second, the TED/KISR projection adds a naturalisation coefficient to reflect expatriates becoming Kuwait citizens (section 4.2.1.1). Third, data used to project future population is the best available, drawing on several official governmental entities (PACI, CSB, and MSAL), whilst the UN has only had access to the CSB supplemented with unofficial international surveys. Fourth, when comparing projections, the TED/KISR projection is clearly a better fit than the UN medium-variant projection Figure 4.3, as well as, when comparing the UN population variants and TED/KISR projection against observed population (Figure 4.4). Demand forecasts based on population projections that are considered superior by Kuwait officials are also likely to be perceived as more credible.

No population projection is ever perfect but they remain very important for planning and policy analyses (Stoto, 1983). Accordingly, the TED/KISR projection has been used in the research as it is considered more suitable, representative, and superior. Nevertheless, this projection needs further enhancement to meet the research needs, by addressing household size, dwelling type, and spatial distribution over Kuwait's governorates. These variables, not present in any of the population projections, are addressed alongside the other variables (domestic workers and non-Kuwaitis in the household sector) in the next sections.

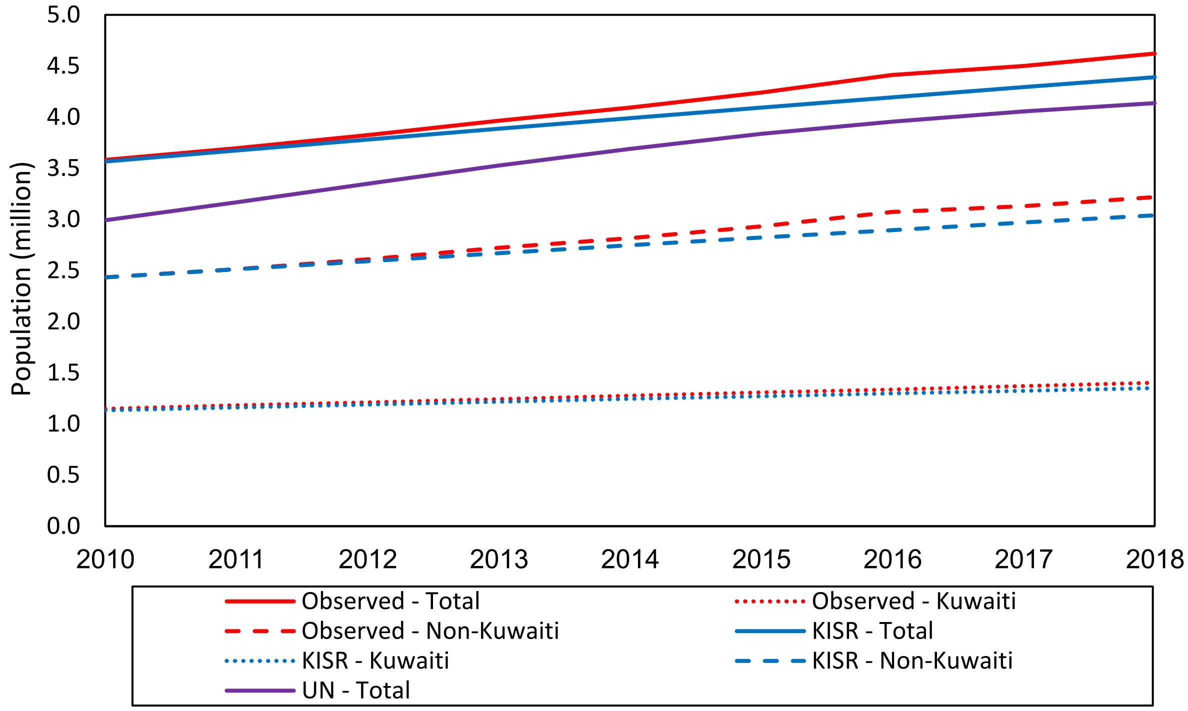

Figure 4.3: Comparison of observed and projected population of Kuwait
Source: Alramadan and Almusallam (2013); PACI (2018); UN (2019)

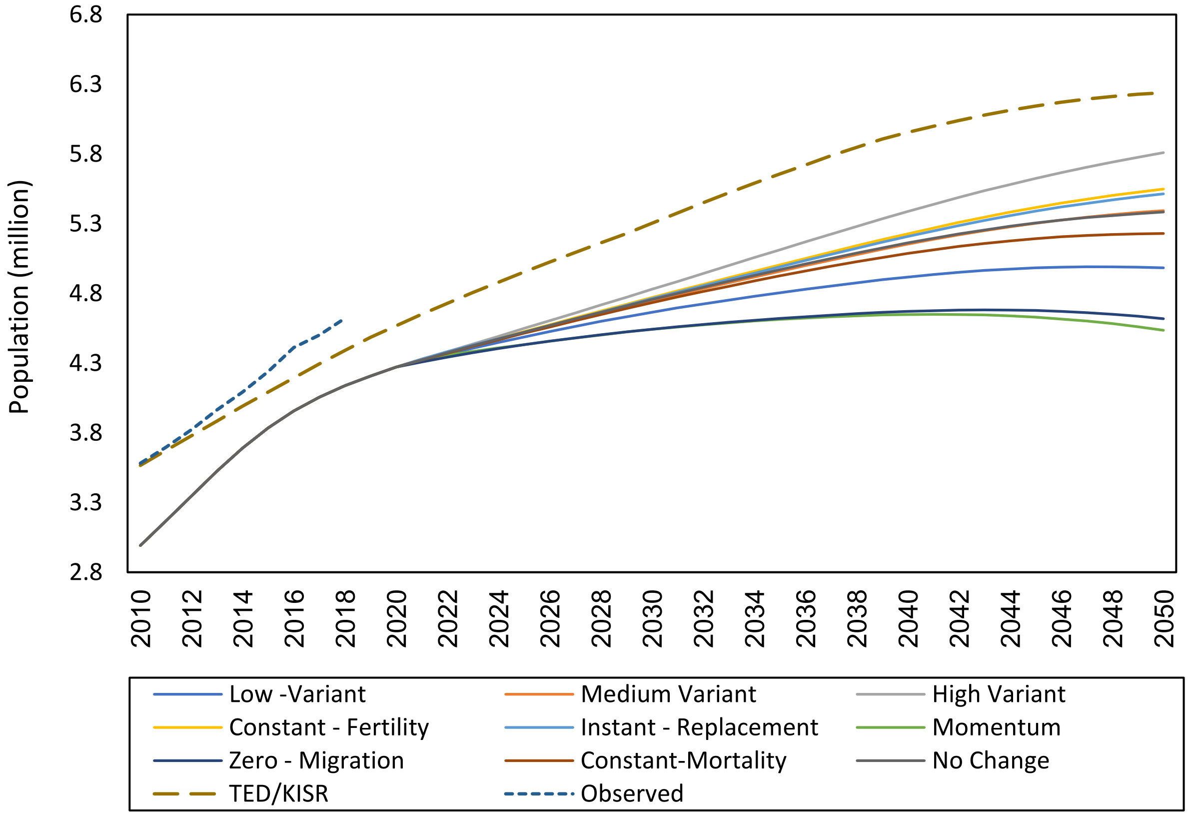

Figure 4.4: UN population variants and TED/KISR projections against observed population
Source: Alramadan and Almusallam (2013); PACI (2018); UN (2019)

4.3 Enhancement of population projection performance

The TED/KISR projection is not specifically designed to serve this research's objectives; therefore, several enhancement procedures have been applied in order to fit the population projection for these objectives. Enhancement procedures of the population projection are crucial to water demand forecast modelling, since forecast modelling is based on different demographic variables used to drive the forecast forward, and it also gives an insight into how these variables perform. The projection is designed to cover all inhabitants in all sectors (household, agricultural, industrial, commercial, military, and inhabitants in the desert), while this research is targeted at inhabitants in the household sector. In the case of Kuwait, population in sectors outside the household sector (e.g., agriculture and industrial sectors) are not considered as inhabitants in the household sector, even though they are settled in households, but they live in households out of the residential sector. Thus, their water demand is not counted as part of household demand but as agricultural or industrial demands, as appropriate. In addition to this, in the country's policy, all nationals (Kuwaitis) are counted in the household sector, whereas expatriates are divided between the household sector and other sectors (explained further in section 4.3.3). Another drawback is that the TED/KISR projection doesn't distribute the population over the governorates, but instead distributes it at the country scale. Although one of the key elements of the cohort component method is the ability to project population over different areal levels (U.S. Census Bureau, 2014), KISR has not used this method to its projection. Furthermore, the TED/KISR projection does not include the household size distribution or its development alongside the population projection but does include age distribution by sex for nationals and expatriates.

From a different angle, in the household population matrix of PACI, the domestic workers (non-Kuwaiti labour) have been added as a proportion of the Kuwaiti population, thus they represent a part of Kuwaiti household's members. Since they are considered members of Kuwaiti households, their water consumption will be as a part of the household consumption. This situation is as a result of the domestic worker's law released by the General Department of Immigration – Ministry of Interior. The law has been issued to organise the relationship between the workers and employer (householder), and to define the rights and tasks towards each other. One of the law's clauses states that the employer should provide convenient accommodation within the household and all basic needs for a decent life.

Consequently, PACI issues civil registry for a domestic worker and ties it to the employer's civil registry (tied by ID and dwelling address), which states the worker's accommodation as employer's accommodation. For this reason, PACI include domestic workers a part of a Kuwaiti household, and issues statistical tables of the population in the household sector annually. This approach has been applied in the household population matrix to generate water demand in the observed years (2013 - 2018); therefore, this research should apply this procedure and add domestic workers to the Kuwaiti population projection. This procedure will ensure consistency and keep the smoothness of flow of the population growth on a yearly interval.

Before applying the enhancement procedures described above, several concepts need to be defined specifically for the Kuwaiti context. In order to use the TED/KISR projection to forecast demand, adjustments are required, based on the eight demographic categories shown in Figure 4.5. First, the total population, refers to the sum of total Kuwaiti population plus the total non-Kuwaiti populations. Second, the total non-Kuwaiti population, refers to all non-Kuwaiti populations (TED/KISR projection level). Third, the non-Kuwaiti household population, refers to those expatriate's population who are settled in the household sector. Fourth, the non-Kuwaiti population in other sectors, refers to those expatriates who are settled out of the household sector. Fifth, the domestic workers population, refers to the expatriate domestic workers who serve in Kuwaiti households. Attention must be paid to the domestic workers as they will then treated as a part of the Kuwaiti population to constitute the total Kuwaiti population. Sixth, the total Kuwaiti population, refers to the Kuwaiti population plus the domestic workers population. Seventh, the Kuwaiti population, refers to the Kuwaiti population excluding the population of domestic workers. Eighth, the total household population, refers to the population of the total Kuwaiti population plus the non-Kuwaiti household population. The total household population is the population that will be used to project future BAU demands. The total household population is created by adding the non-Kuwaiti household population to the total Kuwaiti population (Kuwaiti population plus the domestic workers). Here, the TED/KISR projection is being employed indirectly to fulfil the research needs.

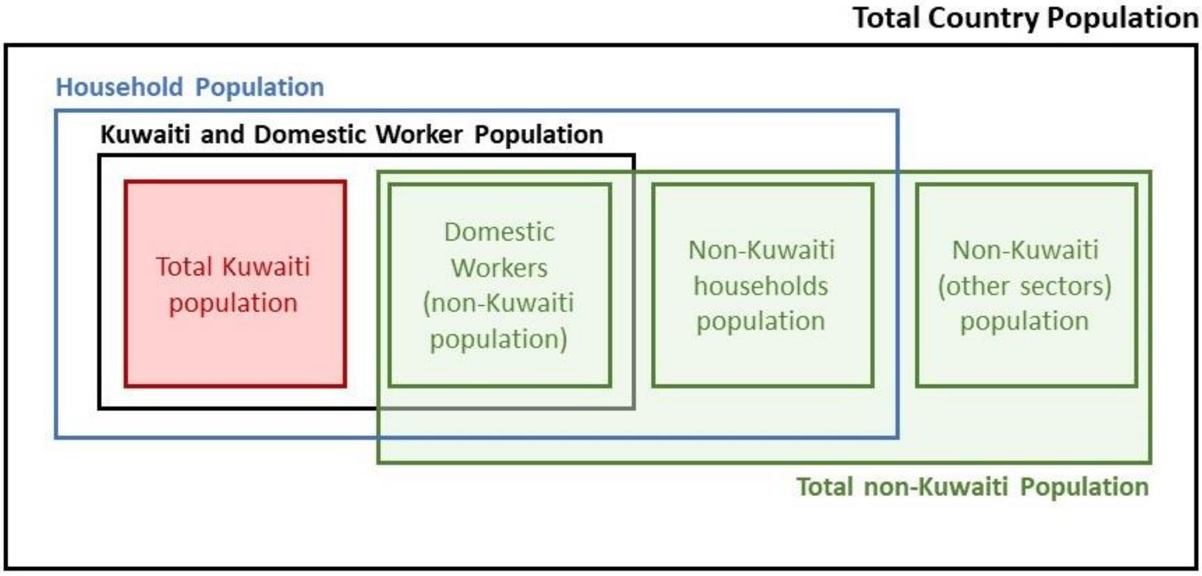

Figure 4.5: The categories of Kuwaiti and non-Kuwaiti populations

Table 4.2: Enhancement of TED/KISR population forecast to support water demand forecasting

Objective/Reason	Data	Method
Procedure 1: Kuwaiti population uplift (bias correction)		
To overcome underestimation of the TED/KISR projection compared with the observed population (2013-2018).	A. Observed Kuwaiti population (2018) B. TED/KISR projection of Kuwaiti population	Develop a constant coefficient to be applied to the period of projection.
Procedure 2: Define the domestic worker proportions in Kuwaiti population		
To maintain consistency of Kuwaiti population projection compared with observed population. The domestic worker proportions will be added to the Kuwaiti projection. See section 4.3.1.	Observed Kuwaiti population (2007 – 2018).	Three constant coefficients will be developed from the historical trend; (i) average of 2007-2018; (ii) average of 2014-2018, as a relative demographic change occurred; (iii) proportion of 2018 as it is the recent observed year. The developed coefficients will be applied to the non-Kuwaiti population, then the obtained number will be subtracted from this population and added to the Kuwaiti population (section 4.3.1).

Objective/Reason	Data	Method
Procedure 3: Define non-Kuwaiti household population and the total household population		
To find the non-Kuwaiti population in the household sector, as the research targeted those inhabitants in the relevant sector.	Observed non-Kuwaiti population (2007 – 2018).	Three constant coefficients will be developed from the historical trend; (i) average of 2007-2018; (ii) average of 2014-2018, as a relative demographic change occurred; (iii) proportion of 2018 as it is the recent observed year. The developed coefficients will be applied to the total non-Kuwaiti population, then the obtained number will be representative to non-Kuwaiti in the household sector.
Procedure 4: Determine population distribution by household size and by the country's governorates		
1. To set PHC demand for each household, which will enable micro-component water demand modelling, and subsequent backcast intervention measurements. 2. To allow spatial analysis amongst the country's governorates.	Observed household size distribution for total population (2007 – 2018).	Percentile distribution of observed household size distribution will be projected on the projected population after satisfying previous procedures. This method is derived from the scaling-up method, see section 4.3.4 for details.
Procedure 5: Define households by dwelling type		
To specify the households' dwelling types, as dwelling type is a determinant of PHC demand.	A. PHC demand matrix, as a sample population table. B. A certain year of population projection e.g., 2019, after modification, as constraint table.	SAE, static spatial microsimulation method, combinatorial optimisation – simulated annealing technique, using FMF software.

4.3.1 Kuwait population uplift

The TED/KISR projection underestimates the Kuwaiti population in comparison with observed Kuwaiti population (see Figure 4.7). The obs-pred difference increases over time (from TED/KISR projection starting point). Such population under- or overestimation is a common in demographic projection due to model uncertainty (Raftery *et al.*, 2012). A decline in Kuwaiti population is not expected in the short-term future or even in the medium-term, as Kuwait is amongst the countries that have high natural growth rates. Therefore, it can be assuming that the Kuwaiti population is in a growth mode, and any underestimation would bring about unreliability in demand forecasting. To cope with such an obstacle, statistical techniques have been used to correct the KISR population projections using the historical trend of the Kuwaiti population.

The first technique is to find a systematic fitting function that can be used to adjust the population. This function is derived from the observed and projected periods (2010 – 2018), where the residuals of these periods have been fitted using a polynomial function, see Figure 4.6. Then, this equation has been applied to the projection period (2019 – 2050), which increases the KISR Kuwaiti population in a systematic way. As a result, the rate of annual growth of the adjusted Kuwaiti population increases progressively. This is contrary to the growth's manner noted in the KISR and UN projections, neither of which grow at the rate actually observed. The population growth rates decrease as the transition theory indicates that Kuwait's natural growth is located in phase II, where the growth rate is lowering towards the future. Consequently, an alternative technique has been applied, in which the difference between the observed and projected populations in 2018 (52,807 people) has been assigned as a constant coefficient. This constant has been used as corrects the under-estimation using the residual for the last observed year, whilst also preserving the natural growth pattern in the TED/KISR projection. It represents a better technique to a systematic fitting function; it has shown as superior and thus it has been set to be added for the projection horizon (see Figure 4.7).

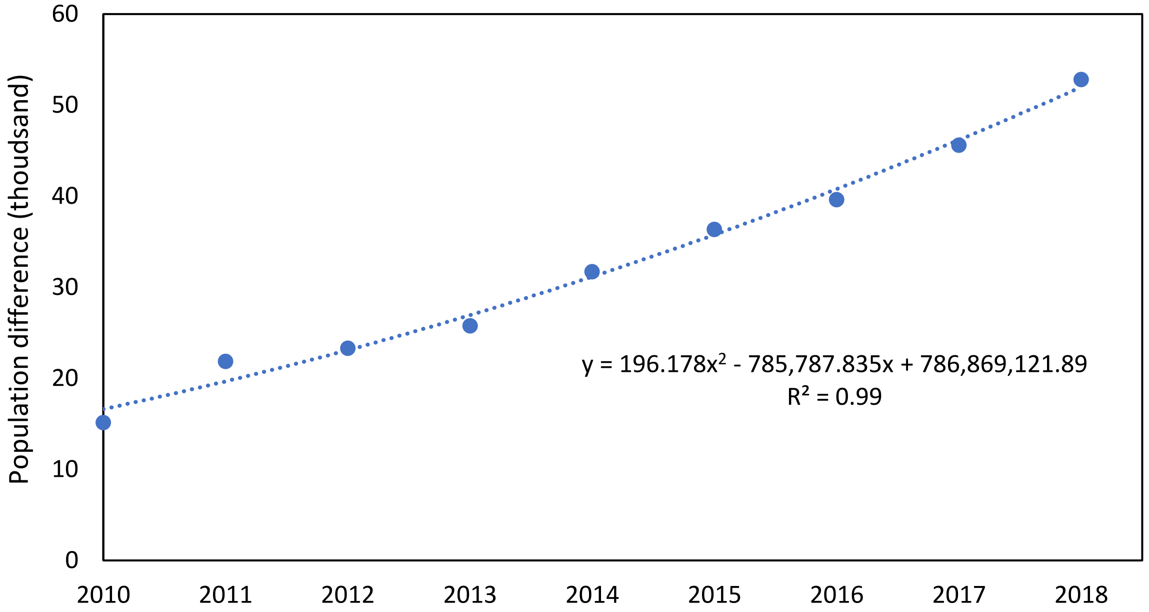

Figure 4.6: The difference between observed and projected Kuwaiti population of TED/KISR

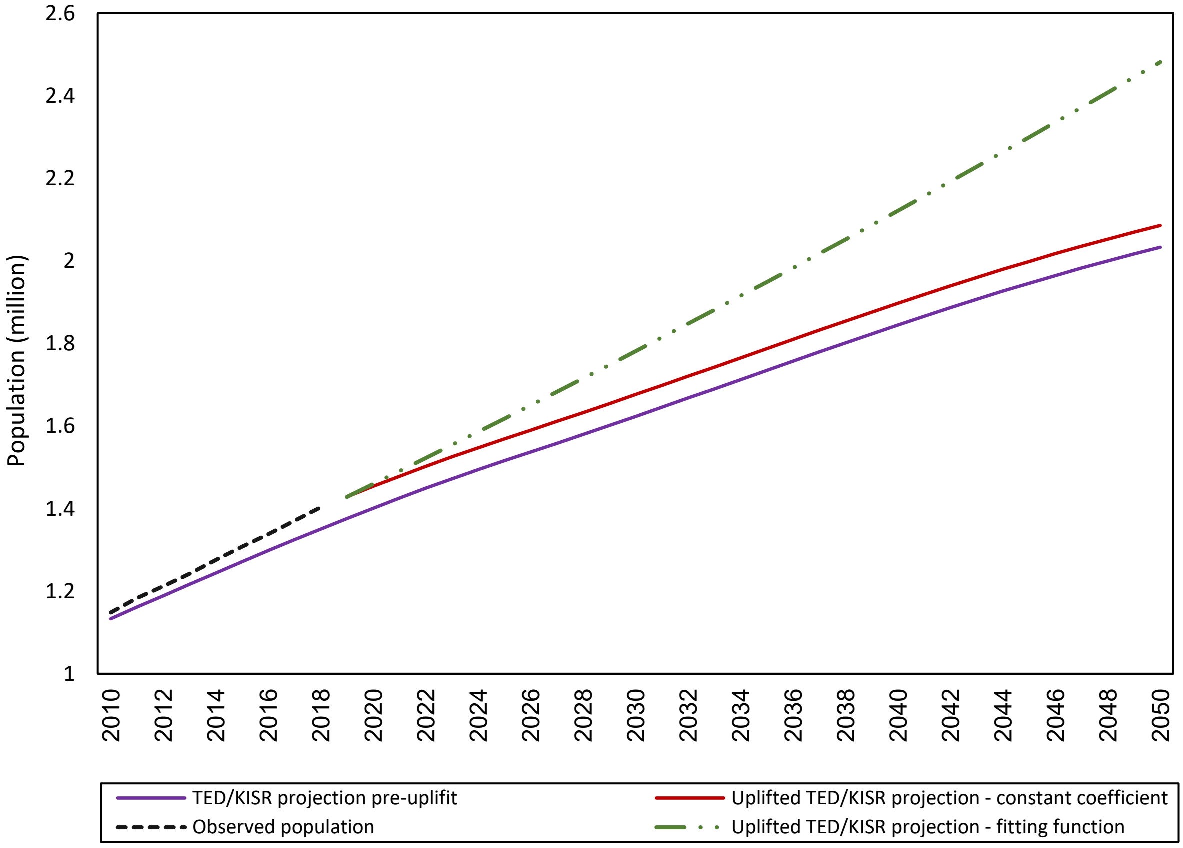

Figure 4.7: Kuwaiti population of TED/KISR projection pre- and post-uplift procedure
Source: Alramadan and Almusallam (2013); PACI (2018)

4.3.2 Domestic worker population proportion

In the modern Kuwaiti household, the domestic workers represent active and productive members of a family, where it is become challenging to accomplish home tasks without them. Domestic workers have several tasks starting with a housemaid who is responsible for a household’s cleanliness and decoration, and in some cases, a family can have a cook, a driver, a household’s guard, and may have a babysitter if there are any children. Private and public housing projects have included facilities for domestic workers in each house plan, comprising bedrooms and fully equipped bathrooms, showing the importance of the domestic workers in Kuwaiti households (Alotabi, 2004).

Domestic workers do not fall under the Kuwait labour law but are addressed by specific Department of Immigration law (Ministry of Interior law 69, 2015) that gives a domestic worker more rights than the basic Labour law (Alanba, 2016), including with respect to goods and services:

> *‘’The employer is required to provide the domestic worker with food, clothing, medicine and medical treatment, and housing; the employer must provide suitable housing for the domestic worker that enables decent living standards’’*[9]

In this context, water demand of domestic workers is therefore included as part of water demand of Kuwaiti households; thus, their consumption (domestic workers) is part of the household consumption (PHC). On a PCC basis, we might speculate that their use is lower, but there is no specific data for domestic worker consumption to evidence this. Nevertheless, the domestic workers population needs to be known because they comprise a considerable proportion of the Kuwaiti households, about 60% of the total Kuwaiti population; i.e., for every two Kuwaitis there is a domestic worker. The population of domestic workers can be extracted from the total Kuwaiti population (Kuwaiti plus domestic worker populations), as the observed values of this population subset are available. Observed values of Kuwaiti population (2007 to 2018) are deducted from the total Kuwaiti population to give domestic

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[9] Quotes from the document of the domestic workers law in Kuwait provided by the International Labour Organisation (ILO)

workers (Figure 4.8). Unfortunately, there is no available forecast of the future growth of domestic workers in Kuwaiti households, to add to the Kuwaiti TED/KISR projection, so we consider two estimation methods. First, is Exponential Smoothing (ES), a time series forecasting technique for univariate data that can be extended to support data with a clear trend or seasonal pattern (Brownlee, 2018). This is simple to apply, making a determination based on prior assumptions, and it is often used for the analysis of time series data. Techniques include Single and Double Exponential Smoothing, Holt's (Brown) Exponential Smoothing, and the Adaptive Response Rate Exponential Smoothing (ARRES). ES has been applied, for example in economics, and is widely used in population forecasting (Nazim and Afthanorhan, 2014; Walters and Chai, 2008; Openshaw and Van, 1983).

A second method is to find a fractional coefficient of the historical trend, which can be applied to the projected population. This method has been applied in the TED/KISR projection to find the coefficient of naturalisation, where a time series of past observations of naturalisation has been calculated, then, the average of these values has been set as a constant coefficient. The obtained coefficient is constant for each year of the projection. The second method is used as it has already been used in the TED/KISR projection and has been applied to test the uncertainty in the UN projection. Accordingly, this method is more representative in such situations. Developing a fractional coefficient derived from historical trends as a constant coefficient that will be applied in the entire period of projection would be suitable. A table of Kuwaiti population and the total Kuwaiti population has been prepared (from 2007 to 2018). The fractional coefficient is then:

$$DW = (\{n - k\} \div n * 100) \tag{4}$$

Where DW is the number of domestic workers; n represents the total Kuwaiti population including the population of the domestic workers in a certain year; k is the Kuwaiti population for the same year. The calculated number will be divided by n (total Kuwaiti population), then, multiplied by 100 to get the percentage of the domestic workers out of the total Kuwaiti population (n). This procedure is applied for each year between 2007 and 2018; from the results, two constant coefficients are used, the fraction for the last observed year, and the most representative coefficient will be adopted (see further below). Figure 4.8 shows the extracted domestic workers populations and its proportion of the total Kuwaiti population.

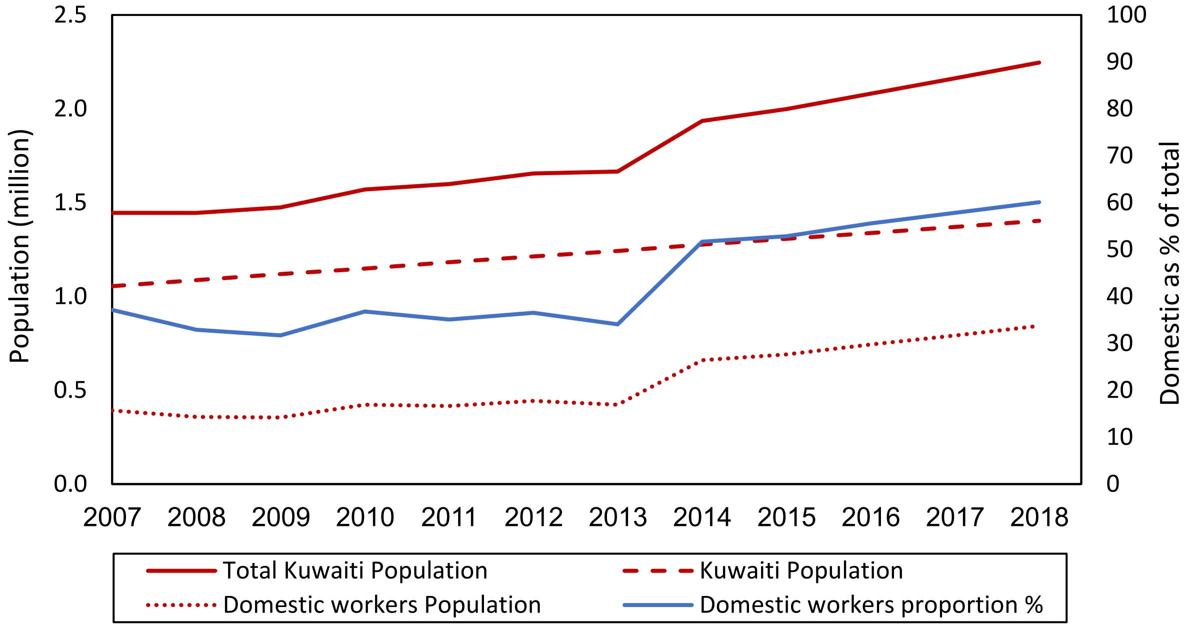

Figure 4.8: The domestic workers population in the Kuwaiti population
Source: PACI (2018)

The fraction coefficient figures of domestic workers have been calculated from the observed years (2007 – 2018); 43.51% is the average of the domestic workers for the full period of the historical dataset (2007 – 2018). This average can be used as a constant coefficient to calculate the population of the domestic workers in the projected Kuwaiti population. As shown in Figure 4.8, the proportion of domestic workers in the Kuwaiti population has jumped dramatically in 2014 and kept growing until the last observed year. To illustrate the difference, the average of domestic workers 2007 - 2013 is 34.88%, while the average from 2014 - 2018 is 55.59%, and the peak of domestic workers reached 60.08% in 2018. The growth in population of domestic workers indicates several demographic changes in Kuwaiti households making it more dependent on domestic workers. There are no governmental or organisational reports that explain such a high increase in the domestic workers in the Kuwaiti population. However, some statistical indicators can assist in understanding such dramatic growth, such as income and expenditure in Kuwaiti households, and female empowerment and participation in the workforce. In a CSB survey of household income and expenditure, the average Kuwaiti household income for 2007 was 8,461 US$, whilst the household expenditure on goods and services was 3,550 US$ (42%). In 2013, the average household income was 11,015 US$ (not adjusted for inflation), and the average expenditure on goods and services was 6,245 US$ (57%).

Household expenditure behaviour has received a considerable change in such a short period of time as household income has had a significant increase. Female participation in the workforce has increased from 50% in 2007 (out of the total Kuwaiti female population), to 60% in 2015. Furthermore, the Kuwait parliament has issued several resolutions concerning the wage system in the period 2012 to 2014 in which wages have increased in the public sector. Even in the private sector, the government has supported national employees in this sector by granting financial subsidies. These factors might result in Kuwaiti households becoming more dependent on the domestic workers.

The calculated coefficient (43.51%) has been applied to the uplifted Kuwaiti population of TED/KISR projection (section 4.3.1). The application of this coefficient led to a notable decline of the projected population (2019 – 2024) compared to the observed population in 2018. Such a decline would affect the water demand forecasting trend and will eventually lead to demand underestimations. Therefore, the fraction of domestic workers in 2018 (60.08%) has been applied instead since it is the highest value compared with the other observed years. It is also the last given observation of the domestic worker population, possibly offering a better future projection of the Kuwaiti household dependency on domestic workers. For example, the Kuwait Times newspaper reports that the number of domestic workers has increased rapidly by 24.2% in 2019 compared with the total in 2018 (Saleh, 2019). The minister of social affairs Maryam Al-Aqil announced on January 15th 2020 a government plan to target domestic worker recruitment from several markets (e.g., Nepal, Ethiopia, India, and Indonesia) (Bushra, 2020). Figure 4.9 shows the domestic workers population in five years intervals after applying the 2018 coefficient on the projected Kuwaiti population. The obtained population for the domestic workers will be deducted from the total non-Kuwaiti population, then the result will be added to the Kuwaiti population to get the total Kuwaiti population.

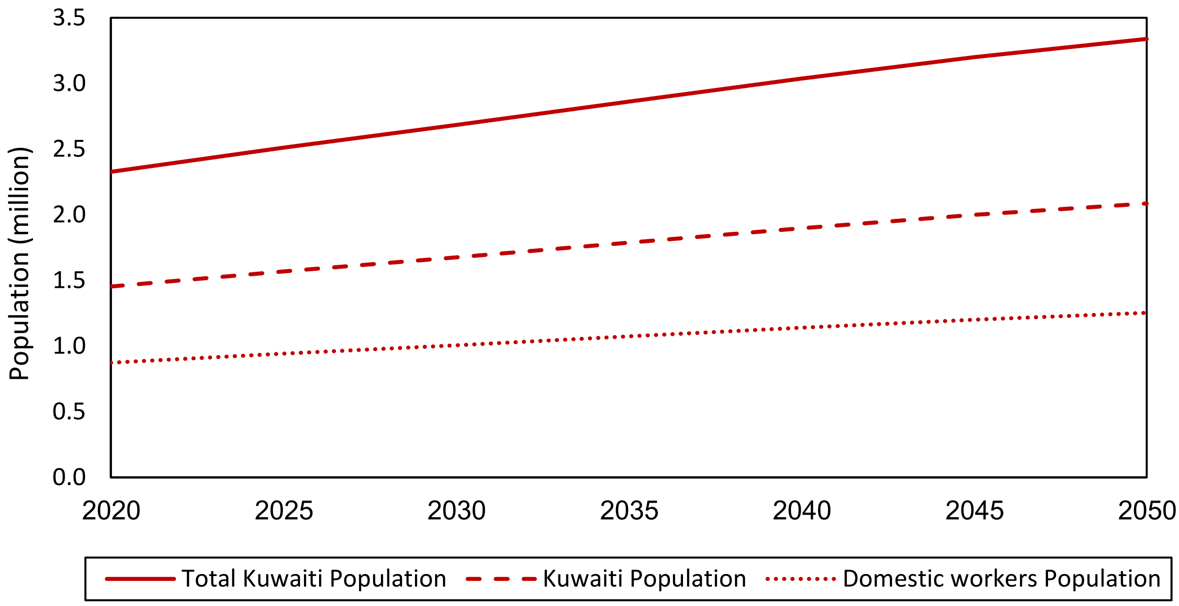

Figure 4.9: Calculated domestic workers population in the projected Kuwaiti population

4.3.3 Determine the non-Kuwaiti household population

This final procedure enables the development of the total household population (the total Kuwaiti population plus the non-Kuwaiti household population), which will be the population used to forecast water demand. The TED/KISR population projection is designed to project the whole population over all the country's sectors, which include inhabitants in the agricultural, industrial, municipal, and commercial sectors. However, the population in the household sector alone can be investigated from the TED/KISR projection since PACI has the historical trends of the population in the household sector. PACI has the spatial and sectoral distribution of the population in the country, and has the household type, whether it is a collective or a private household[10]. All the Kuwaiti households are considered as private households, while the non-Kuwaiti households consist of private and collective households. This is a result of: (i) the real estate registration law (decree 5/1952) which doesn't allow non-Kuwaiti to own property except if citizens of other GCC countries, and therefore most non-Kuwaiti live in rented households (to reduce rental cost some non-Kuwaiti tenants live in shared 'collective' households); and (ii) the compact geographical scale of the country encourages employees and students to move daily from their residence to their work

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[10] A collective household is a household that consists of members that sharing the same religion, race, or sharing a similar job, or they work with a particular employer, whilst a private household is consist of relatives whether it is nuclear or extended family.

location, encouraging private households. In contrast to, the KSA, for example, where the vast geographical area encourages people to move and live in the work area, encouraging collective households.

For non-Kuwaitis, low-wage jobs are a significant reason to encourage collective households amongst them, where a large proportion of non-Kuwaitis are working with low salaries (Ramadan, 2016). The monthly average wage for non-Kuwaitis is 1,012 US$ which is five times lower than the average Kuwaiti wages (ALshal, 2021). The high occupation of low-wage jobs amongst non-Kuwaitis is referred to the qualifications they acquired, where a high proportion (80%) have only received elementary and secondary education, and (4%) are illiterate workforce (Alnba, 2020). Thus, a high proportion of non-Kuwaiti's workforce work in the service and blue-collar jobs. According to PACI, the most occupied jobs amongst non-Kuwaitis are; (i) domestic worker; (ii) driver; (iii) ordinary worker; (iv) cleaner; and (v) waiter, categorised in ascending order (PACI, 2022). Most of the non-Kuwaiti workforce is from Asia (37.8%), then Arab (27.9%), African (1.9%), and other ethnicities (1.1%) out of the total country population (Ochsenwald *et al.*, 2022). Therefore, a considerable proportion of non-Kuwaitis arrive in Kuwait without their families and settle in collective households (in the household sector and other sectors) in order to save money to send it home to their families (Kamal, 2022). As a consequence, the rate of non-Kuwaiti males is much higher than females which created a gender imbalance amongst non-Kuwaitis; non-Kuwaiti males constitute (72%) and females (28%) of the total non-Kuwaitis (PACI, 2022).

The situation for Kuwaitis differs than non-Kuwaitis, where all Kuwaitis must register (by law) their location of residence within official residential zones. The Kuwaiti government is committed to providing the national population with suitable accommodation and provides subsidies (housing allowance) for those nationals who are waiting for housing grants from the government. Therefore, PACI explicitly connects Kuwaiti’s home addresses in the civil registry to the residential zones in the country. For non-Kuwaitis, they can be registered in any of the country’s sectors based on the person’s status. For instance, if a person is a public contract (government) employee then they have the choice to find accommodation by themselves. They can rent their accommodation and invite their family to stay or can share their rented accommodation with a group of people in the household sector. In contrast, for private contract employees, it depends on the form of contract as to whether the employer provides suitable accommodation or a housing allowance for the employee. For instance, if the employment contract is in agriculture, to provide farmers and labours for an agricultural enterprise, then most probably the employer will provide accommodation (labour accommodation) in the agriculture sector (and hence these people would not be represented in household demand statistics). If the contract is with an individual, say a citizen who owns farm(s), then employed farmers and labours should be provided with housing on the farm.

Policy dictates that all the Kuwaiti households must be within the household (residential) sector, whilst non-Kuwaiti households can be within or outside of it. Hence, the non-Kuwaiti population needs to be subdivided and the size of the population in the household sector should then be determined. To do so, a time series of the observed non-Kuwaiti population in the household sector is used to extract the fractional coefficient which has been used to subdivide the non-Kuwaiti household population from the total non-Kuwaiti in the TED/KISR projection. It has been noted that the non-Kuwaiti household population increases from 2007 - 2014 to peak at 50.71%, then decreased to 45.84% in 2018 (Figure 4.10). This pattern is a consequence of the growing non-Kuwaiti population in the other sectors, i.e., blue collar jobs, and the government plan to reduce non-Kuwaiti employees in the public sector, i.e., white collar jobs (Scott, 2018). This is as a result of the Kuwaitisation process plan to replace non-Kuwaitis with Kuwaiti employees in the governmental sectors. The government is undertaking to provide employment and to reduce the unemployment rates amongst the nationals. It has set out the employment replacement agenda over the following five-year state plan. As a result, 6,200 non-Kuwaiti have had their service terminated out of 102,000 non-Kuwaitis in the public sector in 2018, which is the highest service termination number ever recorded in the public sector since the establishment of the Civil Service Commission (CSC) (Bin Tarif, 2018).

Despite concerted efforts to reduce non-Kuwaiti employees in the public sector, the non-Kuwaiti population is still increasing, albeit at a lower rate than previous years. However, this reduced rate of increase will only last for a short period since the country is heading towards privatisation and positioning the country to be the region’s top trade and financial hub, as part of Kuwait vision 2035 (Helmy, 2011). The vision will evolve and transition the country’s sectors towards productivity, security, and stability, through expansion of the commercial and financial sectors. Such a transformation would effectively attract foreign investments and would increase the workforce in the country. This would lead to the government increasing the number of work permits for international workers since the Kuwaiti population is not enough on its own to run such a transformation. As a result, this will lead to an increase of non-Kuwaiti households. Consequently, the population of non-Kuwaiti in the household sector would continuously increase in the future. For example, Silk City is an ongoing ambitious project that is part of the Kuwait vision, and the city capacity has reached 700,000 people, and includes several types of housing (Paris and Rubin, 2016).

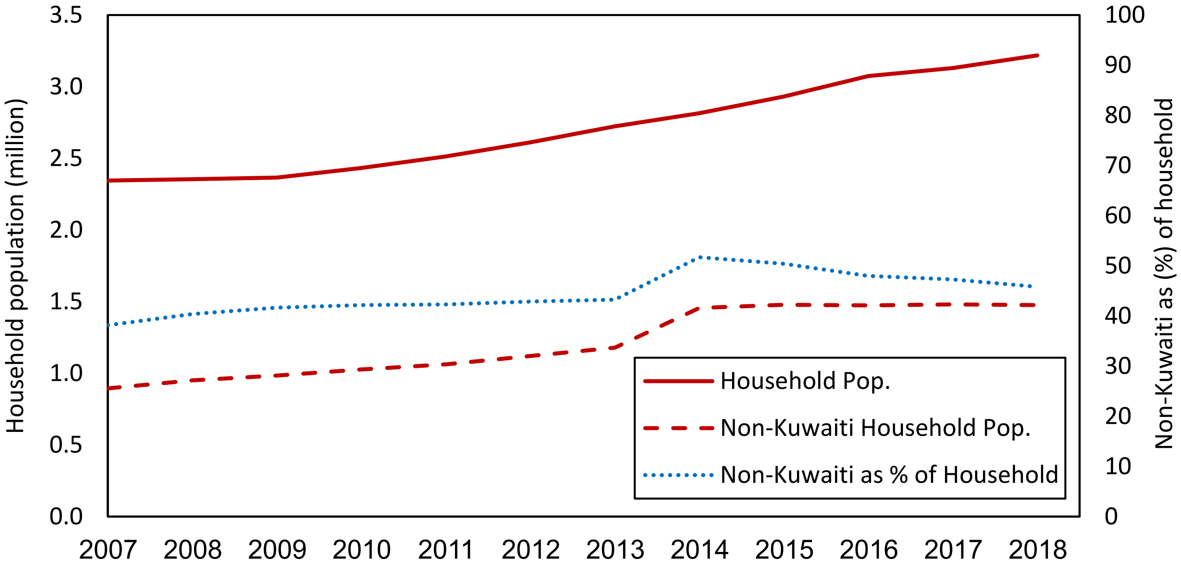

Figure 4.10: The observed non-Kuwaiti population in the household sector
Source: PACI (2019)

Non-Kuwaitis are not just expatriates who entered the country legally (e.g., work, study, or family/dependant visas), but also refers to illegal residents settled in Kuwait for decades. A population of “Bedoons” or stateless citizens exist who have been denied citizenship rights (“Bedoons” is derived from “Bedouins”, Arabian tribes who inhabit the desert) (Abu-Hamad, 1995). These nomadic tribes look for freshwater and pastures for their livestock, and travel more widely in Arabia (Iraq, Jordan and Saudi Arabia). After independence from Britain in 1961, modern Kuwait was established, and its borders defined. However the Bedouins recognised no borders and are remained undocumented (e.g., no identification document, travel document, or birth certificate) (Home Office, 2016).

Nomadic life-patterns have dramatically changed in recent decades, and the government has imposed control measures (e.g., required travel documents, gave incentives to move settle in urban areas), before then naturalising Bedouins through identification committees. Bedouins who could not prove that they inhabited the Kuwaiti desert, were given an identity (not citizenship) until they could prove they were part of the indigenous population (Lund-Johansen, 2014). This identity allows them to work in the public sector and join the military, get free facilities such as education, healthcare, housing, subsidised catering, and residency with no need to get a visa. These facilities, in addition to the opportunity to get citizenship in a wealthy country, means that being a "Bedoon" has more value than being an expatriate. Accordingly, the number of Bedoons has dramatically increased in the 1970s compared with the 1960s. Therefore, the government has assumed control from the identification committees as they were sceptical there were so many Bedoons that were Kuwaiti desert inhabitants. In the 1980s the government withdrew the Bedoon rights and privileges and the Bedoons have become persecuted, becoming an internal political issue, and international human rights issue. The government has alleviated pressure on Bedoons by increasing their access to some public sector's services.

The Bedoons have a private civil registry "the Central System for the Remedy of Situations of Illegal Residents", operated by the statistics department, PACI. Bedoons don't have civil I.D.s, but have identities that approve their residency, and thus, they can get jobs, healthcare, education, and access to some other public services. The population of Bedoons was 51,466 in 1965, 39,461 in 1970, but increased greatly from 1975 to 124,085, before reaching a peak in 1990 of 219,027. Two years later, following the Iraqi invasion, the population had fallen to 117,115, and is currently around 85,000 (Al-Qabas, 2019). The majority live in low-income houses in the Al-Jahra governorate, with large households (mostly is traditional house dwelling type); The Bedoons experience is similar in other GCC countries (Krause, 2013). Currently, the government treats the Bedoons as illegal expatriates; hence, they have been considered as non-Kuwaiti households in the model.

To extract the non-Kuwaiti household population from the TED/KISR projection, two fractional coefficients have been used in addition to the last observed year proportion of 45.84%. The first coefficient is 44.5% which is a mean for 2007 to 2018; and the second is 48.65%, the mean for 2014 to 2018; the equation is:

$$NKH = (\{n - e\} \div n * 100) \tag{5}$$

Where NKH is the average of the non-Kuwaiti household population; n represents the total non-Kuwaiti population in the country in a certain year; e is the non-Kuwaiti population in the household sector for the same year. The calculated number is divided by n (total non-Kuwaiti population) and multiplied by 100 in order to give the percentage of the non-Kuwaiti household population. Three populations of the non-Kuwaiti household population (from coefficients mentioned earlier this section) have been extracted from the TED/KISR projection. Compared to the observed population, the projected non-Kuwaiti population is lower than the observed population; for example, the observed population in 2018 is 3,218,525 people, whereas the projected population in 2019 is 3,109,519 people. Therefore, a 44.5% coefficient has been applied to extract the non-Kuwaiti population in the household sector. For 2019-2022, the extracted populations are lower than the observed population in 2018. When the 48.65% coefficient is applied, the extracted non-Kuwaiti population in the household sector in 2019 has shown increased compared to the 2018 observed value. The decline of the non-Kuwaiti household population between 2017 and 2018 (5,398 people) is a result of the government efforts in reducing the non-Kuwaiti employees in the public sector. However, the CSC authority continues to provide work permits for non-Kuwaiti employees for job vacancies where no Kuwaiti employees are available to take over, especially in the health and education sectors. On the other hand, the private sector is expanding according to the Kuwait Vision 2035, which will employ non-Kuwaitis in this sector. These factors will stimulate the population to increase, despite the government plan to reduce non-Kuwaiti employees. As a result, the median coefficient (45.84%) has been adopted to find the non-Kuwaiti household population. Figure 4.11 shows the non-Kuwaiti household population, plus the total household population after the total Kuwaiti population to this population.

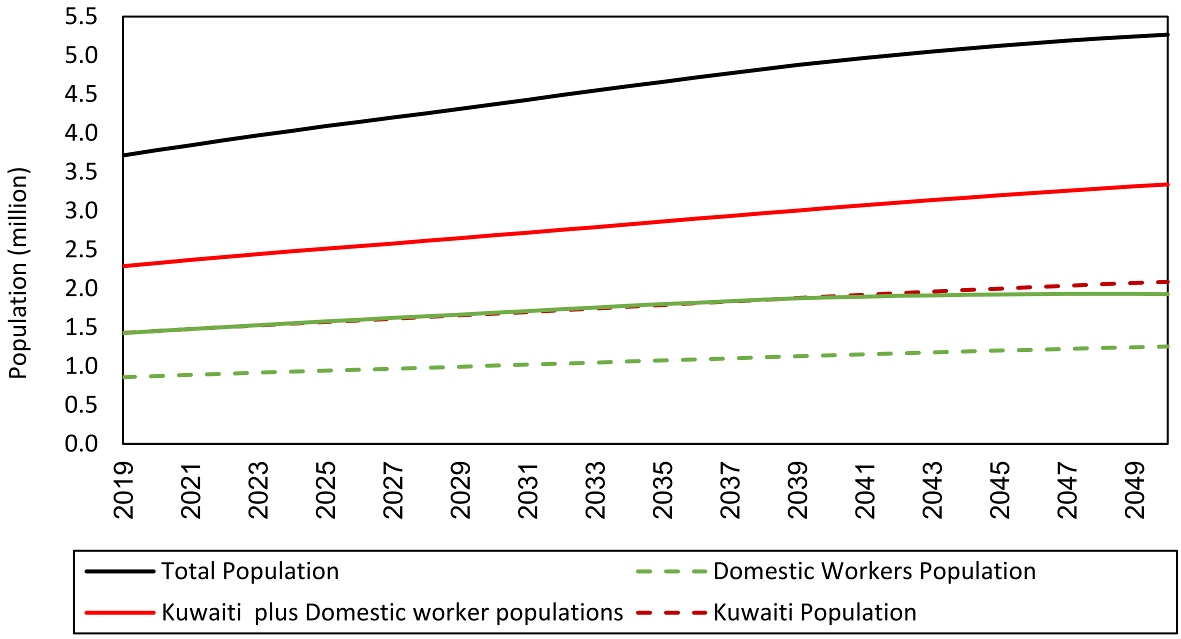

Figure 4.11: Total household population after modification of the TED/KISR projection

4.3.4 Total household population: Spatial and household size distributions

The total household population has been developed in the previous section and it is now possible to select and apply a statistical technique to derive the spatial and the household size distributions. The scaling-up technique is a statistical tool that can be used to find the spatial and/or household sizes distributions over an area or a country from an aggregate scale to disaggregate scale and/or vice versa, i.e., scaling-down, a technique used in Small Area Estimate methods (see chapter three). Scaling is a vague term which brings a difficulty of creating and developing a cohesive theory of scale-up/down effects (WHO, 2010). The term’s use and meaning varies across and within disciplines, and can be referred to as a temporal, spatial, and quantitative tool to measure and investigate objects and processes (Evans *et al.*, 2003). It might be referred to as micro, meso, and macro scales to spatially explain a small, medium, and large-sized phenomena in a region. Further, it can be temporal - e.g., a second, an hour, or a day, the scale used depends on what is being measured. Curran *et al.* (1997) identified that the terms scale-up/down are vague when used as stand-alone but is a precise method of description when specifying the scales of the data being transformed. The significance of ‘’scale’’ is broadly recognised due to its ability to overcome the limitation of size-estimation and is considered an effective size-estimation technique. It is also applicable to estimating populations that are hard-to-reach or what are so-called hidden population[11] (UNAIDS, 2010).

Evans *et al.* (2003) stated that the scale-up/down in the social science paradigm could be represented as a social unit of analysis in which socio-demographic data (e.g., individual or household level) is used to reflect the broader or narrower scale such as regional and/or national scale. For example, a survey of household-level data can be scaled-up to show the demographic attributes at the national level using census enumeration units. In geography, spatial scaling methods are common and apply to both human and physical geography. It should be taken into consideration that scaling methods can affect the variables that are scaled-up/down; for example, from household-level to aggregate-level. Therefore, it is essential to describe how data is collected (e.g., how the sampling frame is drawn at the household-level to reflect the entire population, so that it can be representative).

Scaling is widely used amongst geographers and demographers as a size-estimation method in population studies (Johnsen *et al.*, 1989; Snidero *et al.*, 2007; Salganik *et al.*, 2011; Scutelniciuc, 2012; Sheikhzadeh *et al.*, 2016; Yang and Yang, 2017), with the most straightforward scaling procedure being the application of average values at a lower level to a higher level or vice versa (Maltiel *et al.*, 2015). Accordingly, this technique is applied for the total household population in order to transfer the population spatially (from the country to the smaller governorates) and to scale down the total aggregate population to reflect household characteristics to a more disaggregate level.

In this study, the scaling procedure is applied from the aggregate level (the projected household population) to disaggregate attributes (household size) in the aggregate population (the household population matrix). This is achieved by applying the observed household matrix (2007-2018) to the aggregate population for future years. This procedure has ensured that the attributes of the household population matrix will be appropriately conveyed without distortion since it will be transferred at the same level (aggregate to aggregate).

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[11] The definition of hard-to-reach population is referred to describe those groups in the community that are difficult to be involved in a public participation, such as homeless people or groups of people who don’t want to be contacted.

Given the data available of observed household population from 2007 to 2018, the average population distribution by the governorates and the household sizes can be attained using the equation below:

$$Scale\ distribution = \frac{The\ total\ household\ population\ in\ a\ certain\ year\ (N)}{The\ population\ in\ each\ household\ size\ (n)} * 100 \tag{6}$$

The scaling equation has been applied to the entire period of the observed population (2007-2018), to derive scale coefficients to apply to the future population projection from which the household size distribution has been derived. The reason for this is that this application lies behind measuring the household size and type changes through time. Based on that, three percentile matrices have been generated to be applied to the projected population; (i) an average percentile matrix *"High"*; (ii) a weighted average matrix *"Medium"*; and (iii) a percentile distribution of the last observed year *"Low"*. The weighted average distribution is derived from the weighted moving average forecasting technique; the principle of this forecasting is that the recent years of a variable have more influence than the earlier years of an observation period (Holt, 2004). These three matrices have been used as parameters to the projected population to test the uncertainty and sensitivity (section 4.4.2). The weights that are given for each point of the observation depends on the forecaster's judgment, which is selected randomly, but in descending order. A value of (1) has been distributed over the observed points, as following;

$$\begin{aligned} Weighted\ Average\ (Medium) \\ = (t_{2018} * 0.4) + (t_{2017} * 0.15) + (t_{2016} * 0.1) + (t_{2015} * 0.08) + (t_{2014} \\ * 0.07) + (t_{2013} * 0.06) + (t_{2012} * 0.05) + (t_{2011} * 0.04) + (t_{2010} \times 0.03) \\ + (t_{2009} * 0.01) + (t_{2008} * 0.005) + (t_{2007} * 0.005) \end{aligned} \tag{7}$$

The difference between *High* (Table 4.3), *Medium* (Table 4.4) and *Low* (Table 4.5) distributions is that *High* gives equal weights for the observed points, while *Medium* gives more weights for the recent observations than the earlier ones and in *Low*, the distribution of the last observed point is only applied as it is the most recent, hence known as a naïve forecasting technique. The *Medium* distribution is selected for the next stage of this research and applied to the projection period of the total household population because; (i) it reflects the recent observations better; and (ii) doesn't ignore any of the observation points. After the application of the *Medium* distribution on the entire projection period, the FMF has been used to add the dwelling type attribute to the sample population.

Table 4.3: The share (%) of total household population geographically and by household size (High distribution)

Kuwaiti population												
Zone_ID[12]	**HZ_1_K[13]**	**HZ_2_K**	**HZ_3_K**	**HZ_4_K**	**HZ_5_K**	**HZ_6_K**	**HZ_7_K**	**HZ_8_K**	**HZ_9_K**	**HZ_10_K**	**HZ_11_K**	**HZ_12_K**
CAP	0.220	0.364	0.585	0.840	1.117	1.401	1.716	1.946	2.017	1.922	1.674	6.274
HAW	0.223	0.369	0.593	0.906	1.274	1.653	1.946	2.070	1.953	1.703	1.367	3.777
AHM	0.230	0.382	0.557	0.796	1.078	1.394	1.679	1.888	1.930	1.917	1.764	6.480
JAH	0.115	0.201	0.292	0.415	0.558	0.728	0.915	1.055	1.143	1.200	1.155	4.623
FAR	0.247	0.392	0.576	0.805	1.063	1.371	1.642	1.813	1.829	1.780	1.607	5.383
MUB	0.098	0.192	0.307	0.478	0.675	0.880	1.059	1.124	1.124	1.056	0.946	3.152

Non-Kuwaiti population												
Zone_ID	**HZ_1_NK**	**HZ_2_NK**	**HZ_3_NK**	**HZ_4_NK**	**HZ_5_NK**	**HZ_6_NK**	**HZ_7_NK**	**HZ_8_NK**	**HZ_9_NK**	**HZ_10_NK**	**HZ_11_NK**	**HZ_12_NK**
CAP	1.772	0.637	0.719	0.877	0.787	0.601	0.432	0.322	0.256	0.193	0.148	0.447
HAW	4.259	3.084	4.290	6.103	5.492	3.808	2.218	1.305	0.784	0.522	0.339	0.728
AHM	2.903	1.383	1.911	2.441	1.819	1.243	0.780	0.561	0.424	0.333	0.258	0.832
JAH	1.343	0.517	0.626	0.796	0.881	0.921	0.947	1.078	1.144	1.172	1.180	5.071
FAR	4.981	2.505	3.377	4.451	3.735	2.573	1.670	1.134	0.838	0.665	0.483	1.599
MUB	0.364	0.079	0.094	0.120	0.127	0.109	0.091	0.074	0.059	0.050	0.038	0.099

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[12] It refers to the Kuwait governorates, where CAP is referred to the Capital governorate; HAW refers to Hawalli governorate; AHM is to Al-Ahmadi; JAH is to Al-Jahra; FAR is to Al-Farwaniya; MUB refers to Mubarak Al-Kabir governorate.

[13] It is an abbreviation of household size of ten, in Kuwaitis' category, etc.

Table 4.4: The share (%) of total household population geographically and by household size (Medium distribution)

Kuwaiti population												
Zone_ID	**HZ_1_K**	**HZ_2_K**	**HZ_3_K**	**HZ_4_K**	**HZ_5_K**	**HZ_6_K**	**HZ_7_K**	**HZ_8_K**	**HZ_9_K**	**HZ_10_K**	**HZ_11_K**	**HZ_12_K**
CAP	0.150	0.322	0.538	0.781	1.037	1.317	1.626	1.872	1.955	1.868	1.656	6.418
HAW	0.151	0.328	0.556	0.847	1.200	1.572	1.891	2.041	1.933	1.740	1.410	4.137
AHM	0.150	0.322	0.502	0.718	0.976	1.296	1.602	1.865	1.970	1.972	1.846	7.026
JAH	0.076	0.178	0.276	0.391	0.525	0.709	0.906	1.085	1.226	1.298	1.272	5.277
FAR	0.150	0.313	0.499	0.723	0.948	1.245	1.551	1.770	1.833	1.801	1.647	5.797
MUB	0.073	0.179	0.301	0.470	0.671	0.871	1.052	1.117	1.080	1.004	0.901	3.194
Non-Kuwaiti population												
Zone_ID	**HZ_1_NK**	**HZ_2_NK**	**HZ_3_NK**	**HZ_4_NK**	**HZ_5_NK**	**HZ_6_NK**	**HZ_7_NK**	**HZ_8_NK**	**HZ_9_NK**	**HZ_10_NK**	**HZ_11_NK**	**HZ_12_NK**
CAP	1.582	0.549	0.646	0.844	0.808	0.626	0.463	0.333	0.260	0.204	0.151	0.526
HAW	3.825	2.844	4.163	6.257	5.638	3.905	2.265	1.365	0.826	0.571	0.362	0.836
AHM	2.934	1.363	2.002	2.651	1.988	1.322	0.855	0.587	0.436	0.363	0.271	0.910
JAH	1.250	0.477	0.613	0.813	0.940	0.959	0.964	1.031	1.066	1.043	1.021	4.728
FAR	4.837	2.265	3.140	4.462	3.888	2.684	1.760	1.222	0.902	0.702	0.506	1.862
MUB	0.331	0.076	0.094	0.127	0.146	0.122	0.100	0.077	0.062	0.052	0.034	0.110

Table 4.5: The share (%) of total household population geographically and by household size (Low distribution)

Kuwaiti population												
Zone_ID	**HZ_1_K**	**HZ_2_K**	**HZ_3_K**	**HZ_4_K**	**HZ_5_K**	**HZ_6_K**	**HZ_7_K**	**HZ_8_K**	**HZ_9_K**	**HZ_10_K**	**HZ_11_K**	**HZ_12_K**
CAP	0.118	0.308	0.522	0.764	1.014	1.304	1.611	1.854	1.942	1.871	1.698	6.494
HAW	0.117	0.313	0.550	0.826	1.168	1.528	1.837	2.012	1.876	1.759	1.413	4.266
AHM	0.112	0.292	0.480	0.686	0.932	1.250	1.539	1.842	2.001	2.019	1.902	7.377
JAH	0.058	0.170	0.285	0.391	0.518	0.708	0.881	1.070	1.250	1.332	1.345	5.623
FAR	0.102	0.270	0.465	0.684	0.890	1.137	1.451	1.691	1.784	1.795	1.669	5.877
MUB	0.061	0.177	0.307	0.484	0.692	0.880	1.053	1.144	1.078	0.999	0.878	3.203
Non-Kuwaiti population												
Zone_ID	**HZ_1_NK**	**HZ_2_NK**	**HZ_3_NK**	**HZ_4_NK**	**HZ_5_NK**	**HZ_6_NK**	**HZ_7_NK**	**HZ_8_NK**	**HZ_9_NK**	**HZ_10_NK**	**HZ_11_NK**	**HZ_12_NK**
CAP	1.447	0.507	0.615	0.844	0.848	0.657	0.501	0.349	0.260	0.210	0.148	0.577
HAW	3.631	2.700	4.064	6.355	5.718	3.915	2.284	1.357	0.806	0.578	0.359	0.877
AHM	2.974	1.350	2.035	2.787	2.080	1.362	0.901	0.604	0.445	0.381	0.280	0.945
JAH	1.167	0.469	0.618	0.860	1.019	1.034	1.037	1.063	1.082	1.008	0.968	4.496
FAR	4.785	2.095	2.936	4.388	3.943	2.715	1.798	1.264	0.938	0.705	0.504	1.985
MUB	0.282	0.077	0.099	0.142	0.167	0.139	0.111	0.081	0.068	0.055	0.034	0.116

4.4 Results

4.4.1 Base population scenario

The enhancement procedures above were applied to match the population estimation period with the baseline projection period and develop a functional distribution (e.g., household size) in the aggregate forecast population consistent with that in the observed data. First, a constant coefficient (52,807) was applied (to uplift/bias correction) in the Kuwaiti population to tackle the population underestimate. A constant coefficient (60.08%) was then applied to extract the domestic workers from the total non-Kuwaiti population, adding them to the Kuwaiti population to represent the total Kuwaiti population. Next, to develop the non-Kuwaiti household population, a constant coefficient (45.84%) was applied, and the resulting population added to the total Kuwaiti population to find the total household population. Scaling was applied to distribute the total household population over household sizes and governorates of the country, using a *Medium* weighted distribution. Finally, static spatial microsimulation using the FMF software was applied to determine the distribution of the dwelling type by total household population. All coefficients were selected from analysis of the historical datasets; and selection criteria were based on quantitative analysis and judgment.

4.4.2 Projection sensitivity and uncertainty tests

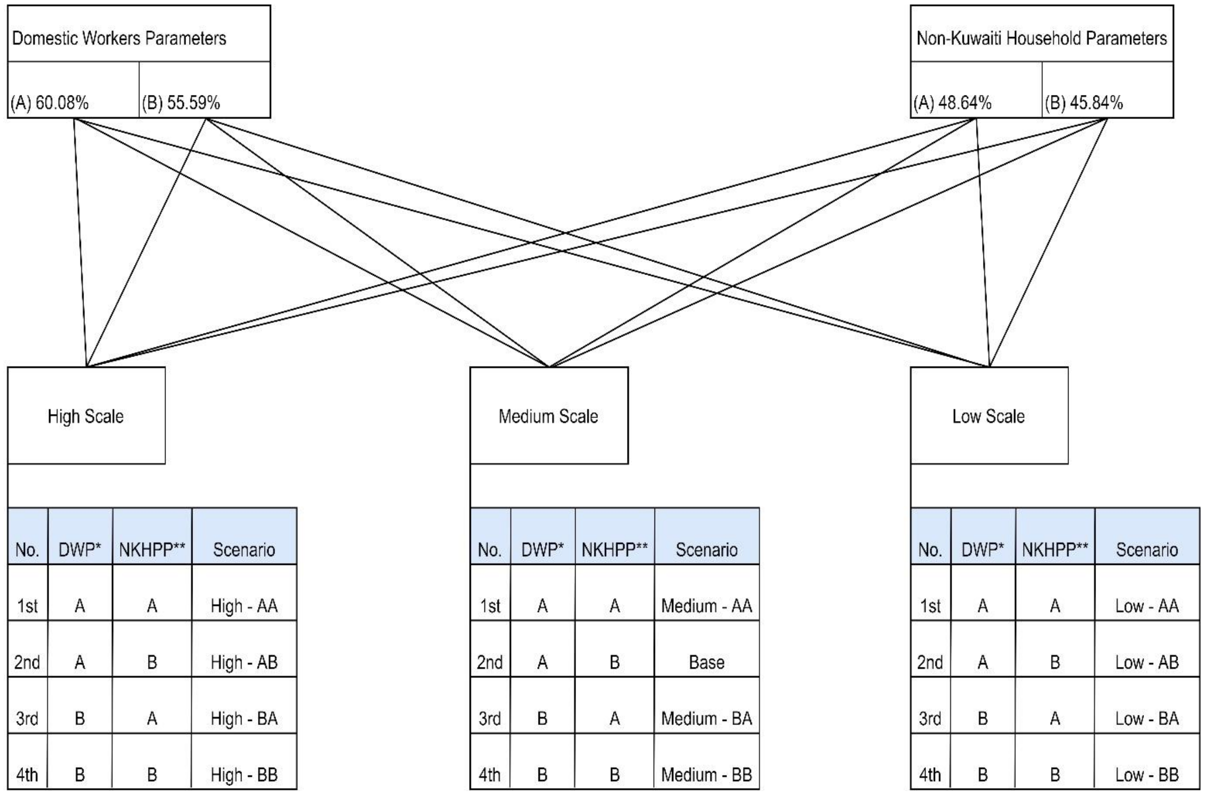
Estimates of future household water demand in Kuwait under a BAU scenario are strongly driven by demographics. However, due to uncertainty in model input data and how datasets have been manipulated to generate the best possible estimate of population to 2050, there is inevitably uncertainty in the projected population. To explore the potential variability in BAU population forecast, sensitivity testing has been applied to determine variant population projections under the modelling assumptions summarised in section 4.4 above. These are illustrated in Figure 4.12.

A sensitivity analysis is a test that defines uncertainty in the model through the variation of the input parameters (independent variables) to measure the effect in the outputs (dependent variables) (Saltelli *et al.*, 2008). Sensitivity analysis can be deterministic or probabilistic (stochastic) and can be applied to a single input (univariate) or several inputs (multivariate) with parameters varied simultaneously (Oakley and O'Hagan, 2004). Deterministic sensitivity analysis can be employed when the forecasting/projection model is based on the point estimation techniques such as averaging forecasting (Cacuci *et al.*, 2005). Probabilistic sensitivity analysis can be used when interval estimation (randomness) techniques are applied, such as the confidence interval (frequentist approach) and credible interval (Bayesian approach) (Oakley and O'Hagan, 2004). There are several ways to test the sensitivity in a model, whether determinist or probabilistic. Monte Carlo simulation is a common test in the probabilistic approach, with the standard Monte Carlo simulation used to test frequentist models and the Markov Monte Carlo simulation used for Bayesian models. Ensemble modelling has also been applied to test the sensitivity and uncertainty in Bayesian models, using BMA, Boostrap Aggregation, Bayesian Model Combination, and Bi-dimensional techniques (Feldkircher, 2012).

In population projection, sensitivity has conventionally been tested by generating population projections as variants of the base projection. Demographers use expert judgment to introduce uncertainty into the projections at all stages of the process, then the most reasonable future projection trend of the demographic components is set to represent the base population scenario. Once a single deterministic variant (projection) is developed, other variants are generated from the base scenario to uncover the uncertainty (Daponte *et al.*, 1997). Here the probability of the uncertainty is implicitly employed. This is known as the variant approach and was used by the population division of the UN from 1951 to 2010, after which ensemble prediction BMA modelling was used to reveal model uncertainty. Before the application of BMA, the UN was developing multi-variant projections, but it is not based on a probabilistic term. Another example of single variant projection is made by the Brazilian Institute of Geography and Statistics, where the most likely scenario has been set to represent the future growth of population where there is no other variant to gauge the uncertainty (Guimarães, 2014). As the population growth is the sole parameter used to predict the future under the current situation of water demand in the household sector, different population scenarios have been developed in parallel with the base scenario. The variation of the parameters that produced the modified TED/KISR projection (domestic worker and non-Kuwaiti household population, and the distribution of the household size and of the country’s governorates), will be used to test sensitivity and uncertainty.

The sensitivity in the water demand forecasting of the household sector can be represented in the change of an input parameter in the range of 15 per cent (Billings and Jones, 2011). The variation of input within this range would allow us to study and test the impact on the output variable in the analysis. This approach would uncover the most significant impacts on the output; which variable has more influence and thus would have a relatively large impact on the output variable. Consequently, the three parameters (domestic worker, non-Kuwaiti population, and scale levels) have been manipulated and put together interchangeably to produce twelve potential population variants (Figure 4.12). The scaling technique has not influenced population growth, but its effect has been seen in the demand forecasting. The scaling technique affects the household size distribution; hence, the household size tends to be high or low compared to each other. Therefore, the higher the household size distribution gets, the higher the demand and vice versa.

For domestic workers, two parameters have been assigned, (A) represents 60.08% and (B) 55.59% (section 4.3.2). As well, the non-Kuwaiti household population has been set with two parameters, (A) is 48.64%, and (B) 45.48% (section 4.3.3). These parameters have interchangeably been applied with the scaling levels, *High*, *Medium*, and *Low*. The interactions amongst those parameters, the twelve variants are developed, including the base scenario. The identification of a variant is denoted by, for example, (*AB-High*), where A refers to the domestic workers parameter (60.08%), B refers to non-Kuwaiti household population parameter (45.48%), and *High* is the level of the scaling. Each of the three scales has four parameters hence twelve variants are explored. Figure 4.13 shows the population variants after the application of the domestic workers and non-Kuwaiti household parameters. The effect of the scaling levels has occurred after the application of the spatial microsimulation where the dwelling types have been simulated, and the household demand has been assigned.



No.	DWP*	NKHPP**	Scenario
1st	A	A	High - AA
2nd	A	B	High - AB
3rd	B	A	High - BA
4th	B	B	High - BB

No.	DWP*	NKHPP**	Scenario
1st	A	A	Medium - AA
2nd	A	B	Base
3rd	B	A	Medium - BA
4th	B	B	Medium - BB

No.	DWP*	NKHPP**	Scenario
1st	A	A	Low - AA
2nd	A	B	Low - AB
3rd	B	A	Low - BA
4th	B	B	Low - BB

Figure 4.12: Total household population scenarios under different parametres

*Domestic Worker Parameters; **Non-Kuwaiti Household Population Parameters.

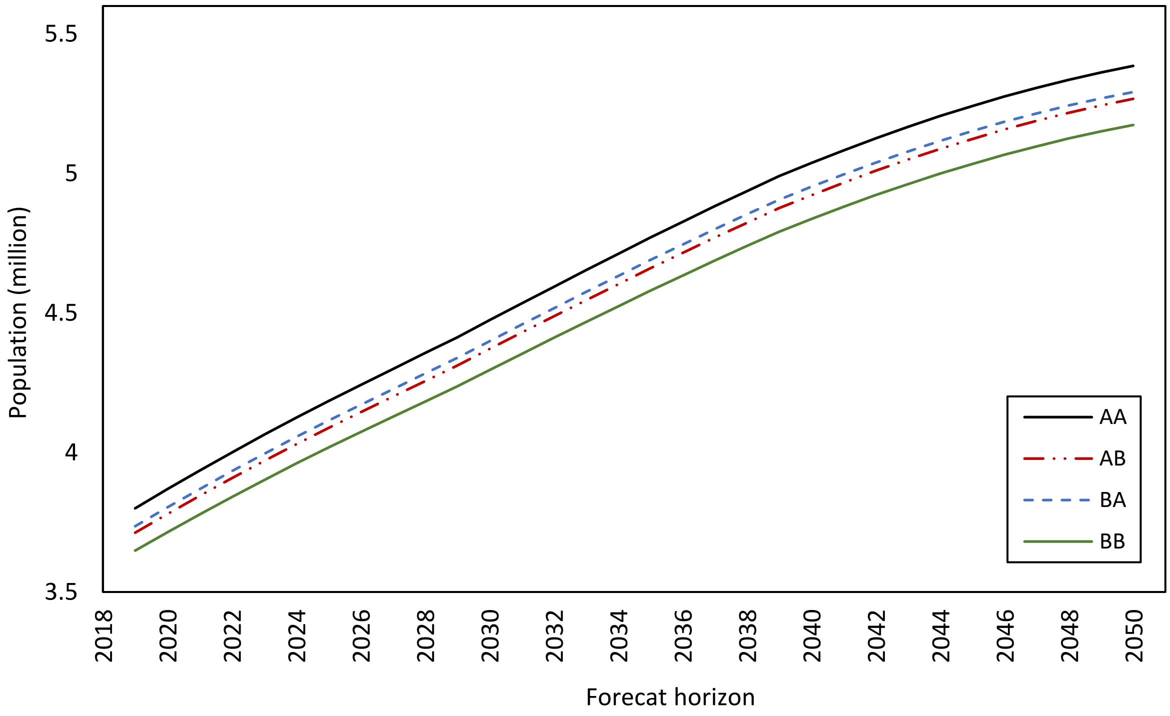


Figure 4.13: Population variants of different parameter applications

4.4.3 Household water demand under base population scenario

Twelve population scenarios have been produced through parameters' variations, including the base scenario. Then, dwelling types have been added to those scenarios by applying microsimulation using the FMF software. After which, aggregate water demand has been developed for each scenario throughout the forecasting period, reaching the 2050 target year. In the base population scenario, the high domestic workers and the low non-Kuwaiti household population parameters have been selected, plus the *Medium* level of scaling (*AB – Medium*). The selection of these criteria for the base scenario was justified in sections (4.3.2, 4.3.3, and 4.3.4).

Water demand in the base scenario represents a *"*central demand projection*"*, with demand forecast for the other population variants discussed in the next section. Figure 4.14 shows forecast water demand to 2050. Demand increases from 463.5 MCM in 2019 to 664.1 MCM in 2050, an overall increase of 30.21%, the highest increase rate is 1.8% in 2020, and the lowest is 0.6% in 2050, with an average annual increase 1.15% yr^{-1}. For Kuwaiti households, demand increases from 345 MCM in 2019 to 503.1 MCM in 2050, an increase of 31.5% (average 1.2% per annum), with an annual increase peaking at 1.75% in 2020, with a trough of 0.75% in 2050. For non-Kuwaiti households, demand increases from 118.4 MCM in 2019 to peak at 160.4 MCM in 2048 followed by a decline to 160.1 MCM in 2050. Non-Kuwaiti demand increases 26% overall (average 0.97% per annum), with the annual increase rate peaking at 1.88% in 2020, with a trough of -0.12% in 2050. Figure 4.15 shows demand has a steady distribution, with Kuwaiti water demand representing just over 74% of total demand, and non-Kuwaiti demand slightly over 25%. The annual proportion demand rate of Kuwaiti households decreases a little in the future (2020 = 74.42% of total demand, and 2034 = 74.26%) but increases to peak in 2050 at 75.89%, whilst the annual share of non-Kuwaiti households rises from 25.57% in 2020 to reach peak at 25.73% in 2034, before dropping to 24.1% in 2050.

Figure 4.16 illustrates population growth (demand's key driver) patterns of the aggregate and disaggregate (Kuwaiti and non-Kuwaiti) populations. By way of comparison, from Figure 4.14, it can be noticed that the patterns of water demand (aggregate and disaggregate) parallels population growth levels. At the aggregate level, total population increases from 3.712 million in 2019 to 5.267 million in 2050, an increase of 29.52%; the annual increase rate peaks at 1.77% in 2020, with a trough of 0.45% in 2050 (average annual increase of 1.12%). On the disaggregate level, the Kuwaiti population increases from 2.287 million in 2019 to 3.339 million in 2050; the overall increase is 31.51%, a peak of 1.72% in 2020, a trough of 0.78% in 2050, and annual average increase of 1.21%. The non-Kuwaiti population increases from 1.425 million in 2019 to peak at 1.930 million in 2048, then declines by 2050 to 1.928 million. The overall increase is 26%, a peak increase of 1.84% in 2020, a trough decline of -0.11% in 2050, and an average of 0.975% annually. These rates of population growth on aggregate and disaggregate levels show how water demand is highly dependent on population growth.

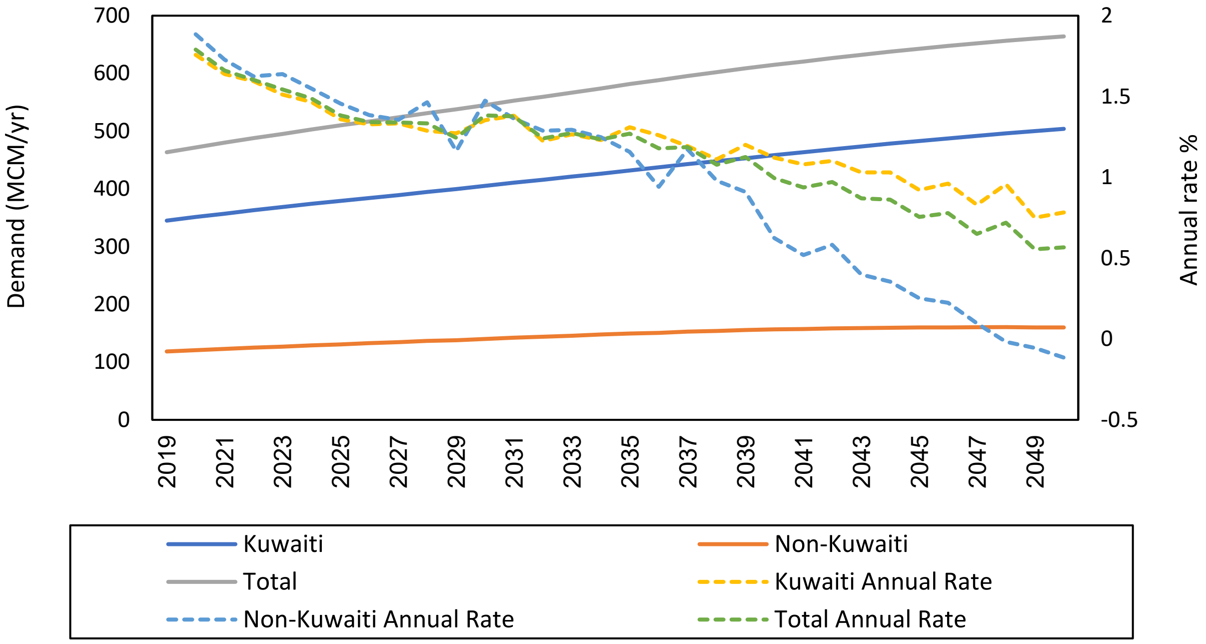


Figure 4.14: Base water demand forecast to 2050

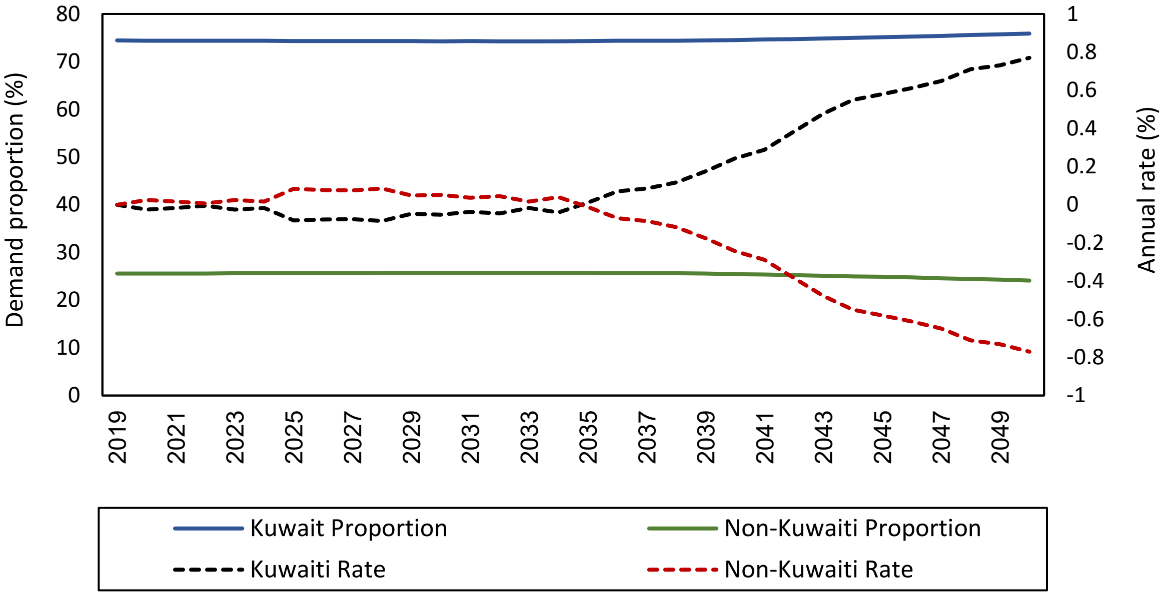


Figure 4.15: Demand distribuation between Kuwaiti and non-Kuwaiti populations

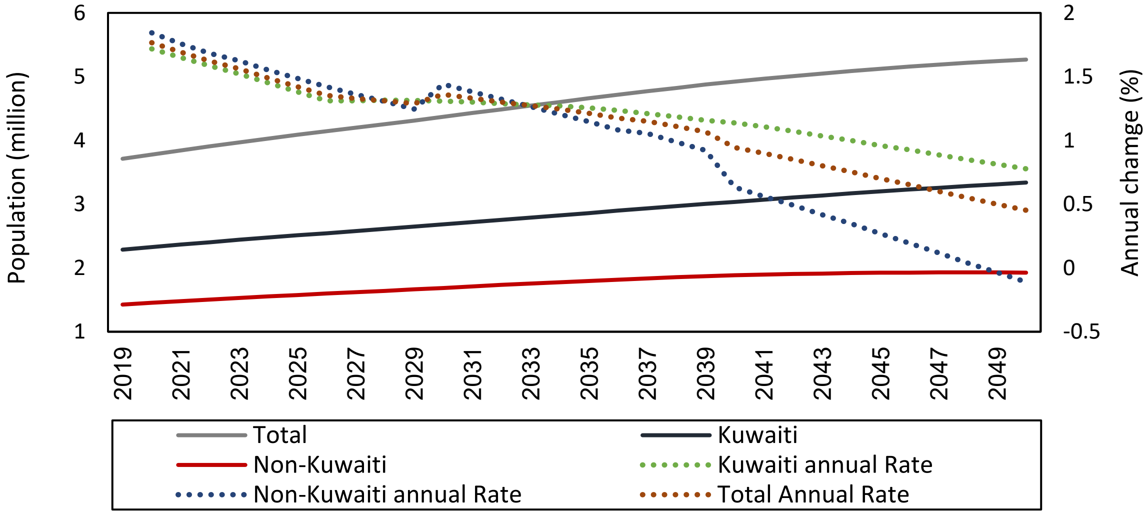


Figure 4.16: Population growth: Total, Kuwaiti, and non-Kuwaiti

Figure 4.17 shows the geographical distribution of demand in Kuwait's governorates. Hawalli, the smallest by area, has highest demand (103.4 MCM in 2020 and 144.2 MCM by 2050) reflecting its high population (ranked 1st for non-Kuwaitis, and 3rd for Kuwaitis) (Figure 4.18). Mubarak Al-Kabeer has lowest demand (40.5 MCM in 2020, 58 MCM in 2050) due to low Kuwaiti and non-Kuwaiti populations. For Kuwaiti demand only, Al-Ahmadi governorate is highest (70.1 MCM in 2020; 100.6 MCM in 2050), and Mubarak Al-Kabeer lowest (38.8 MCM in 2020; 55.7 MCM in 2050). Non-Kuwaiti demand is greatest in Hawalli least in Mubarak Al-Kabeer, reflecting the prevalence of non-Kuwaiti households.

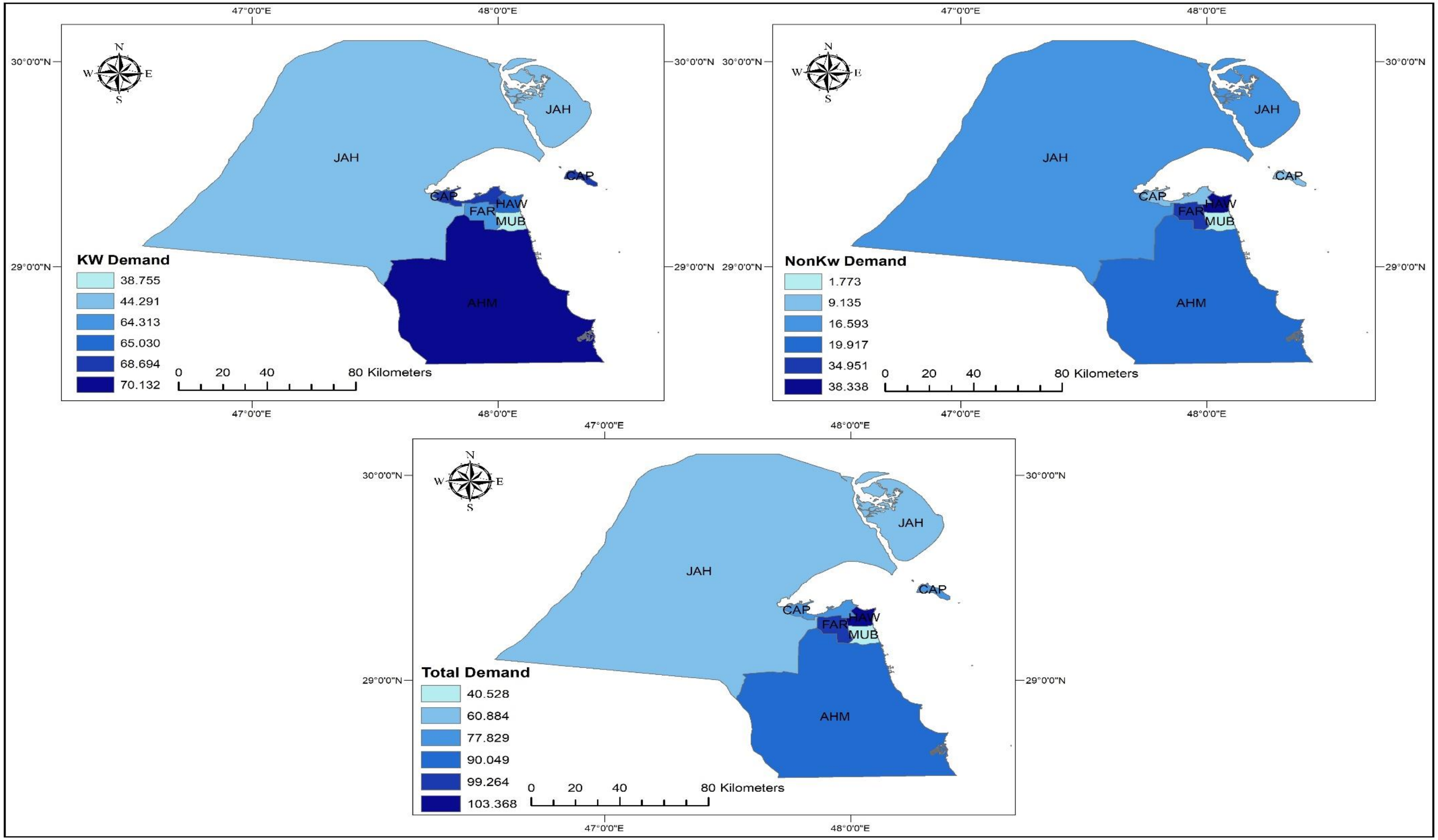


Figure 4.17: Household water demand (MCM/yr) by governorate in 2020

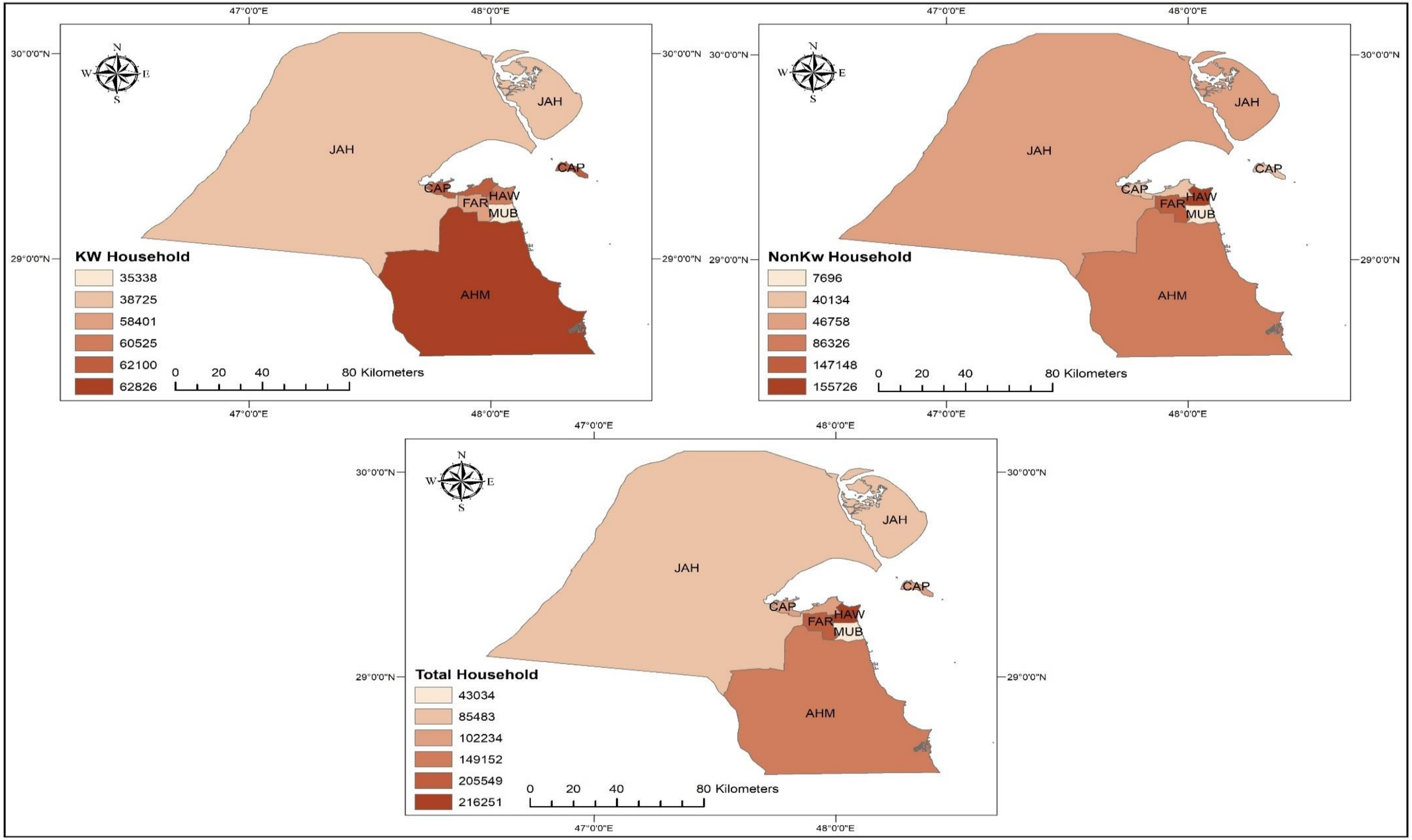


Figure 4.18: Household frequency distribution by governorate in 2020

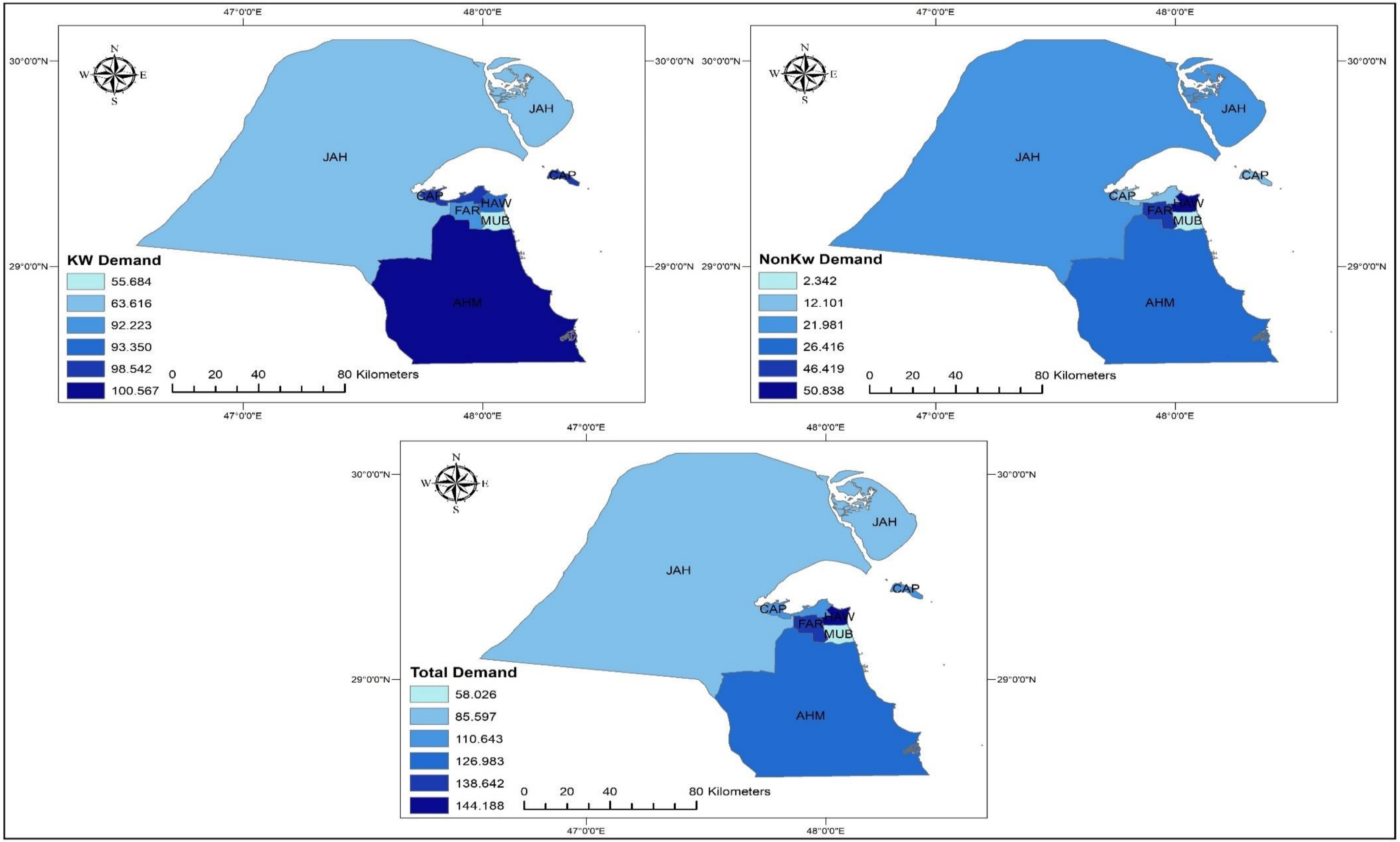


Figure 4.19: Household water demand (MCM/yr) by governorate in 2050

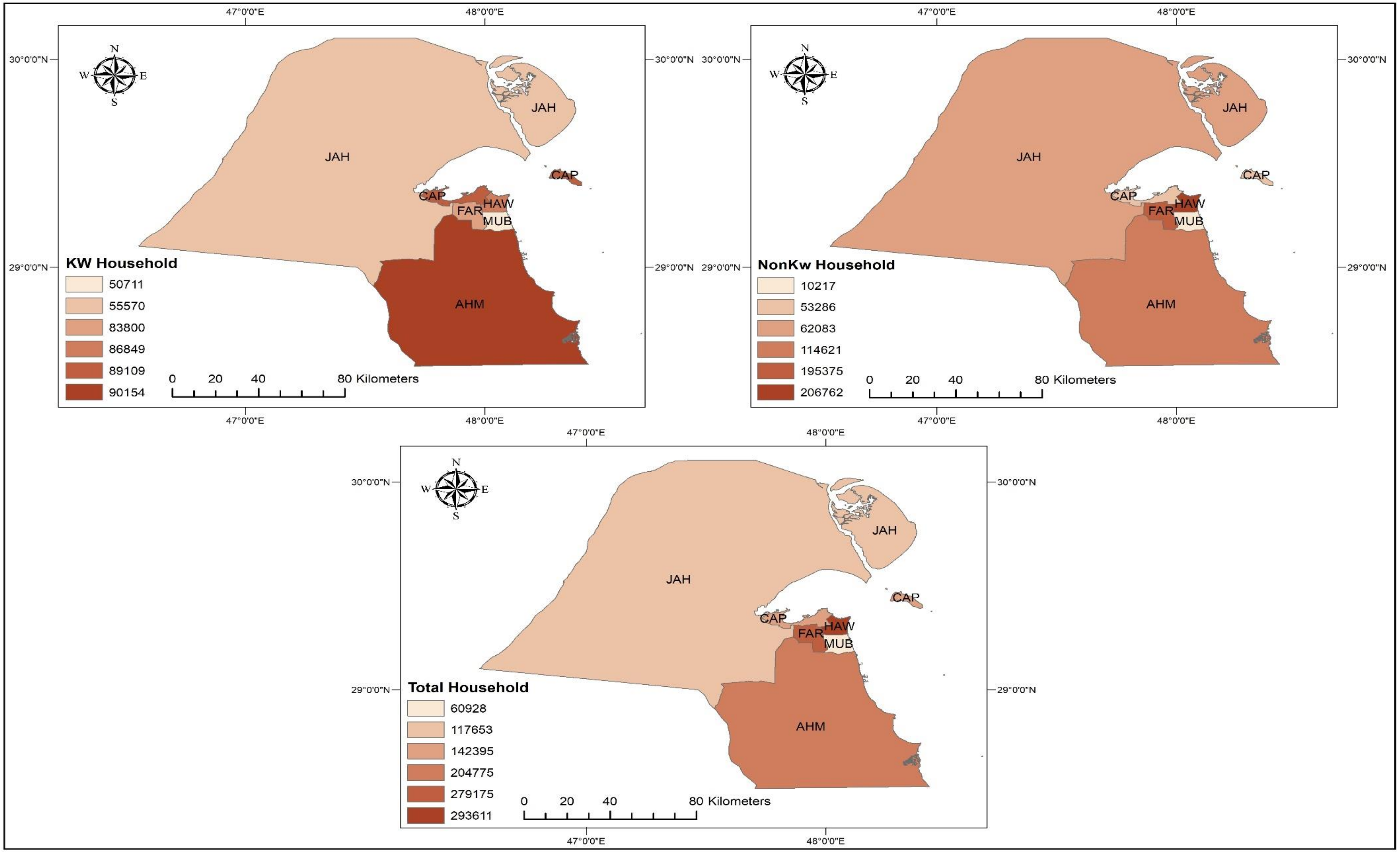


Figure 4.20: Household frequency distribution by governorate in 2050

4.4.4 Household demand of variant population scenarios

Twelve demand scenarios have been developed, including a base scenario, in which each scaling level has four different population scenarios. Unsurprisingly, higher population projections show higher demand (and vice versa), but importantly, we have been able to quantify these effects. The *High-AA* scenario is the highest demand scenario whilst the *Low-BB* scenario has the lowest water demand. Aggregate demand reached 482.9 MCM in the *High-AA* scenario in 2020, compared to 457 MCM in the *BB-Low* scenario. All the *AB* scenarios show higher demand than the *BA* scenarios despite the *BA* population scenario growth being above the *AB* population scenario. This indicates that the domestic worker parameter has more influence on demand than the non-Kuwaiti parameter.

The difference between the highest and lowest demand scenarios increases as we approach the target year. For instance, it is 33 MCM in 2019, and 46.7 MCM in 2050. The base scenario comprises a more moderate scenario where base high-low differences are less extreme. For example, the difference between *Low-BB* and the base scenario is 14.5 MCM in 2019, whilst the difference between *High-AA* and the base scenarios is 29.4 MCM for the same year. Scaling Parameters (*High, Medium, Low*) exert a major influence in forecasting the total demand but a minor influence in terms of the demand share by Kuwaiti and non-Kuwaiti. When applying *High*, *Medium*, and *Low* scales, considerable variations in total demand (Kuwaiti and non-Kuwaiti) are evident, but little variation is noticed regarding demand proportions between Kuwaiti and non-Kuwaiti. Figure 4.21 shows the demand scenarios of all the scaling levels in comparison with the base scenario.

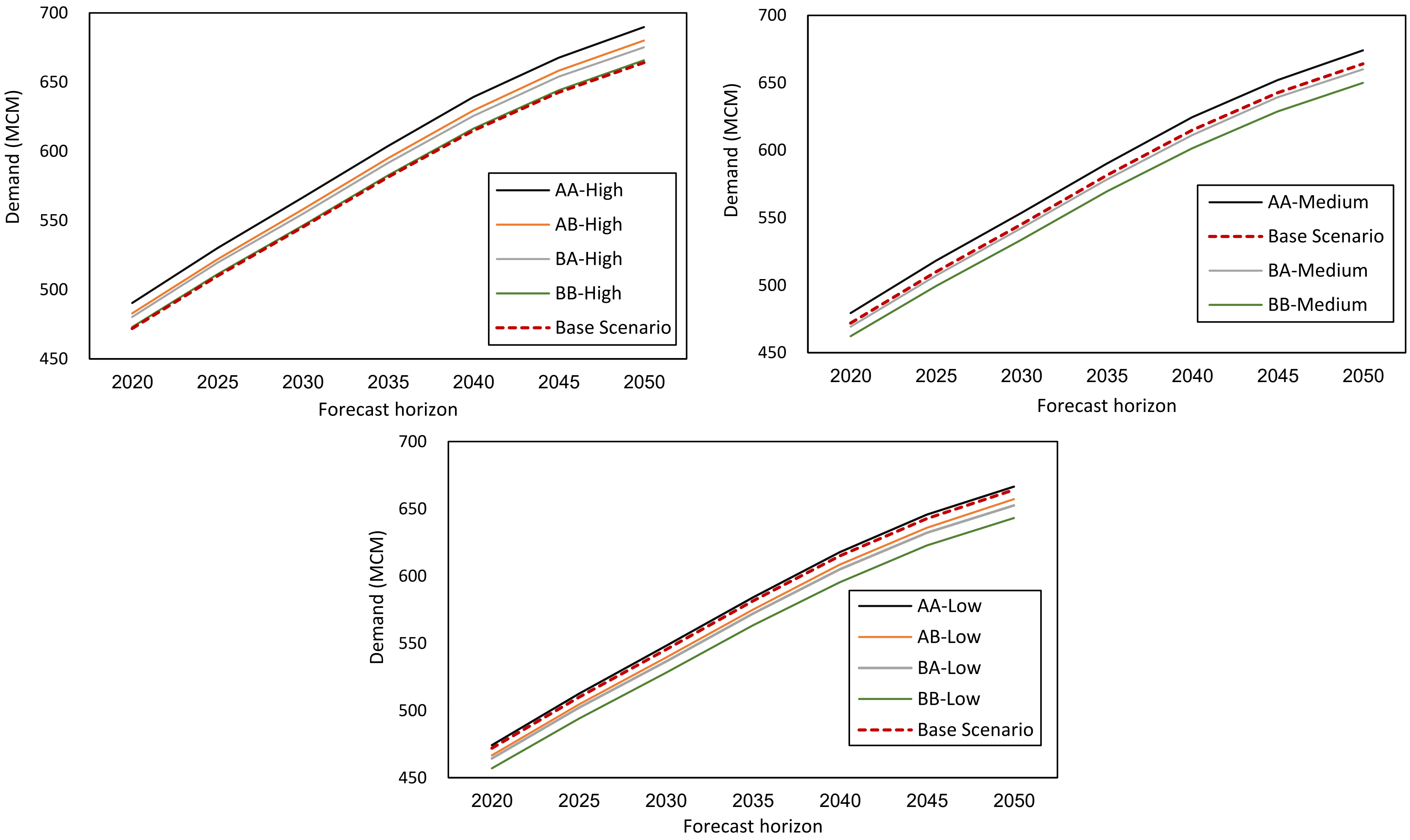


Figure 4.21: High, Medium, and Low levels scenarios in comparison with the base water demand scenario

4.5 Conclusion

The forecasting of household water demand in Kuwait under a BAU scenario, is strongly dependant on population growth, hence effort has been made to develop the best possible population projections whilst retaining some functional heterogeneity in the population model (dwelling type, household size, citizenship) so as to provide greater scope for application of a micro-component model in chapter five. The TED/KISR projection has been used in this research and developed to meet the specific research needs. The forecasting has proved challenging given the relative lack of demographic data available for Kuwait, although sufficient data was available from TED/KISR and elsewhere to develop credible projections, following suitable modifications. These modifications include, the uplifting of the Kuwaiti population, defining the domestic worker population, defining the non-Kuwaiti household population, and the application of a scaling technique to find the household sizes distribution, and its distribution over the country's governorates.

A base scenario has been developed for BAU demand forecast to 2050, and a series of population and demand forecast variants developed by manipulating demographic parameters to reflect input uncertainty. These variants were generated to test the uncertainty in the model via a deterministic sensitivity test. This has shown high sensitivity to the share of domestic workers and a high sensitivity in terms of the scaling levels.

At this point, it is useful to compare our base demand forecasts for Kuwait with others reported in literature (Figure 4.22), of which only four are known (Al-Humoud and Jasem, 2008; AL-Zubari, 2010; EPA, 2012; Odhiambo, 2016). These literature are not directly comparable as they do not treat household demand explicitly but lump it with other sectors (e.g., models municipal demand which includes household, governmental and commercial demand, or just models total country demand).

Al-Humoud and Jasem (2008) applied time series forecasting to predict total demand to 2025. This study used the past observations of total demand as a univariate predictor variable. As 60% of water demand goes to the household sector, we show 60% of Al-Humoud and Jasem total forecast in Figure 4.22. Al-Zubari (2010) predicted municipal demand (household plus governmental demands) to 2025 using a System Dynamic Model exploiting correlation between population (Kuwaiti and non-Kuwaiti), per capita consumption, and aggregate demand. This study stated that the household demand represents 90% of municipal demand; thus, 90% of the municipal demand forecast is shown in Figure 4.22. EPA (2012), Kuwait's Environmental Public Authority (EPA) produced a forecast for municipal demand to 2030 using the WEAP model (Sieber, 2006), with aggregate population and per capita consumption acting as independent variables. A fixed per capita consumption (440 l/d), and an annual population increase of 3.5% was assumed. Odhiambo (2016) stated that domestic water demand would increase to 670 MCM in 2025 as a result of the annual population growth of 3.5%, but the study gives no information on methodology.

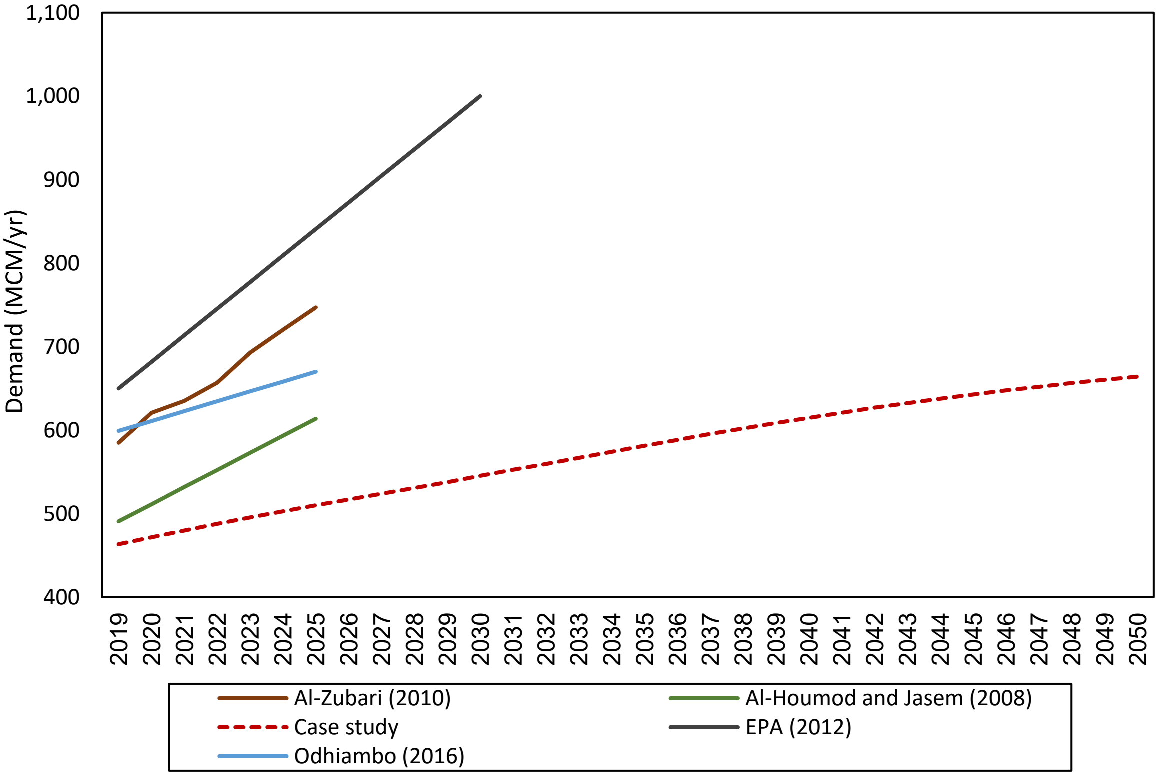


Figure 4.22: Base scenario forecast (this study) compared to Kuwait forecasts from literature

The case study forecast appears superior to those others available, which apear to overestimate demand, and its growth rate. A recent evaluation of global water withdrawal forecasts is notable in this respect, as it shows that older forecasts (1980s, 1990s) tend to over-estimate demand whilst more recent forecasts tend to show a levelling of off demand

and even a reduction to 2100 (Gleick and Cooley, 2021). This is attributed to the decoupling of water demand from economic and population growth, plus that more recent models have more sophistciated assessments with better representation of population dynamics (and interventions such as water efficiency programmes). We can speculate that this is also the case for this national demand forecast, which developed household demand separately whereas others lump it with other sectors, and where our forecast explicitly addresses known key drivers of household size, household status, and dwelling type. Furthermore, the forecast is based on a more sophisticated population projection (cohort component methodology) enhanced to develop the household population.

Having developed a credible BAU household water demand forecast to 2050, we can then move on to the next phase of the research, the backcasting of water demand scenarios, so as to identify water conservation interventions needed to reduce demand to a target level. This work begins with the development of a micro-component forecast model in the next chapter.

Chapter 5 Micro-component model development

5.1 Introduction

A base demand forecast scenario has been developed after a series of enhancement procedures on the TED/KISR population projection. These procedures were used to define the household population projection and to adjust it to fit the observed population in the model's baseline demand. Afterwards, twelve demand scenarios have been produced based on twelve different household population projections to test sensitivity and uncertainty in the household demand forecast model. These household population projections have been generated depending on three variables; domestic workers, non-Kuwaiti household population, and household size, in which the input coefficients have been selected from the historical demographic trends using different statistical methods (section 4.3). The base demand scenario has been compared against other demand forecasts, where the sensitivity and uncertainty have been tested (section 4.4.4).

This chapter describes the development and projection of the micro-component model for the base demand scenario. The model's development has been informed by literature available on MC use in Kuwait's households and through personal knowledge of Kuwait water use practices. Two modifications of the base MC model (here after ‘derivatives’) have been used in parallel with the base MC model to address some specific differences amongst households (e.g., that one household has a garden/lawn irrigation component, whilst another has not). Once the MC base model and its derivatives have been developed, a calibration of these model designs onto the household PHC demand matrix to breakdown PHC consumption into end-use components was applied. This projection procedure was dependent on three elements; appliance ownership (e.g., ownership of a dishwasher), the volume of consumption for each component, and the frequency of use of each appliance in the household. This is the Ownership-Volume-Frequency (OVF) approach that is a characteristic feature of MC forecasting.

5.2 Micro-component model of Kuwait households

A micro-component model is adopted due to its key ability to breakdown household water consumption into specific components (e.g., bathing, washing, toilet flushing) which allows more specific investigation into the consumption of each component. Herrington and Britain (1996) have stated that the micro-component approach is a key element in controlling water demand in household uses. It is also known as the OVF approach, referring to the ownership, volume of use, and frequency of use of water using components (McDonald and Mitchell, 2013; Browne, 2015). The micro-component approach is designed to better investigate and monitor a consumer's behaviour, which in turn enables direction of their behaviour towards wiser water consumption. This can be done through gauging the frequency of water use (use factor), and use duration, e.g., time spent having a shower or a bath. The micro-component approach offers scope for reduction in consumer demand without change in consumption behaviour and habit, via installation of more efficient water using appliances and the adoption of water saving devices (WSDs) (Parker and Wilby, 2013). Furthermore, it allows investigation of consumer water use behaviour with respect to implementation of educational, economic, and technical measures. These include awareness campaigns; shifting to an effective and feasible tariff structure; and shifting to adoption of efficient water appliances (e.g., a low flowrate showerhead).

This research attempts to identify water conservation backcast interventions (a mix of measures and their degree of uptake) that if implemented, could lead Kuwait along a transition pathway from the current high demand to the 2050 target(s). The starting point to produce backcast scenarios is the development of the micro-component model in which Kuwait's household PHC is divided into end-use components. These components can then be analysed and modelled to reduce the PHC demands to the desired target(s) by the application of OVF elements, which can be presented through the adoption of the efficient water use devices, and rising consumer awareness (education).

Before discussing the development of the MC model, it is necessary to first explain Kuwait's property context briefly, as there a clear distinction between Kuwaiti and non-Kuwaiti in term of property ownership that in turn influences household water use behaviour.

5.2.1 Property ownership

The real estate registration law in Kuwait differs in terms of ownership eligibility from other countries in the GCC region. The real estate registration law, presented in decree no. 5 for 1959, has only given the right of perpetual ownership of property to Kuwaitis. This law was amended via decree no. 1 in 2004 to allow citizens of the GCC to own real-estate property (Al-Mohami, 2017), but with restrictions, e.g., a GCC citizen should have a family settled in Kuwait and should prove they are permanently resident. The implementation of this law has led to; (i) non-Kuwaitis (excluding GCC citizens) being ineligible to own property, even for those who have lived in the country for decades; and (ii) all the non-Kuwaitis being settled in rented dwellings owned by Kuwaitis or GCC citizens.

The consequences of this law associated with the housing law (section 4.3.3) have spatially separated Kuwaitis and non-Kuwaitis. Accordingly, most Kuwaitis settle in villas in residential areas that the government has assigned to them. A minority of Kuwaitis settle in flats in high-rise buildings, which are out of Kuwaiti’s resident areas. Whilst many non-Kuwaitis settle in high-rise buildings or labour housing, a small proportion do settle in Kuwaiti resident areas, most of whom live in annexes to the villas. Such a situation has directly and indirectly affected household members' consumption; first, the granted villas that the government provide for Kuwaitis acts to encourage higher water use. These villas have more land which may include gardens/lawns, and they also have more bathrooms per head (allowing occupants to spend more time showering and bathing). Second, an indirect affect, is that their ineligibility to own property results in most non-Kuwaitis renting flats as these are cheaper to rent than villas. They therefore consume less water than is typical of Kuwaiti consumption to reduce water bills, saving money for rent. Thus, the explanation of this situation would help in the MC model development.

Property units are registered with the MEW by a property owner (Kuwaitis or GCC citizens). The MEW installs a water meter for each dwelling, against which a uniform tariff (a flat tariff in some Kuwaiti literature) is applied. Non-Kuwaitis can pay their water bills in two ways. The first is to pay the exact volumetric cost of the water used by getting the meter reading for the dwelling; this fee is separate from the tenancy. The second is to include the cost of water in the tenancy; in both cases, the customer/landlord (who owns the dwelling unit and is registered with the MEW) should pay the water bill to the provider.

5.3 Micro-component development

Even though the household sector accounts for most water use in the country, studies on micro-component use are uncommon, with no comprehensive analysis. Five studies cover micro-component use in Kuwait (Mukhopadhy *et al.*, 2001; Al-Humoud and Al-Ghusain, 2003; Al-Humoud and Jasem, 2008; Burney *et al.*, 2017; Aliewi and Alayyadhi, 2018). Of these, most ignore non-Kuwaiti households, despite the fact that they represent around 70% of the total country population. They also have insufficient presentation of indoor and outdoor components, or the use of OVF elements. Furthermore, none of these studies have used the micro-component methodology to explore potential PHC/PCC demand reduction. The limited data on the MC use in Kuwait's households has brought challenges in designing a suitable MC model. Nevertheless, it has been possible to develop an adequate MC model and MC Water Efficiency Calculator (WEC) for our purpose, as described below.

Designing a micro-component model depends here on three elements: (i) “Ownership” of devices such as washing machines, taps, and dishwashers; (ii) “Volume” which refers to water flowrate (litres per minute) or load capacity volume of those devices, e.g., load capacity of a washing machine, and duration of use; and (iii) “Frequency” of use of those devices per day. These three elements of the MC design were used to obtain the proportional consumption for each component of the PHC demand in every category of the PHC demand matrix. The obtained MC water use of the households was applied throughout the forecasting period; i.e., it is a static MC model OVF values are fixed along the forecasting horizon. After which, the WEC was developed where the effect of WSDs (technology intervention) was measured through the implementation of the market penetration rates, using a diffusion of innovation (DOI) market strategy approach (section 6.4.1). Economic and education conservation measure interventions (sections 6.4.2 and 6.4.3) were also applied in this way through model manipulation to reach the backcast targets via transition pathways. The application of these interventions means the MC model is converted from a static to a dynamic model. Table 5.1 shows the steps that have been followed to develop the MC model in this chapter.

Table 5.1: Micro-component (MC) model development

Purpose/Reason	Data/Method	Output
Task 1: Collect, organise, and classify data on household MC demand		
To explore data available to develop Kuwait's household MC model.	Data were obtained from literature (section 5.3.1) and regulatory documents regarding OVF elements.	(i) Very poor data on Ownership, and Volume elements, but sufficient data on Frequency element; (ii) OVF data for non-Kuwaiti households is largely absent (section 5.3.2).
Task 2: Define and apply methods and procedures to fulfil the data shortage		
To overcome data limitations in building Kuwait's household MC model.	(i) Qualitative method (intuitive judgment) for missed data (e.g., appliance Ownership); (ii) Quantitative methods (proportional redistribution and normality test to determine use parametric or non-parametric statistics (section 5.4.2); (iii) Collect primary data on Volume (flowrate/load capacity) from appliance manufacturers.	(i) Adoption of WRC/KISR's MC model; (ii) A MC base model and alternatives (derivatives) to fit differences amongst Kuwait's households (Table 5.2); (iii) Determine non-parametric median values (for Frequency element) to be used in the MC model; (iv) Obtained Volume (appliances flowrate/load capacity) and Ownership element data.
Task 3: Build up the Kuwait's MC model		
To apply the MC model in backcast water conservation intervention packages.	(i) Implementation of linear combination equations to calibrate the MC model and derive missed Volume and Frequency elements; (ii) Accuracy and validity tests to gauge uncertainty in the model.	(i) A calibrated MC model (base, first, and second derivative models); (ii) Good accuracy of output judged using Nash-Sutcliffe Efficiency (NSE), MAPE, and MED accuracy tests; (iii) A complete MC model ready for backcast modelling.

5.3.1 Datasets on micro-component use

Data from the five MC studies cited above were abstracted and used to develop the MC model for this study, as no single study adequately covers the OVF elements needed for our MC model development. Examples are the absence of reporting of the distribution of the proportional PHC based on the household size, and the exclusion of non-Kuwaiti households in prior studies (excepting the TED/KISR study; Burney *et al.* (2017)). However, the data from this literature has been collated (Appendix A), analysed, and categorised into indoor and outdoor MC activities based on the OVF elements to produce an MC model.

Mukhopadhy *et al.* (2001) conducted a study of 48 Kuwaiti households who settled in villas for a yearlong survey of indoor and outdoor MC activities. Monitoring was on a weekly basis, using indoor and outdoor meters. The objective was to understand the drivers of demand in the household sector, so as to support better forecasting and demand control. This study provides relatively little MC data but does provide valuable data on garden/lawn water use. The study describes the proportion of gardens/lawns present out of the total surveyed villas, which is 45.8%, and the size of gardens/lawns irrigated, which ranges between 10 m^2 and 600 m^2. The shortcomings of the study are: (i) the absence of OVF elements; (ii) low participant numbers in the survey; and (iii) it usefully splits total consumption into outdoor and indoor consumption but allows for no further MC breakdown.

Al-Humoud and Al-Ghusain (2003) used a questionnaire with Kuwaiti households in all the country's governorates, with the aim of understanding water supply and consumption. With a 95% of confidence interval, the study identified that 385 households were the minimum representative sample size, but the study was able to address 3,000 households which allowed good representation of various socioeconomic groups (see section 2.3.1.6 for the groups addressed). Concerning the use of OVF elements, the study only surveyed ownership and frequency of use for some components, e.g., car ownership and the frequency of garden/lawn irrigation. It excluded several indoor activities such as showering, bathing, washing dishes, and toilet use. Later, Al-Humoud and Jasem (2008) used this same sample size but with the addition of consumption volume estimates of the car washing component (Appendix A), so as to develop an enhanced forecasting of total water demand.

Burney *et al.* (2017), referred to as the “TED/KISR” study, conducted a survey of 1,500 households, of which 552 are Kuwaiti households (37%), and 948 are non-Kuwaiti households (63%). Survey participants were selected using the snowball sampling approach, taking into account the household status, the regional distribution of the sample, and the dwelling type (villa, floor or flat in a villa, flat, and annex) to ensure national representativeness. The advantage of the TED/KISR study is the disaggregation of households by Kuwaiti and non-Kuwaiti, and by dwelling type. Furthermore, it delivered a relatively good presentation of OVF elements, for instance, volume use (as duration of consumption), and devices ownership for some components. A shortcoming is that the study has not mentioned household water consumption in l/d or by household size, but it has provided a good idea of device ownership, and average consumption by duration (e.g., having a shower for 20 minutes, etc.).

Aliewi and Alayyadhi (2018), which is referred to as the “WRC/KISR” study, surveyed 153 Kuwaiti households who live in villas. The targeted number of households is based on the sample size equation (differs from Al-Humoud and Al-Ghusain sample size) with a 95% of confidence interval. The objective of this study was to disaggregate per capita consumption into micro-components to assess household demand, and then find trajectories for household demand conservation. MCs were resolved using ultrasound recording of the supply pipe, where different uses (flush, shower etc.) generate different sonic profiles, allowing MCs to be resolved. The study developed an explicit MC model, which is defined by proportional MC consumption “volume element” presented in seven components distributed to indoor and outdoor end-use (Figure 5.1). Despite the clear MC model design, the study has some shortcomings, which are: (i) it only accounts for Kuwaiti households in villas; (ii) it doesn't present the frequency and ownership comprehensively; and (iii) it does not recognise MC consumption by household size.

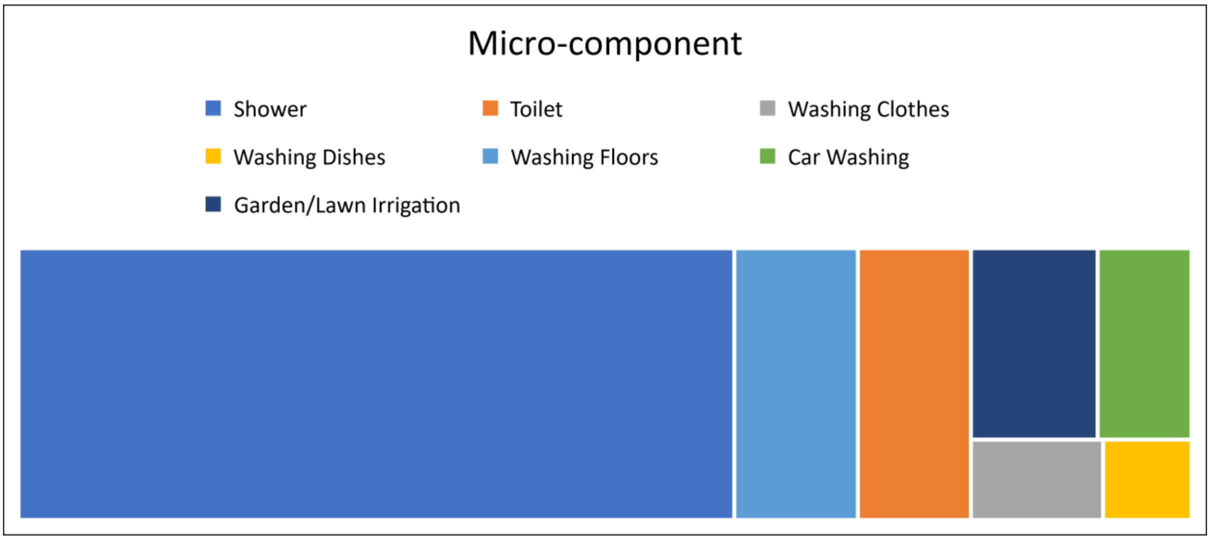


Figure 5.1: The relative distribution of consumption in WRC/KISR's micro-component model

5.3.2 Ownership, Volume, and Frequency elements

The obtained data from the literature has been classified under indoor and outdoor micro-component uses (Appendix A). Further discussion and review, however, is necessary to: (i) consider how Kuwait's household living patterns affects consumption behaviour (e.g., having cars to wash); (ii) define and fill the gaps of missing components and/or a partly missed component in terms of OVF elements (e.g., having the volume and ownership elements of showering but missing the frequency of use element); and (iii) select the best OVF elements to take forward into this study’s MC model.

5.3.2.1 Indoor micro-component use

Showering and Bathing

Although baths are considered a common component in Kuwait's household, household members have showers much more frequently baths. Therefore, bathing has been treated as showering. Showering is the largest water component use of Kuwait's households in terms of a daily PHC, and accounts for 61.03% of consumption (Figure 5.1). The frequency of showering amongst the households' members is once a day, which is stated in most of the cited literature. According to the WRC/KISR study, 73% of households' members having one shower a day, while 23% reported as having two to three showers a day. Based on the TED/KISR's study, the average duration for having a shower is 30 minutes for Kuwaitis, and 25 minutes for non-Kuwaitis. The maximum duration of showering lasts for more than 60 minutes, for Kuwaitis and non-Kuwaitis. Kuwaitis who shower for less than 30 minutes constitute 50.7% of total Kuwaiti PCCs, while 47.4% of them are between 30 to 60 minutes, and only 2% above 60 minutes. Non-Kuwaiti PCCs who have a shower for less than 30 minutes represent 66% of total non-Kuwaiti PCCs, whilst 33% are between 30 to 60 minutes, and only 0.9% for more than 60 minutes (Figure 5.2). Here, the volume element (shower flowrate) has not been mentioned for the consumption by household size or household status, nor the ownership element. So, the "O" element is missed, the "V" element is partially missing (flowrate), but the "F" element is available.

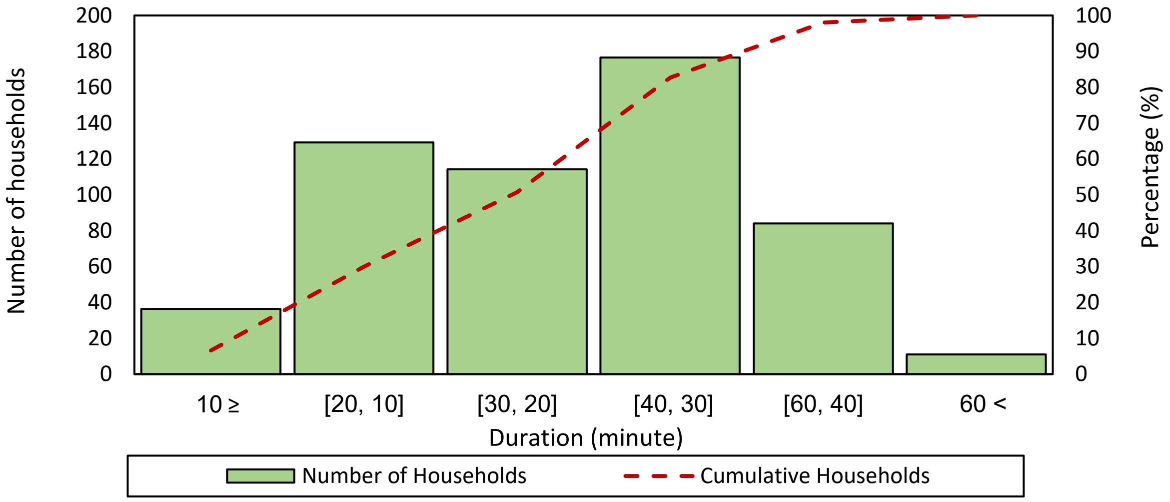


Figure 5.2: Average shower duration (mins/cap/day) in Kuwaiti households.
Source: Burney *et al.* (2017)

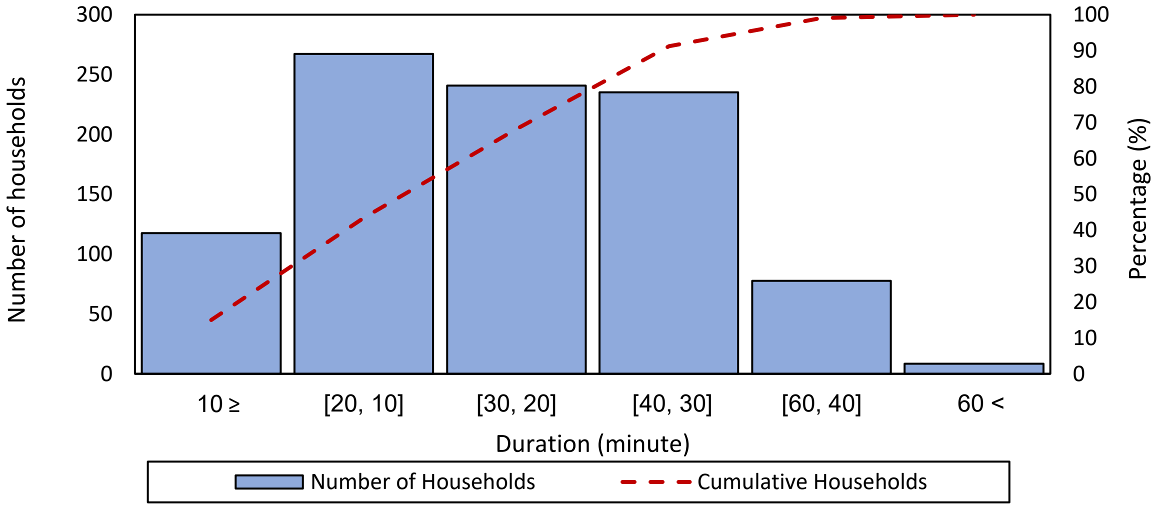


Figure 5.3: Average shower duration (mins/cap/day) in non-Kuwaiti households
Source: Burney *et al.* (2017)

Toilet

Toilets are the most frequently used component on a daily basis in all the households, taking a considerable proportion of indoor water demand. According to WRC/KISR's study, 9.6% of total PHC goes to toilet flushing. The frequency of use per day is three visits on average, two visits at a minimum, and seven visits at a maximum. Here, the “O” and the “V” elements are missing, but the “F” is given.

Washing Clothes

In Al-Humoud and Jasem (2008), the frequency of washing clothes differs from one household to another, some of which wash once a week, and some seven times or more a week. Washing using washing machines is the main method used rather than washing by hand in Kuwait's households. Washing machines are widely distributed amongst Kuwaiti and non-Kuwaiti households. According to TED/KISR study, the ownership of washing machines is 97.3% in Kuwaiti households, and 97.6% for non-Kuwaitis. Therefore, as a result of the widely available washing machines amongst Kuwait's households, for simplicity, it has been assumed to be the only method available in the washing clothes component in the model. The volume of washing machines has not been discussed in literature, such as the duration of washing and water capacity each load. Here, the “O” element is available, the “V” is missed, and the “F” is available.

Washing Dishes

Washing dishes represents the lowest proportional of water demand of the indoor components, accounting for 2.2%, according to the WRC/KISR's study. The most common method of washing dishes is by hand using a kitchen sink tap. According to TED/KISR's study, dishwashers are uncommon in Kuwait's households, with only 2.9% of Kuwaiti households using dishwashers, and 1.2% for non-Kuwaiti households. The frequency of washing dishes is ten times a week on average (1.42 a day), twenty-one times a week at maxima (three times a day), and three times a week at minima (0.428 a day). Regarding the volume of wash, there are neither data on kitchen sink tap flowrate, nor duration of washing, or even dishwasher load capacity. Similar to the washing clothes component, the “O” element is available, the “V” is missed, but the “F” is available.

Taps/faucets

Taps are installed in different facilities in a household, whether indoor or outdoor; for instance, kitchen/sink tap, and bathroom sink tap. Consequently, taps have different uses, whether for washing dishes, floors, or for personal hygiene, such as washing hands. Here we focus on washing floors as other mentioned functions are addressed elsewhere. Washing floors, regularly, is a very common practice in Kuwait's household due to the prevailing climate of the country, with dusty winds, and high humidity in different periods of a year. According to Al-Humoud and Jasem (2008), the frequency of washing floors ranges from once to seven times a week. About 10.5% of total PHC goes to washing floors. Data on volume (duration and flowrate) has not been provided. Similar to the toilet component, the “O” and the “V” elements are missing, but the “F” element is given.

5.3.2.2 Outdoor micro-component use

Car Washing

Private and cab cars are the most common form of transport in Kuwait. According to the Ministry of Interior (MOI) report in 2017, car ownership increased from 1.21 million in 2007 to 2.25 million in 2017 (KUNA, 2007; Alazmi, 2018). The only public transport method available in the country is bus and coach owned by the Kuwait Public Transportation Company (KPTC). Although this government transport company has low prices for daily trips and has symbolic prices for subscriptions (e.g., 100 US$ for all routes for a full year), it is an undesirable transport method especially for Kuwaitis, for several reasons. The first is the harsh weather, which prevents pedestrians from walking around comfortably. The second is the station pickup points, with most inconveniently located at the edge of residential areas. The third is timing, where it is common to have delayed trips every day. The fourth reason is the social norm amongst Kuwaitis; it is rare to see a Kuwaiti getting using public transport which is usually occupied by non-Kuwaitis who can’t afford a car and/or are ineligible for a driving licences (e.g., domestic workers, except drivers).

Thus, based on the data available, every Kuwaiti household has at least one car, whilst 90% of non-Kuwaitis who live in the household sector have at least one car, with the remainder (10% of non-Kuwaiti households) having no car. Therefore, we assumed that every

Kuwaiti household would have a Car Washing component in the micro-component model. For those non-Kuwaiti households, we assumed that all households who live in villas would have the Car Washing component, whilst for the other dwellings, 90% of them have been assigned with the relevant component. The reason that lies behind having a Car Washing component for every non-Kuwaiti household in a villa is that they have a high living standard. They tend to have a high income with which they can rent a villa and own cars. Furthermore, Kuwait doesn't apply a road tax nor a VAT tax, the compulsory car insurance fee is meagre (nearly 70 US$ per annum); and fuel costs are amongst the cheapest internationally.

TED/KISR has mentioned that the frequency of car washing is that 72% of Kuwait's households wash their car(s) daily, while WRC/KISR has stated five times a week. The ownership of car(s) is declared, but ownership of a hosepipe is not; the volume of consumption has not been reported. So, the “O” element is partly presented, the “V” is missed, whilst the “F” is completely presented.

Garden/Lawn irrigation

Gardens and lawns exist only for villas, but beyond this there are no statistics on the distribution of those gardens in Kuwait's governorates or their average space area. This is despite the regulation of home gardening (back yard, and front yard gardens) issued by the Ministry of State for Municipal Affairs (MSMA) in 2007 that has fourteen regulatory clauses to organise the establishment of gardens/lawns in the household sector (MSMA, 2007). However, key points can be abstracted from this regulation to help populate the garden/lawn irrigating component. The first key point is the clause of the areal extent which helped to assume the average garden/lawn space which in turn helped to assume the average irrigating points (e.g., drippers/sprinklers) needed for each water irrigation system (dripping/sparkling), and thus assume the duration of irrigation (as this is not given in the available datasets). The areal extent clause defined the maximum size limits possible of a garden/lawn, tied to villa width (e.g., 20 meters, as the average of the Kuwaiti villas do), and a maximum length of 20 meters (400 m^2 - maximum) from the villa boundary. Hence, the average garden/lawn extent is (200 m^2) as the midpoint (average) of the maximum areal extent is (10 meters) multiplied by the average villa width (20 meter).

The second regulation's clause stats that hosepipe irrigation is prohibited and a householder who breaks this regulation will be penalised. Hence, householders are encouraged to adopt modern irrigation systems (e.g., automatic drip/sprinkler systems). Based on this, the MSMA in co-operation with the Public Authority of Agriculture Affairs and Fish Resources (PAAFR) have developed a program that assists householders (who have gardens/lawns, or new householders who intend to have their own) in garden/lawn design. The assistance includes consultations on, for example, irrigation system design, and types of plants to be planted (Anwar, 2017). From the regulation, we can assume that the average garden/lawn is 200 m^2, irrigated with an irrigation system (dripping/sparkling) as hosepipes are banned. This assumption is helpful in the estimation of a garden/lawn consumption as there are no data available on the volume element, such as irrigation duration and the flowrate of, for example, emitters/drippers in a drip system and flow rate in sprinkler systems. Furthermore, the ownership of these irrigation systems amongst households is not given; the available data on the garden component is very poor.

Thus, the data available from literature on the garden/lawn component is: (i) the proportion of surveyed villas with gardens/lawns, i.e., 45.8% and 46.7% have been reported in Mukhopadhy *et al.* (2001), and the WRC/KISR, respectively; (ii) irrigation methods have been installed, which include drip, sprinkler, and an installed sprinkler in a hosepipe; (iii) the minimum and maximum size of gardens/lawns, as Mukhopadhy *et al.* (2001) stated that 10 m^2 is the minimum, and 600 m^2 is the maximum size; and (iv) the frequency of irrigation, according to the WRC/KISR, 63% of household gardens/lawns are irrigated daily, while two times a week is the least frequent irrigation (1.5%); six times irrigation per week is the average. Garden/lawn irrigation constitutes 7.63% of the total PHC consumption.

The proportion of garden/lawn availability of the WRC/KISR was selected for use in the MC model as it is the most recent available data in comparison with Mukhopadhy *et al.* (2001). We assume that this proportion will be applied in all Kuwaiti and non-Kuwaiti households living in villas, as non-Kuwaiti households are living in rented villas owned by Kuwaitis or GCC citizens. Besides, the average size of garden/lawn of 200 m^2 has been selected for the MC model, with drip/sprinkler irrigate systems used throughout. In sum, the OVF elements are not presented sufficiently in the component; the ownership (availability) of gardens/lawns is reported, but the ownership of the irrigation systems is not. The frequency of use/irrigation is given; but not the volume of irrigation in terms of irrigation duration and flowrate by irrigation systems system. So, this component has “O” partly available, “V” missing, while “F” is available.

Swimming pools

Swimming pools are considered in the WRC/KISR study, whose survey shows nearly 4% of the participating households have swimming pools. Although swimming pools might be a significant water consumption in Kuwait's households because of high evaporation potential, they are not widespread in the WRC/KISR study who thus considered them no further. Given the lack of data on the swimming pools as an outdoor component in Kuwait's household it was decided to omit the swimming pool component from the MC model.

The above review highlights the poor and insufficient data regarding OVF elements for Kuwait households and indicates the difficulty of developing a MC model. Therefore, several decisions were made to address the evident obstacles. First, the WRC/KISR MC model was selected as the base model but also used to develop ‘derivatives’, supplementary models that address specific data challenges (e.g., a derivative that excludes the uncertain garden/lawn component). The reasons for this are: (i) the WRC/KISR model has complete proportional MC indoor and outdoor consumption from its ultra-sonic monitoring; and (ii) there is no alternative available MC model that matches Kuwait's household consumption components, nor data that can be combined to develop one. The WRC/KISR's model addresses only Kuwaiti households in villas but is used here for all categories in the household PHC demand matrix. This decision is made as a result of: (i) the very limited MC data for Kuwaiti households in other dwelling types, and for non-Kuwaitis; and (ii) shared factors, such as the same water tariff, and similar socioeconomic characteristics. Second, the Garden/Lawn component was assumed to apply equally to (46.7%) of total Kuwaiti and non-Kuwaiti households in villas. In addition, the adopted means of garden/lawn irrigation are modern irrigation systems (drip and sprinkler systems) as the hosepipes are banned. Third, the Car Washing component was applied to all Kuwaiti households, and for non-Kuwaiti households, was applied to all households in villas, and 90% of households in other dwelling types.

Hence, two derivatives of the base MC model have been generated; one excluding the Garden/Lawn component, and the other excluding both Car Washing and Garden/Lawn components (full exclusion of outdoor activities). In this situation, the base MC model has seven components (indoor and outdoor) applied only to villas that have garden/lawn facilities (Kuwaiti and non-Kuwaiti villas). The first derivative (garden/lawn exclusion) was applied to all Kuwaitis and non-Kuwaitis in villas that do not include gardens/lawns, plus all Kuwaiti and 90% of non-Kuwaiti households in other dwelling types. The second derivative (all outdoor activities excluded), was applied to 10% of non-Kuwaiti household in different dwelling types, excepting villa categories. The statistical method used to derive alternatives from the base MC model is the proportional redistribution of the excluded component (e.g., garden/lawn) over other components equally. For example, in the first derivative, Garden/Lawn component's proportion (7.63%) has been divided by six (1.27%) as the first derivative model has six components after Garden/Lawn component exclusion, then, redistributed to the other existed components, so as the second derivative has followed the same procedure (Table 5.2).

Table 5.2: The PHC propotions in the base micro-component model and derivatives

Component	**Base model** (%)	**1st derivative** (%)	**2nd derivative** (%)
Shower	61.03	62.30	63.68
Toilet	9.63	10.90	12.28
Washing Clothes	3.33	4.60	5.98
Washing Dishes	2.23	3.50	4.88
Washing Floors	10.52	11.80	13.18
Car Washing	5.63	6.90	Excluded
Garden/Lawn Irrigation	7.63	Excluded	Excluded
Total	100	100	100
Population segment the MC model applies to	Villas with garden/lawn	Kuwaitis and 90% of non-Kuwaitis	10% of non-Kuwaits

At this point, the fundamental outlines of the MC model have been defined, and model derivatives specified to fit differences in Kuwait's households. Here, the breakdown of a household's PHC can be extracted by applying the initial MC model design; still, further modelling requires a full definition of the OVF elements. Table 5.3 shows the conclusion of the review of data availability on OVF elements. It shows that data on ownership is only available for some appliances, data on volume of use is largely missing, and only frequency of use is available for every component. This patchy OVF dataset, on its own, is arguably inadequate for demand forecasting using a MC model (forecasting would at least necessitate drawing of considerable assumptions). However, it is worth recalling that the aim of the study is not to forecast demand, but to identify, via backcasting, potential measures that could reduce future demand to a pre-determined target level. The approach selected to identify as wide a set of measures as possible, was the MC model, as its OVF structure offers considerable scope for investigation of water demand management scenarios. Also recall, that the prior work (chapters three and four) has produced demand forecasts. This has utility in: (a) identifying the size of the "water gap" between target demand and estimated BAU demand, which is needed to define the backcast challenge; but also (b) offers the opportunity to draw inferences as to the missing components in the MC OVF formulation, via a "calibration type" exercise. That is, given knowledge of per household demand by population group (chapter four), how that demand breaks down by water use function, and also the OVF frequency data for that use, then inferences can be drawn for the missing O and V components. This is considered a preferable approach to using values from MC models in other countries where the social and cultural contexts are so different.

Table 5.3: Data availability on OVF elements

Component	Ownership	Volume	Frequency
Shower	N/A*	Duration available, flowrate missing	✓
Toilet	N/A	N/A	✓
Washing Clothes	✓	N/A	✓
Washing Dishes	✓	N/A	✓
Washing Floors (taps)	N/A	N/A	✓
Car Washing	Car ownership available, washing appliance missed	N/A	✓
Garden/Lawn Irrigation	Garden/lawn ownership available, irrigation appliances missed	N/A	✓

* Not Available (N/A)

5.3.2.3 Appliance's volume and ownership assumption

Thus, the MC model was developed, and applied with the household PHC demand matrix to find the "V" and "F" values for the household groups in the matrix. The next section addresses this to: (i) fill the missing volume segments including appliances flowrate and load capacity, and duration of consumption; (ii) fill the missing ownership values of the appliances;

and so (iii) draw the final features of the MC model by the application of calibration fitting exercise through linear combination equations (section 5.4.1).

Volume element

Water flowrate is defined as the volume that passes through a water pipe per unit time; (Woodard, 2018). Water flowrate differs from one household to another, determined by household water pressure/plumbing system, pipe diameter, and friction loss (Heinselman, 2013; Yael, 2017). In the light of plumbing systems, there are two main categories; the first is the low-pressure system, and the second is the high-pressure system (Jones, 2011). The low-pressure so-called gravity-fed system uses gravity to produce water velocity. The gravity-fed system consists of a cold-water tank in the loft and hot water tank in an airing cupboard. Such a plumbing system restricts and limits a householders choice of water appliances and fixtures, or they must install a water pump for higher pressure (Kerner *et al.*, 1988; Niskanen, 2003). A high-water pressure systems allows for combination boilers and unvented systems. The combination boiler heats water directly from the pipes when a user turns on a faucet, and doesn't need a hot water storage cylinder or a cold water header tank (Alkhaddar and Phipps, 2008). The unvented 'Megaflo' system is a cold water cylinder filled from the mains, and kept continuously under pressure by incoming mains water and heated indirectly from an external source (BPEC, 2016). The typical water pressure for households ranging between 40 – 60 PSI, over 60 PSI pressure can cause water mains faults (Norman, 2006).

Plumbing diameter is another factor that determines flowrate. As the diameter of a pipe increases, flowrate increases under constant pressure (EPA, 2008) but water pressure may be too low to reach the maximum flow of a given pipe size. Thus, pressure reduction is a leakage reduction strategy used in some countries. Households with a common mains pressure but different plumbing diameters (e.g., standard vs micro-bore) may have varied flow rates. Water friction is additional factor that affects the flowrate and pressure, as water passes through a pipe, friction will slow it, depending on the texture and diameter of the pipe. The smoother the pipe, the less friction, and the faster water can flow through the pipe (YTL, 2019).

Water flowrates can thus vary from one household to another, giving rise variation in end-use components consumption. In Kuwait, no regulation specifies the upper bound of flowrate and there are no plumbing codes in the household sector. Thus, flowrates in micro-components were determined from manufacturer and regulator (USA/UK, there are no equivalents in Kuwait) grey literature on standard plumbing appliances (Water Anywhere, Premier Water, Freshwater Systems, Portland Water Bureau, Water Sense, and the US Environmental Protection Agency). Table 5.4 shows the minimum, maximum, and average flowrate of micro-components derived from these sources. For washing machines, dishwashers, and toilets, flowrate is replaced by water consumed per load or flush. Washing machines vary in size, in type (front or top loaders), each of which has a different water use capacity. Manufacturers report load capacity of traditional washing machines ranges between 90 to 220 litres per load (Muthu, 2015). Dishwashers ranged between 27 and 65 litre per load. For toilet flushing, a standard flush ranges from 8.3 to 22.7 litres. These data are used in the MC model, selecting a value within the reported ranges so as to reach the exact demand proportion for each household category in the PHC demand matrix (see calibration section 5.4.1.3).

Garden/lawn irrigation demand is a function of garden/lawn area, the density of plants, and plant type (e.g., palm trees consume much water). Planting data is unavailable so to estimate the micro-component we use: (i) types of irrigating system (drip and sprinkler systems); (ii) the average garden/lawn area; and (iii) the proportion of household consumption for irrigation. We assume all gardens use drip irrigation/sprinklers, that average garden area is 200 m^2, whilst we know that Garden/Lawn component accounts for 7.63% of total use. Thus, the average area for each irrigating system in association with its flowrate have been used to: (i) determine the number of installed drippers/sprinklers; and (ii) to estimate the duration of irrigation.

A drip system is a method where water flows through drip pipes, with emitters set at a different spacing in which water is distributed within the emitters/drippers directly into the soil near the roots through a particular slow-release device (Shamsuddula, 2014). The drip system is preferable in gardens that have shrub areas, flowerbeds, and vegetable garden (Hartz and Hochmuth, 1996). In contrast, a sprinkler system is a watering technique similar to rainfall with water sprayed into the air such that it breaks into small drops which fall to the targeted area (Shankar *et al.*, 2015). Sprinkler irrigation is preferable for lawns and grass areas (USDA, 2016). The flowrate of this system depends on the pressure, pipe diameter, and irrigation nozzle size (Gerry and Michael, 2017). Sprinkler systems may have spray or rotor nozzles (Impact, Gear-Driven, or Multi-Stream), each of which have different sizes with different flowrates (Kincaid, 2005; Carbone, 2013). Systems vary in diameter and length of coverage, some having a long water throw, and some that can cover a planted area at many different angles (e.g., 40 to 180 degrees). In drip systems water nozzles (emitters) vary little by types or sizes, and flowrate is determined by pipe pressure.

The flowrate of home garden/lawn's sprinklers is 5 to 18 litres per minute, based on PSI range of 20 to 30 PSI and nozzle sizes appropriate for home gardens/lawns (Ley, 1988; Hill and Banks, 2000). Drip emitter's flowrate ranges from 2 to 8 litres per hour (Taghvaeian, 2017). According to garden industry manufacturers and water institutes such as Green Grass, Go Farm, Aqua Light Irrigation, Tucson water, and Southern Nevada Water Authority; the average duration of sprinkler irrigation is 10 to 30 minutes (average of 20 minutes), with longer duration in summer (20 to 40 minutes) as temperature and evaporation increases. Drip irrigation needs more time as the flowrate is lower; duration ranges from 40 to 60 minutes (average of 50 minutes) depending on the system flowrate and season.

Based on irrigation system manufacturers guidance (T3 Smarter Living, Backyard Boss, Hozelock, Irrigation Tutorials, and Easy Garden Irrigation), the average coverage of a drip system depends mainly on the density of the planted area and the type of plants. It is recommended to set drippers two to three meters apart. Sprinkler system depends on the area to being irrigated but, it is recommended for home gardening that a range of nine meter is sufficient throwing range for a lawn of 200 m^2. With estimates of the; (i) average area coverage of an irrigating system; (ii) average garden/lawn space; and (iii) average irrigation duration for each irrigation system, calculations have been made to estimate the number of sprinklers/drippers installed, from the calibrated duration of irrigation has been obtained (with given consumption proportional in the base model and flowrates for both irrigating systems).

The number of drippers/sprinklers is estimated as:

$$(i)\ Drip\ coverage = \frac{a}{c} = \frac{200}{2.5} = 80\ drippers^{14};$$

$$(ii)\ sprinkler\ coverage = \frac{a}{c^2} = \frac{200}{9^2} \cong 3\ sprinklers. \qquad (8)$$

Where a is the average garden/lawn space; c is the coverage area for dripper; c^2 is the average throwing range for sprinkler. Having satisfied the garden/lawn component's elements (average areal space, dripper/sprinkler flowrates, number of drippers/sprinklers), it is possible to use these in the MC model calibration fitting process to derive values for garden/lawn consumption and duration of irrigation (section 5.4.1.3). Table 5.4 shows the derived statistics for the irrigation component, as well as the flowrate/load capacity for the other micro-components discussed above. These data are taken forward into the calibration process described below.

Table 5.4: Water volume of the household appliances

Appliance	Measurement unit	Minimum	Maximum	Average
Toilet	Litres/per flush	8.3	22.7	13.65
Dishwasher	Litres/per load	27	65	45.4
Washing Machine	Litres/per load	90	220	145
Emitter	Litres/per minute	2	8	5
Hosepipe	Litres/per minute	9	25	16
Shower	Litres/per minute	10	22	14.65
Sprinkler	Litres/per minute	5	18	10
*Taps**	Litres/per minute	9.5	11.4	10.45

* Including washing floor and kitchen sink taps

Ownership element

Data on appliance ownership is partial (Table 5.3), with no Kuwait data for showers, taps, and toilets appliances, but logically all households have a tap and a toilet, and most probably have a shower. Therefore, we assume every household has these components. There is no data on irrigation system ownership in Kuwait, nor available indirectly, e.g., via

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[14] 75 drippers have been applied rather than 80, to keep the irrigation duration above average (50 minutes) as the dripper's installation is mainly related to the number of plants not to the space of the garden.

reports of the proportion of gardens more suitable for drip or sprinkler irrigation. In this case, it has been assumed that half of households with gardens/lawns have a sprinkler system, and half have drip systems (46.7% of villas have a garden/lawn watering component). The majority of households wash dishes by hand, with 2.9% of Kuwaiti households using a dishwasher (1.2% of non-Kuwaiti households). For the Car Washing component, a hosepipe connected to an external tap has been fixed as the method of washing. For the Washing Clothes component, ownership of washing machines exceeds 97% for Kuwaiti and non-Kuwaiti, and with this high ownership share we assume that all households having washing machines.

Above we have sought to develop understanding of the Ownership, Volume, and Frequency elements for Kuwait household water use, this understanding is then used to develop specific OVF values for use in the MC model, via a calibration process (possible as we know PHC and a credible range of values for Kuwait OVF components). Before engaging with the calibration process note that a distribution of OVF values by micro-component (e.g., dishwashers) has been determined that allows for identification, following normality testing, of values to take forward into the MC model. Such values are determined through the calibration process which allows PHC values to be reproduced by the MC model, with knowledge gained as to whether model OVF values are close to the average of observed OVF values, or more toward the extremes. The next section addresses the Ownership element distribution, normality testing, the calibration work to derive OVF values for use in the MC model, including an accuracy test of the calibrated values.

5.4 Results

5.4.1 Development of OVF values of the household population and PHC demand matrices: MC model

This section starts by determining appliance ownership distribution over the household population (i.e., ownership by population segment). It was assumed that ownership distribution proportions are static throughout the forecasting period (but note that when backcasting manipulating the market penetration rate of new technologies adoption introduces a dynamic element to the ownership distribution). With the ownership distributions determined, normality test have been employed demonstrating non-normal data and hence the decision to use median values in the calibration process. Linear combination equations have been used to calibrate the MC model, after which, accuracy and validity tests are used to validate the calibrated MC model.

5.4.1.1 The distribution of appliances ownership over the household population

Two equations were developed to systematically distribute appliance ownership throughout the household population. The first addresses distribution of garden/lawn availability and irrigation systems in villas; and the second addresses the distribution of washing dishes using a *"dishwasher"*. The garden/lawn equation is:

$$GLD = \frac{v_t}{100} * \frac{\beta_1}{100} * z_{t(1-12)} * \beta_{2t(1-12)} \tag{9}$$

Where GLD refers to garden/lawn distribution; v is the total population of villa households (Kuwaiti and non-Kuwaiti) for a given year t e.g., 2020, divided by 100 then multiply by the coefficient β_1 (the proportion of villas with garden/lawn = 46.7) to extract the number of households with garden/lawn. Then, the extracted number is divided by 100 to enable extraction of the household size proportional distribution z in the household size vector (1-12) for the same given year t. This ensures a systematic distribution as every household size in the household vector has a different proportional distribution (weight by household size and by governorate); this process keep the weight as it is. Afterward, the resultant number of households with garden/lawn is multiplied by β_2 (the proportion having drip/sprinkler irrigate system = 0.5) over the household size vector to extract the number of households that have drip/sprinkler irrigating systems. Table 5.6 shows an example before and after equation implementation for Kuwaiti villa Households in 2020.

The second equation is the dishwasher distribution;

$$DD = \frac{P_t}{100} * \frac{\beta_{1(c-e)}}{100} * \frac{M_{t(b,f,s)}}{z_{t(1-12)}} \tag{10}$$

Where DD refers to dishwasher distribution over the household population. P refers to the total population (this population is distributed over the base model and its derivatives) for a given year t which has been divided by the coefficient $\beta_{1(c-e)}$ (the proportion of households with a dishwasher out of the Kuwaiti and non-Kuwaiti household proportions; for Kuwaiti households it is 2.9%, while non-Kuwaitis it is 1.2%). The extracted households with dishwasher appliance have been divided by 100 (to allow obtaining the number of households in the micro-component M for the same given year t). Then, it has been multiplied by the weight of the base model b, first derivative f, and second derivative s for the given year. It is better to not distribute the obtained number after applying β_1 equally to the base model and derivatives since the base model is only assigned to villas (i.e., low weight). The first derivative is assigned to all households except villas with garden/lawn and 90% of non-Kuwaiti households (i.e., high weight). The second derivative is only assigned for 10% of non-Kuwaiti household in all dwelling except villas (i.e., low weight). Thus, it is better to distribute dishwasher appliances based on the weight of the base model and each derivative to simulate the household population distribution. Finally, a projection of the household size proportional distribution z in the household size vector (1-12) for the same given year t is made, to project the weight for each household size by governorate and by the base model plus its derivatives.

The distribution for other components, washing by hand using kitchen sink tap (Washing Dishes component) has been distributed by 97.1% of total Kuwaiti households (100 – 2.9 = 97.1%), while non-Kuwaiti it is 98.8% (100 – 1.2 = 98.8%) using the same dishwasher distribution (DD) equation. The remaining components (Shower, Toilet, Washing Clothes, Washing Floor, and Car Washing) have been distributed to the MC base model and derivatives without disaggregation as we assume these components are equally distributed to all households. Equation 11 defines the number of generated MC tables[15] of the base model and derivatives, as follows:

$$MC_{n,e,j,w,v,d,i} = (\{c + e\} * jwv + \{cf + ef\} * jw + ejwi) \tag{11}$$

Where $MC_{n,e,j,w,v,d,n}$ denotes MC model tables; c and e to household status, Kuwaiti and non-Kuwaiti, respectively (c = 1; e = 1); j indicates the number of the household size in the model (j = 12); w denotes methods used in Washing Dishes component (dishwasher and

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[15] MC tables refer to the PHC micro-component (PHC-MC) level for each household category; e.g., micro-component use for a non-Kuwaiti household of five members in a flat in the second derivative, and so on.

wash by kitchen sink tap; w = 2); v denotes the irrigation methods used in the base model (drip/sprinkler; v = 2); cf refers to the number of dwelling categories for Kuwaiti households in the first derivative (cf = 4), while ef refers to the non-Kuwaiti dwelling categories for the first derivative (ef = 5); i refers to the number of dwelling for non-Kuwaitis in the second derivative ($i = 4$).

From this process, the MC base model has been developed with four different ownership types for each household status (Kuwaiti and non-Kuwaiti). The first derivative model has two ownership types for each household status, and the second derivative model has two ownership types, as it is only used with non-Kuwaiti households. Consequently, in the base model, 96 MC tables have been generated, 48 tables for each household status distributed by the household sizes (12 household sizes). The first derivative has 216 MC tables in total, whilst the second derivative has 96. Table 5.5 shows the disaggregation of the base model and the derivatives by the dwelling type and household status.

Table 5.5: The generated tables of the MC model

Model	Dwelling type	Kuwaiti	Non-Kuwaiti	Total
Base	*Villa*	48	48	96
1st derivative	*Villa*	24	24	48
	Floor or flat in villa	24	24	48
	Flat	24	24	48
	Traditional house	24	24	48
	Annex	N/A	24	24
2nd derivative	*Floor or flat in villa*	N/A	24	24
	Flat	N/A	24	24
	Traditional house	N/A	24	24
	Annex	N/A	24	24
Grand total		144	264	408

* Not/Available (N/A)

Table 5.6: The Garden/Lawn distribution in the Kuwaiti household population 2020

	(1) Villa households prior to equation implementation													
	Household size	1	2	3	4	5	6	7	8	9	10	11	12	Grand total
Household population	*Cap*	699	818	1,736	1,829	2,465	2,782	3,409	3,534	3,570	3,473	2,730	9,943	**36,988**
	HAW	720	791	1,764	2,020	2,755	3,352	4,007	3,933	3,592	3,149	2,344	6,393	**34,820**
	AHM	750	787	1,556	1,734	2,283	2,786	3,394	3,580	3,639	3,629	3,045	10,853	**38,036**
	JAH	385	446	856	944	1,254	1,475	1,941	2,017	2,228	2,380	2,096	8,102	**24,124**
	FAR	749	792	1,587	1,742	2,221	2,639	3,265	3,322	3,320	3,295	2,789	8,900	**34,621**
	MUB	334	435	956	1,117	1,513	1,801	2,212	2,088	1,946	1,833	1,504	4,948	**20,687**
	Total	**3,637**	**4,069**	**8,455**	**9,386**	**12,491**	**14,835**	**18,228**	**18,474**	**18,295**	**17,759**	**14,508**	**49,139**	**189,276**
	(2) Villa households after applying the proportion of villas with garden/lawn β_1 (household population = 91,579)													
	(3) Villa households after extracting household size by governorate proportional distribution z													
	Household size	1	2	3	4	5	6	7	8	9	10	11	12	Grand total
Household weight (%)	*Cap*	0.36	0.42	0.89	0.93	1.26	1.42	1.74	1.80	1.82	1.77	1.39	5.07	**18.86**
	HAW	0.37	0.40	0.90	1.03	1.40	1.71	2.04	2.01	1.83	1.61	1.20	3.26	**17.76**
	AHM	0.38	0.40	0.79	0.88	1.16	1.42	1.73	1.83	1.86	1.85	1.55	5.53	**19.40**
	JAH	0.20	0.23	0.44	0.48	0.64	0.75	0.99	1.03	1.14	1.21	1.07	4.13	**12.30**
	FAR	0.38	0.40	0.81	0.89	1.13	1.35	1.66	1.69	1.69	1.68	1.42	4.54	**17.65**
	MUB	0.17	0.22	0.49	0.57	0.77	0.92	1.13	1.06	0.99	0.93	0.77	2.52	**10.55**
	Total	**1.85**	**2.07**	**4.31**	**4.79**	**6.37**	**7.56**	**9.30**	**9.42**	**9.33**	**9.06**	**7.40**	**25.06**	**96.52**[*]
Household dist. after weight	*Cap*	326	382	811	854	1,151	1,299	1,592	1,650	1,667	1,622	1,275	4,643	**17,273**
	HAW	336	369	824	943	1,287	1,565	1,871	1,837	1,677	1,471	1,095	2,986	**16,261**
	AHM	350	368	727	810	1,066	1,301	1,585	1,672	1,699	1,695	1,422	5,068	**17,763**
	JAH	180	208	400	441	586	689	906	942	1,040	1,111	979	3,784	**11,266**
	FAR	350	370	741	814	1,037	1,232	1,525	1,551	1,550	1,539	1,302	4,156	**16,168**
	MUB	156	203	446	522	707	841	1,033	975	909	856	702	2,311	**9,661**
	Total	**1,698**	**1,900**	**3,948**	**4,383**	**5,833**	**6,928**	**8,512**	**8,627**	**8,544**	**8,293**	**6,775**	**22,948**	**88,392**

	(4) Villa households after applying the proportion of villas with garden/lawn β_2 (= 0.5)													
	Household size	1	2	3	4	5	6	7	8	9	10	11	12	Grand total
Gardens	*Cap*	163	191	405	427	576	650	796	825	834	811	637	2,322	**8,637**
	HAW	168	185	412	472	643	783	936	918	839	735	547	1,493	**8,130**
	AHM	175	184	363	405	533	651	792	836	850	847	711	2,534	**8,881**
	JAH	90	104	200	220	293	344	453	471	520	556	489	1,892	**5,633**
	FAR	175	185	371	407	519	616	762	776	775	769	651	2,078	**8,084**
	MUB	78	102	223	261	353	421	517	488	454	428	351	1,155	**4,830**
	Total	**849**	**950**	**1,974**	**2,192**	**2,917**	**3,464**	**4,256**	**4,314**	**4,272**	**4,147**	**3,388**	**11,474**	**44,196**
Lawns	*Cap*	163	191	405	427	576	650	796	825	834	811	637	2,322	**8,637**
	HAW	168	185	412	472	643	783	936	918	839	735	547	1,493	**8,130**
	AHM	175	184	363	405	533	651	792	836	850	847	711	2,534	**8,881**
	JAH	90	104	200	220	293	344	453	471	520	556	489	1,892	**5,633**
	FAR	175	185	371	407	519	616	762	776	775	769	651	2,078	**8,084**
	MUB	78	102	223	261	353	421	517	488	454	428	351	1,155	**4,830**
	Total	**849**	**950**	**1,974**	**2,192**	**2,917**	**3,464**	**4,256**	**4,314**	**4,272**	**4,147**	**3,388**	**11,474**	**44,196**

[*] Kuwaiti villa households constitute 96.52% (88,392) of total villa households (91,579); non-Kuwaitis constitute 3.48% (3,187)

5.4.1.2 Normality test of frequency element

The procedure of appliance's ownership distribution has generated 408 tables in the MC model. These tables with the available data and estimated values of OVF elements has been integrated to calibrate the V and F values in the MC model as O has been satisfied. The volume values of traditional appliances have been assumed through obtaining the flowrate per minute and volume capacity per load from plumbing manufacturers, where average values have been used, or a value from within the min - max range when average values were not aplicable due to constraints in the model (see section 5.4.1.3). The frequency of use values have been obtainted from the WRC/KISR's survey which involved 45 participants. The household sizes in the sample survey doesn't comprise the household sizes between 1 – 4 (because the survey has targeted Kuwaiti households in villas which tend to have higher household sizes than other dwellings, and due to the high Kuwaiti household average size c. 7 members).

Insufficient data has prevented the application of regression analysis to test the association between household size (x) and frequency of use (y). As a result of the incomplete household size's sequence, further effort was devoted to finding MC data relevant to the study context (Kuwait, GCC) which could supplements the existing dataset to get provide more robust findings. The search concluded with contact with Prof. Waleed Al-Zubari (the director of Water Centre – GCC; the chairman of the scientific committee – Gulf Water Conference (GWC)) who confirmed that there is no other data available at the MC level. Thus, data reported above is considered the best availabe data for the study.

However, two procedures have been employed to ensure that best use is made of the household size – appliances' frequency of use data we do have. The first is data cleansing and classifying through omitting incomplete obeservations in the sample (observations with undefined household size), whilst household sizes >12 are treated as 12 to ensure consistency. The second is testing to see if these data are normally distributed using graphical and numerical (Shapiro-Wilk) tests. These tests show the data is not normally distributed (Table 5.7 and Figure 5.4); therefore, a decision has been made to use median values (Table 5.8) rather than mean values in the MC model. The median values have shown its effectiveness in representing the “scale of economies”; for instance, the frequency of shower use per person drops as household size increases, suggesting a competition effect. The frequency of Washing Floor component also increases with increasing household sizes, which is considered a sign of the increasing share as household size increases. The Garden/Lawn component has no obvious pattern, which represents a good sign that the irrigating component is not influenced by household size, see Figure 5.5.

Table 5.7: The numeric tests of normality

	(α = 0.05)						
Component	*Skewness*			*Kurtosis*			*Shapiro-Wilk*
	Value	*SE*	*Z*	*Value*	*SE*	*Z*	*P-value*
Shower	0.60	0.42	1.43	-0.55	0.82	-0.67	1.06E-04
Toilet	0.95	0.44	2.15	1.31	0.85	1.53	3.00E-03
Washing Clothes	1.79	0.43	4.20	2.76	0.83	3.30	6.00E-06
Washing Dishes	0.85	0.41	2.10	-0.86	0.80	-0.41	1.20E-05
Washing Floor	0.08	0.46	0.18	-1.07	0.89	-1.21	3.00E-03
Car Washing	-0.38	0.42	-0.89	-1.62	0.82	-1.98	1.10E-05
Garden/Lawn	-0.99	0.55	-1.81	-0.85	1.06	-0.80	5.60E-05

Table 5.8: Median and confidence interval of median for frequency of use per day

Component	Median	Confidence interval (α = 0.01)	
		Lower bound	Upper bound
Shower	1	1	2
Toilet	3	2	4
Washing Clothes	1	0.571	1
Washing Dishes	1	0.857	2
Washing Floor	0.571	0.428	0.857
Car Washing	1	0.571	1
Garden/Lawn Irrigation	1	0.428	1

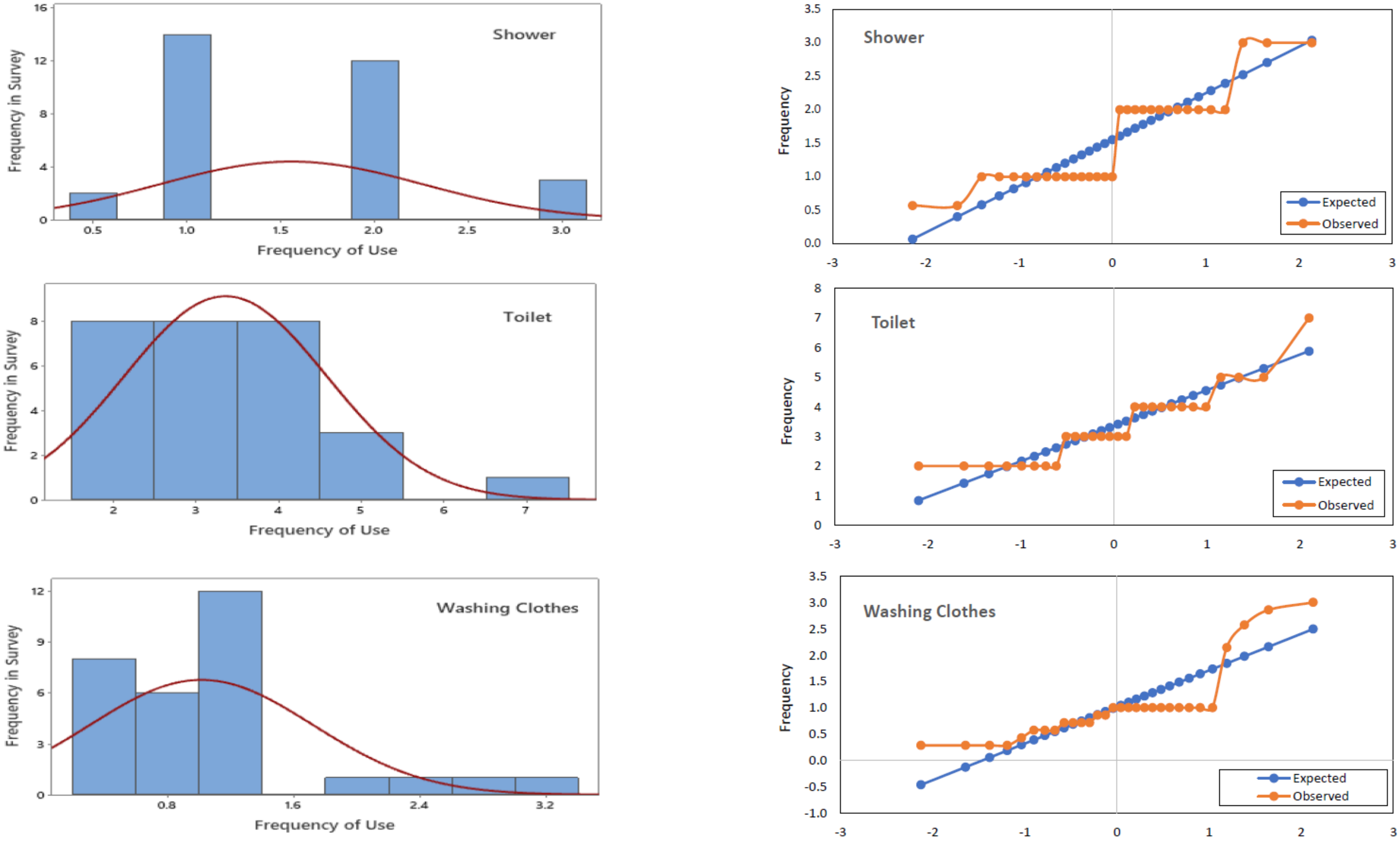

Figure 5.4: The frequency of use per person per day of the observed components

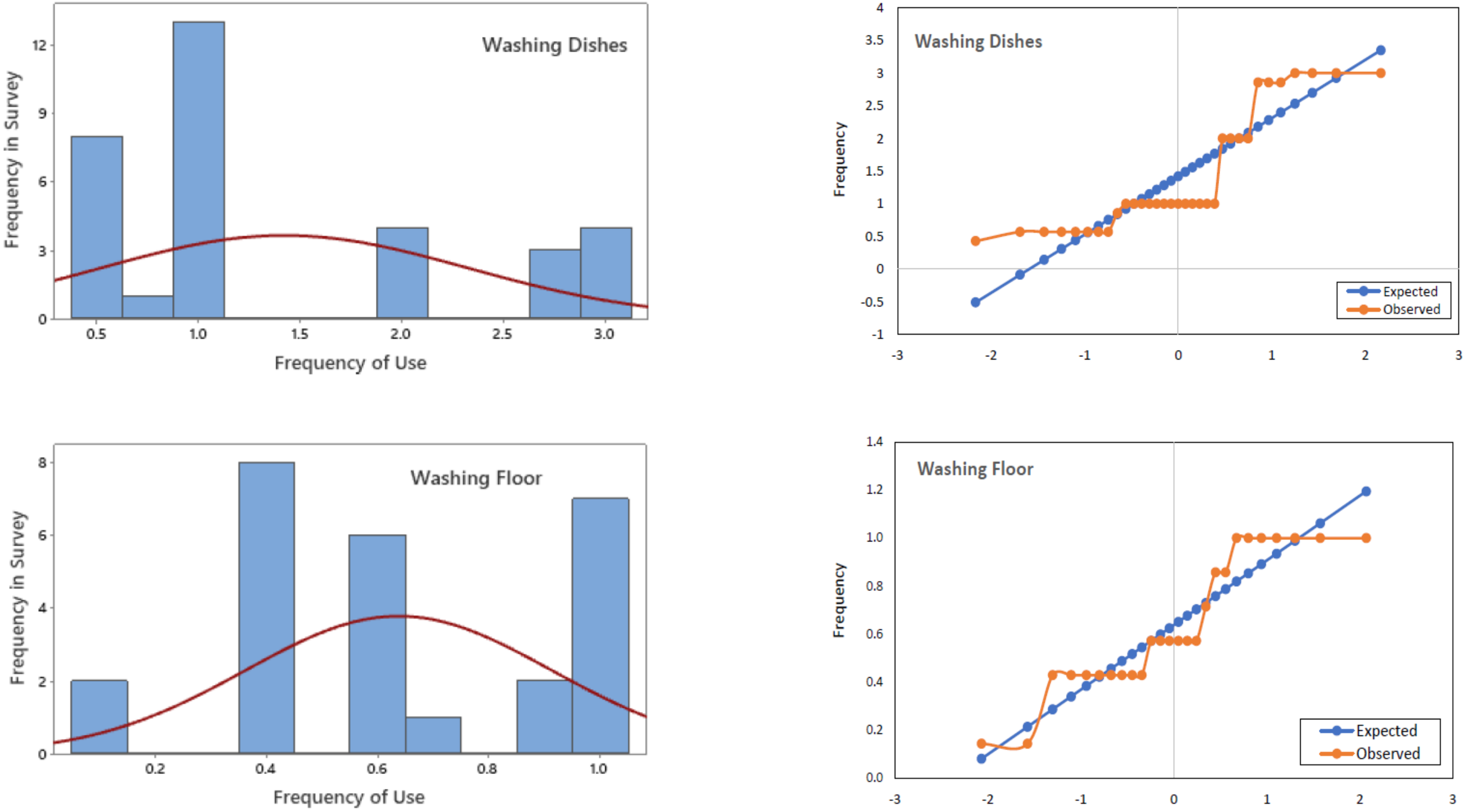

Figure 5.4: (Cont'd.)

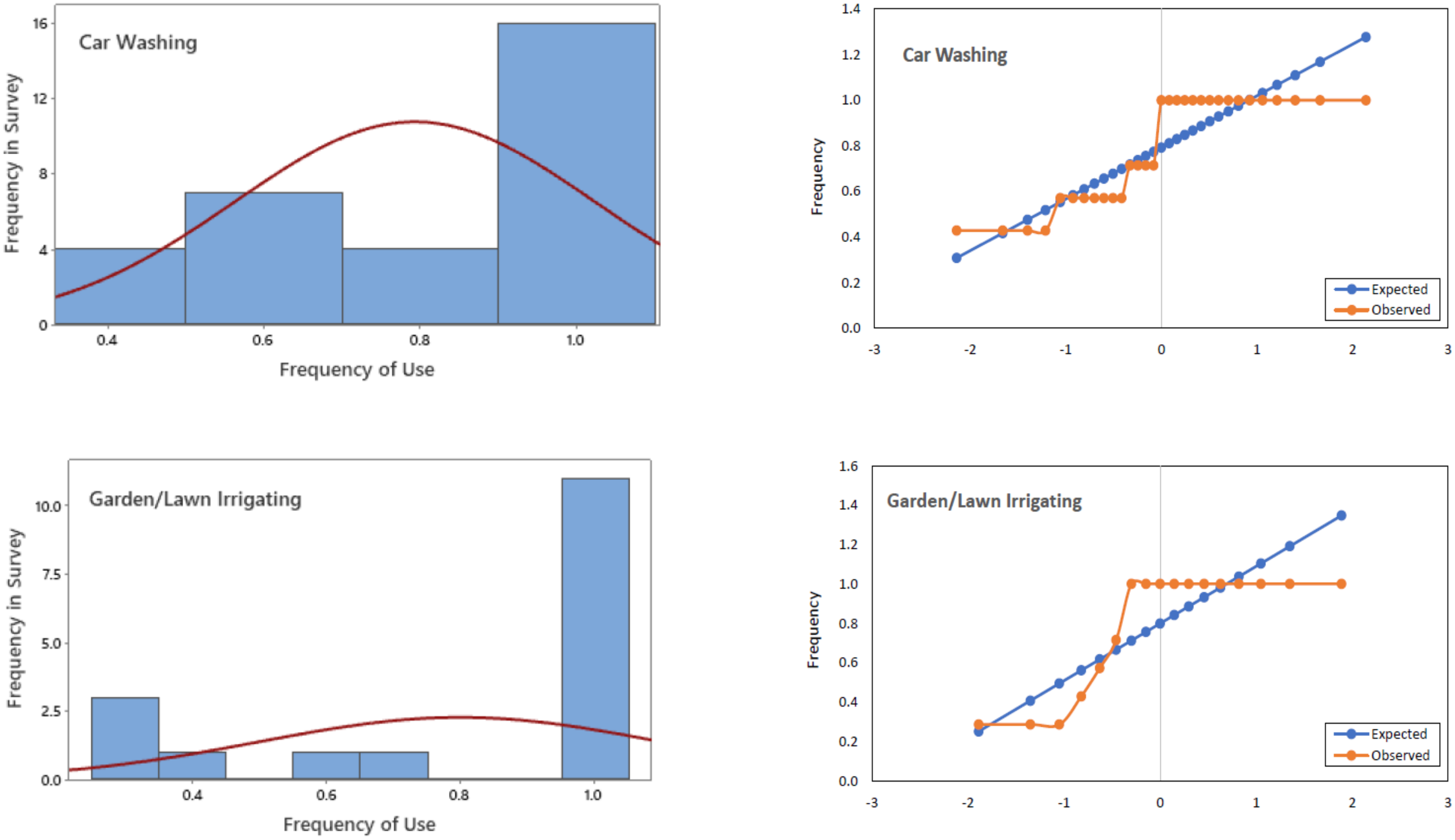

Figure 5.4: (Cont'd.)

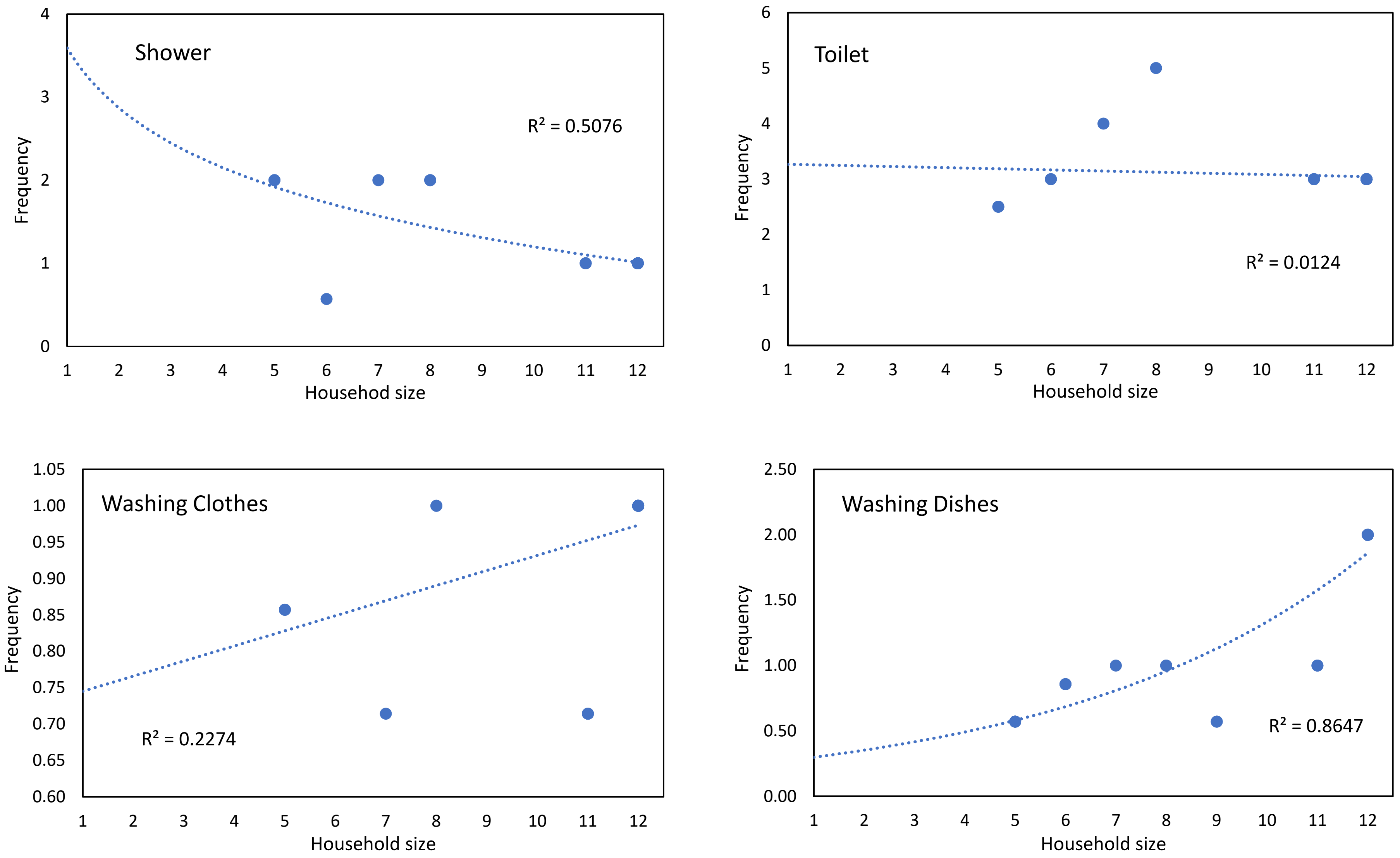

Figure 5.5: The frequency of use per person per day in the observed components using median values

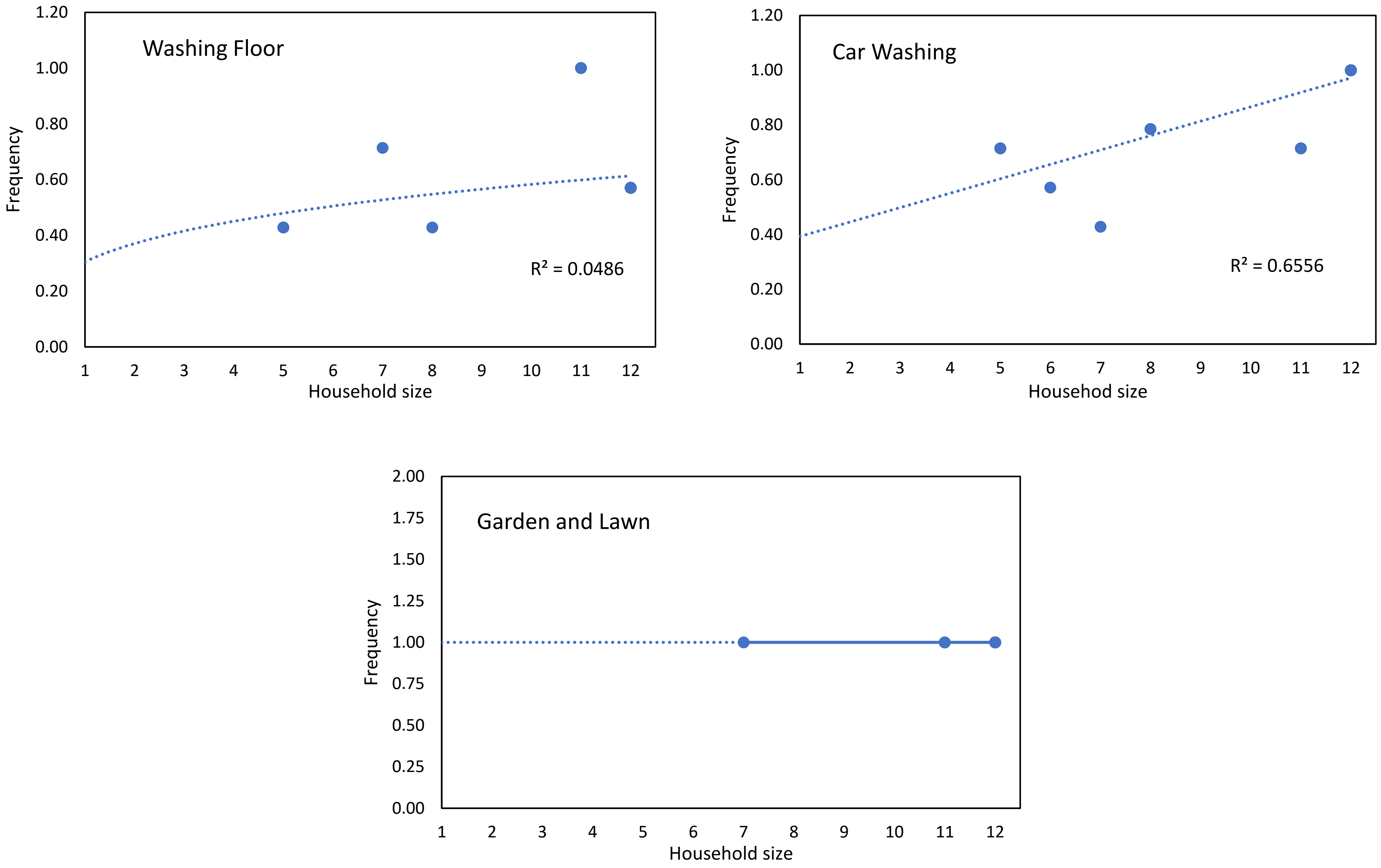

Figure 5.5: (Cont’d.)

5.4.1.3 The calibration of volume and frequency values in the MC model

In the calibration fitting test, the volume average values (Table 5.4) and the frequency median values has been used to calibrate the V and F values in the MC model. Here the calibration test has been applied by using the following equations;

$$f(y) = xb + a\,(xb) - xb \tag{12}$$

Where y is the dependent variable (water demand), which represents a given value in the model; and x is the frequency of use per day. Here, the median of each component has been treated as the fixed value of x. If the median (x) value is not applicable (as many constraints may occur, e.g., maximum and minimum flowrate or volume limits), the confidence interval of median is used, and if the median confidence interval is not applicable (few cases), then the lower and upper bounds frequencies (Figure 5.6) of the observations in the sample is applied. If this cannot be applied (very few cases) due to constraints (e.g., flowrate and frequency limits) then, outlier values in frequency are applied (e.g., the upper bound of toilet frequency, of seven visits per day). Exceptionally, this upper observed bound has been exceeded to allow model fitting. b is the flowrate/volume of a device; flowrate is treated as a constant to the frequency (x) in this equation (i.e., uses the average flowrate of each device); a is the duration of use. This equation was applied to: (a) Shower; (b) Washing Clothes; (c) Washing Floor; (d) Washing Dishes by hand; and (e) Car Washing and Garden/Lawn Irrigating as these components all have three parameters: duration of use (minutes), device flowrate/volume, and frequency of use. A second equation is applied for components with only two parameters (volume of a device and frequency of use) and takes the form;

$$f(y) = x + b\,(x) - x \tag{13}$$

Where y is the dependent variable (water demand), which represents the given value in the model; x is the frequency of use per day; b is the load volume of a device. This equation is applied to: (a) Washing Dishes by dishwashers; and (b) Washing Machine components. It should be taken into consideration that in the Car Washing component, the lower bound of median (four times a week) has been used rather than median value in one-member household size. This decision was made as it is not reasonable to wash a car every day.

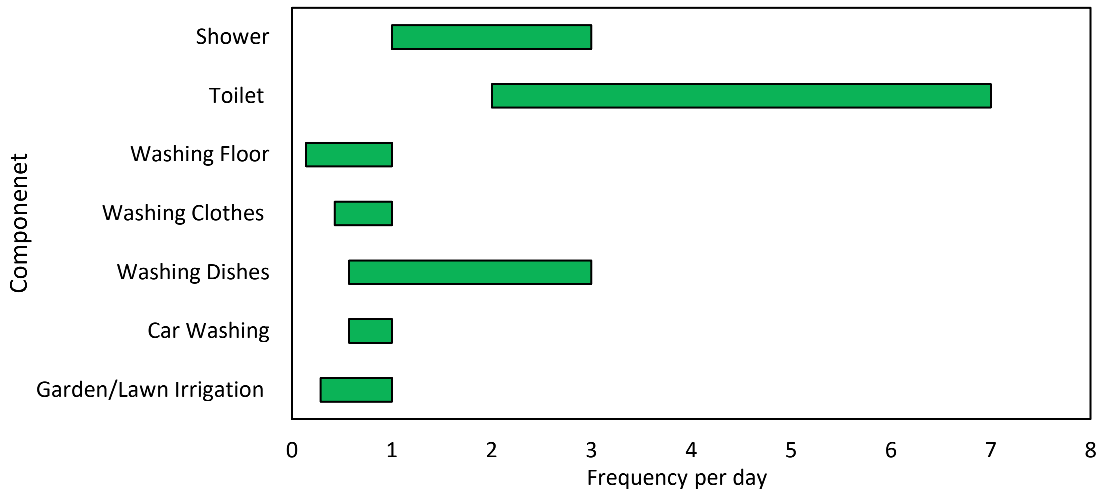

Figure 5.6: Range in frequency of daily use per household of each micro-component

This calibrated MC model has been used through the backcast modelling (chapters six and seven). The backcasting applies a diffusion of innovation approach to the micro-components to identify water conservation uptake and penetration rates needed to reduce demand to the target level by 2050.

5.4.1.4 Accuracy tests of the calibrated MC model

Different accuracy tests have been applied to gauge the uncertainty in the calibrated MC model. These tests comprise of; (a) MAPE; (b) MAD; (c) MSE; and (d) Nash-Sutcliffe Efficiency (NSE). The output of the tests has shown good results compared with the observed data. Table 5.9 shows the result of the accuracy tests.

Table 5.9: The accuracy tests of the calibrated MC model

Accuracy test	Output
MSE	0.92
MAD	0.78
MAPE	15.9%
NSE	0.85

5.5 Conclusion

The limitation of data was the main barrier to MC model development despite household demand dominating all other uses in Kuwait. So, due to insufficient data, several quantitative and qualitative assumptions have been applied, derived mainly from available literature of Kuwait micro-component consumption (section 5.3.1). These assumptions have been pulled together to fill the gaps in the MC's OVF elements which in turn has been applied to calibrate the MC model. It includes, for instance, MC components proportional redistribution to generate more appropriate distribution for certain population segments (the first and second derivatives from the base model). Another example is the application of the fractional equations to distribute the household appliance's ownership over the household population. The last process in the MC model development is the calibration process where two linear combination equations have been developed and applied, to produce a calibrated MC model.

Based on the MC calibration process, 408 MC tables have been generated and distributed over the base model and derivatives, then distributed by the household status. The first derivative has the bulk of the total MC tables (52.9%), whilst the base model and second derivative have (23.5% for each) of total tables. Due to constraints in the model, which are represented in; (i) the upper/lower bounds of appliance's flowrate/load capacity; (ii) the upper/lower bounds of the frequency of use; and the given value of an end-use component's consumption, values beyond the observed upper bound have been used in an exceptional case. This was where the maximum number of toilet visits is seven a day in the observed data, but this had to be increased to 13 visits a day for household size one in the villas/Kuwaitis/base model. Despite this, the consumption in the toilet component (9.63%) is lower than, for example, the UK (30%) (Bello-Dambatta *et al.*, 2014). Furthermore, the total consumption in this category is 2,984 l/d which is considered agree well with empirical evidence of Mukhopadhy *et al.* (2001), who show that per capita consumption is over 2,800 l/d in Kuwaiti household sizes of four members and less in villa dwellings. Although a (very) few outliers existed, the calibrated MC model has shown good performance against the observed data (e.g., note the NSE accuracy-test is 0.85).

Chapter 6 Backcast modelling: Structure development

6.1 Introduction

The MC model has been developed by applying several qualitative and quantitative procedures needed due to inadequate datasets available at the MC level for the case study. The developed model comprises the base model, and the first and second derivatives of the base model. These derivatives have been generated due to socioeconomic and sociodemographic disparities between Kuwaiti and non-Kuwaiti households (see section 5.3.2). The MC model has essentially been developed from a combination of Ownership, Volume, and Frequency, known as the OVF elements. The volume and frequency elements have been developed in the model through the application of the linear combination equations (section 5.4.1.3), whilst the ownership element has been developed using the fractional equations (section 5.4.1.1). The output of the developed model has been tested against the observed datasets and have shown a good fit model (Table 5.9). The MC model can now be applied in backcast modelling where the model diverts from a static to a dynamic status using the Water Efficiency Calculator (WEC), so that the backcast MC-WEC model is developed.

This chapter defines backcast targets and set outs the model structure of the backcast conservation intervention measures to the household water demand. The defined backcast targets (section 6.2.1) have been achieved through backcast MC-WEC modelling (chapter seven), whereby technology intervention dominates the entire process (i.e., every backcast scenario has technology inputs, but not all other possible interventions - see section 6.5.1). The technology intervention has been introduced through implementing the Diffusion of Innovation (DOI) approach, where new technology (efficient water-saving devices) passes through different stages in terms of market penetration (section 6.3.1). In addition to technology, other measures have been implemented in the backcast MC-WEC modelling; (i) public education effect, and (ii) economic measure effect presented in water price signalling. A variety of intervention intensity degrees have been used in the model with the consideration of a conservation measure's introductory time with different measures (mixing). So, the three factors (intensity, timing, mixing) have played a significant role in developing backcast intervention packages that aim to achieve backcast targets. Based on targets reached by applying different conservation intervention packages, several scenarios have been established to transition Kuwait towards sustainability and efficiency (chapter seven).

The chapter starts with backcasting, where the definition and the approach have been discussed. This is followed by setting out the backcast targets and a discussion of how these targets have been obtained. Afterwards, a presentation of the backcast MC intervention measures which contain an exploration of; (i) the DOI approach and how is it utilised in the MC model; (ii) the education effects with the deployment of some applications illustrating the implementation mechanisms; and (iii) water pricing, where water demand price elasticity has been reviewed and discussed to show how water pricing through tariff structure is an effective way to reduce water consumption. Eventually, the development of the backcast intervention structure and intervention packages, where different parameters adopted in each intervention measure (e.g., demand price elasticities) have been used to achieve backcast targets.

6.2 Backcast targets 2050 of the household demand

This study employs the scenario analysis approach using the backcasting or so-called "soft path" approach. Backcasting is a normative approach that begins by establishing a particular desired future endpoint and then examines measures that could be used to reach that point (Dreborg, 1996). In this way, it enables the identification of pathways to transition from the current state to the desired state. Backcasting is the opposite of forecasting, which the later looks forward from the present to the future in a prospective manner. Forecasting relies on the representation of expected processes and anticipated changes to the system, it is used to make a projection about a given future state and is intended to discover what is expected to happen but is often unable to identify potential solutions where radical changes and breaking of trends is required (Kok *et al.*, 2011). In contrast, by working back from the desired goal, backcasting is better suited to exploration and discussion of more adventurous and radical actions needed to resolve a problem, but which are usually neglected in conventional forecasting.

In this study, backcast targets have been established (section 6.2.1) to represent a more desirable water demand for Kuwait in 2050 (target year), where the MC water demand model has been utilised to explore water conservation measures that could reduce demand to the desired levels by 2050. The MC model or so-called “end-use” model is a deterministic model that estimates demand in the household sector, accounting for the principal indoor (e.g., toilet flushing, showering) and outdoor (e.g., garden watering) water uses. The MC model allows an in-depth exploration of a wide range of interventions needed to reach the backcast targets. The MC model is used to examine the effect of (i) technology in reducing water demand and; (ii) public education (e.g., awareness campaigns) and economic (i.e., water pricing) in encouraging a consumer to alter behaviour to more efficient consumption practices, and through incentivising the public of the importance of upgrading traditional water appliances to more efficient ones. The adoption process of new WSDs is represented by market penetration (extent) and uptake (rate). Market penetration is a measure of how many customers use a WSD (e.g., low-flow showerhead) compared to the maximum uptake that is physically possible. Uptake rate is a function of the penetration rate and is the rate of customers' adoption of a WSD in a fixed period. So, the uptake rate is the adoption rate of a WSD by customers per year, whilst the penetration rate is the cumulative uptake measured to the backcast endpoint target. The backcast MC-WEC model has used the classic S-shaped (sigmoidal/Gompertz) diffusion of innovation curve to systematically explore WSDs uptake and penetration rates.

6.2.1 Setting backcasting targets

A key step in backcasting is to establish a desired future with reference to a future target(s). Various methods can be used to define a backcast target, including the Delphi technique, Q methodology, expert judgment, mathematical modelling, historical data calculation, model simulations, and literature survey (Zimmermann *et al.*, 2012). For example, the Delphi technique is based on questionnaires distributed to experts to seek views as a first stage then the range of responses are circulated in a second questionnaire that seeks to establish a consensus view. This technique can continue with further iteration until a final target is agreed (Hurmekoski *et al.*, 2018). The Delphi technique is able to represent a range of perspectives – for example, some might seek a target that is desirable in terms of achieving an objective sustainability goal (e.g., water demand reduction), whereas others may choose a target they consider is more pragmatic. Targets can be derived by choosing demand reduction goals (low, modest, and high) relative to the BAU scenario that represent increasing degrees of ambition. Here, the high demand reduction target is the more desired goal, whereas the modest target is the more pragmatic goal. An example of the expert judgment technique in backcast target setting relates to CO_2 emission reduction by 2030 in some OECD countries, where a target was defined as 80% CO_2 reduction from a base year, so as to meet a stringent environmental objective (Geurs and Van Wee, 2000; Biswas and Kirchherr, 2012).

Literature survey can also support definition of a backcast target, as for example, in Stockholm where a target for GHGs emissions in 2030, based on IPCC recommendations of an acceptable CO_2 level in the atmosphere were made (Robèrt and Jonsson, 2006). Targets may however be set more pragmatically, as often environmental capacities or sinks may be poorly quantified. Thus, a target set with reference to BAU case may be adopted. This was the case in Oliver, Canada (Brooks *et al.*, 2009) where a target of “no new water” was established and intended to keep demand within the existing rate. In the case of the GCC Water Strategy (Al-Zubari *et al.*, 2017), a target (250 l/capita/d) has already been established based on what is considered achievable in some GCC countries, although this remains well above PCC rates observed across Europe. Thus, there is no “correct” backcast target, but target setting should seek to go beyond BAU and consider more ambitious desirable futures. Defining backcast targets is flexible (e.g., it can be selected from national policies or literature on the same field) and multiple (i.e., many methods to obtain a target), but the most important outcome is to ensure targets are selected that encourage consideration of interventions that are likely to be ignored under a conventional forecasting approach.

Three backcast targets for Kuwait water demand were established; these have been developed with reference to literature surveying. Targets are:

(i) No new water “*Light* scenario” to be supplied above the 2018 baseline year (Brooks *et al.*, 2009). This is an ambitious target, particularly given expected growth, and if achieved, it would ensure water stress in Kuwait was not made worse. With this target, demand reduction would be circa 1% per annum (32% in total);

(ii) A much more aggressive target “*Optimistic* scenario”, 2% demand reduction per annum (64% in total), based on an established target for Qatar (Baalousha and Ouda, 2017), and;

(iii) A 1.5% demand reduction per annum (48% in total), as a moderate target “*Intermediate* scenario” between the aggressive (2%) and no new water (1%) targets.

6.3 Types of backcast interventions for household demand sector

Water demand conservation intervention measures are labelled into two main paths, price and non-price conservation strategies (Olmstead and Stavins, 2007; Asci *et al.*, 2015). The price strategy is represented in the pricing-based instruments such as the types of water tariff (e.g., block tariff scheme). The non-price strategy is all instruments that aim to reduce consumer’s consumption, diverging from pricing interventions, which consists of consumption awareness agenda, water restrictions, and the adoption of new technology (e.g., efficient appliances or retrofit existing appliances). These strategies are sometimes mixed to optimise the potential for demand reduction (EEA, 2017). Next, we describe the intervention measures applied in the backcasting modelling. These instruments are the adoption of the conservation technology, using the diffusion of innovation approach, the elasticity of water pricing, and the effectiveness of public education and awareness campaigns.

6.3.1 Diffusion of technology: Adoption of water saving devices

Diffusion Of Innovation (DOI) is expressed as “*a process in which an innovation is communicated through certain channels over time amongst members of a social system*” (Rogers 2010, p. 5). From this definition, it can be observed that diffusion has four main facets, the *innovation* itself, *communication channels*, *time*, and the *social system*. Each facet of the DOI has its conceptual framework and a degree of effectiveness that is interconnected to other facets in the innovation diffusion process.

Innovation

Innovation is defined as an idea, practice, or object perceived as new by an individual or other units[16] of adoption (Rogers, 2010). The newness of an idea (innovation) can vary amongst individuals, for instance, an innovation for the individual (A) is not new, but it is new for individual (B). This is because individual (A) has developed knowledge of the innovation, which ultimately determined adoption/rejection, whereas individual (B) has not yet developed his/her own knowledge and a decision over the innovation. The newness of an innovation doesn't only comprise knowledge development towards it but does expand to involve persuasion and implementing an adoption/rejection decision (García-Avilés, 2020). Rogers has referred to the innovation as it can be developed through a combination of “hard-component” and “soft-component”, or it can be developed separately by a single component, hard or soft component (Murray, 2009). For example, a personal computer has hard-component (hardware) and soft-component (software); other examples, such as political philosophy, government policy (e.g., no smoking in covered public properties ordinance), and religious ideas are considered soft innovations that are based on an idea diffused and adopted by the units of a social system (Sahin, 2006). Innovation is considered a problem-solving instrument for the potential adopter's perceived problem (e.g., seeking an efficient appliance to reduce consumption which will lead to, e.g., lower bills). Therefore, when a potential adopter (unit) knows about an innovation, he or she seeks further information to learn more about the innovation (worth adopting?) that can reduce the uncertainty about its consequences. For instance, developing knowledge of a new innovation that is recognised as a superior alternative (solving-problem) to the previous practice can lead eventually to replacing it (adopt decision). Thus, adoption or rejection of an innovation (innovation-decision process) is an *information-seeking* activity where an individual implements in order to reduce the uncertainty about the consequences and advantages and disadvantages in the innovation (Rogers, 2010).

Innovations vary in terms of the potential diffusion amongst potential adopters in a social system. Some innovations diffuse faster than others; for example, fast diffusion of smartphones compared with the diffusion of hybrid cars. It depends on a potential adopter's

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[16] The unit of adoption in a social system can be an individual, organisation, or informal group of individuals.

perceived knowledge of an innovation, and perception of its characteristics. These characteristics consist of five elements; (a) relative advantage; (b) compatibility; (c) complexity; (d) trialability; and (e) observability (Burkus, 2013). Relative advantage is the index to which an innovation is concerned as a better choice than the old perceived idea which it can superseded. Relative advantage of an innovation is measured as an economic benefit, or offers more psycho-social benefits (e.g., social prestige, convenience). Logically, the more the perceived relative advantage of an innovation, the more rapid the adoption rate. Compatibility constitutes the degree by which an innovation is coherent with the values, norms, past experience, and the needs of the potential adopters in a social system (Ferster, 2017). In contrast, incompatibility is when an innovation stands against a social system's values, norms, etc. Therefore, we can say an innovation is incompatible when it is inconsistent with a social system's values. The compatible innovations have a more rapid rate of adoption than the incompatible ones do, which requires preceded adoption of a new value system. Complexity is the degree of an innovation is perceived as difficult to use and understand while others not or less complex. The degree of complexity can mandate the speed of innovation's diffusion; therefore, comprehending innovation by adopters accelerates speed of adoption whereas complicated innovations diffuse more slowly. Trialability is the ability to try an innovation before the final decision of adoption or rejection. It has been noticed that those innovations with accessible trialability are able to be adopted more rapidly (Karahanna *et al.*, 1999). Observability is the degree to which an innovation's outputs are tangible by the potential adopters. The more visible outputs are to individuals, the more probability they are to adopt. It leads individuals to initiate discussion to exchange information over its worthiness; it is a peer-to-peer process (Cohen and Sundararajan, 2015). Accordingly, innovations that are perceived by adopters as having higher relative advantage, compatibility, trialability, observability, and have lower complexity will be adopted at a more rapid pace than other innovations.

Communication channels

Communication in the diffusion of innovation process has a unique state where the *communication channels* create and share information over a new idea (innovation). In Rogers (2010), communication is defined as a process by which participants (units of a social system) perceiving an innovation to reach a mutual understanding to decide whether to adopt the innovation. That is, reaching a mutual understanding implies that there should be convergence points in the exchanging information process between units of a social system. It is a two-way (i.e., active) procedure in the diffusion process where one individual (unit) seeks to transmit knowledge to another in order to accomplish certain effects (adoption or rejection of innovation). It is considered the core of the diffusion process in which messages are distributed through a process where one individual communicates a new idea to one or several others. The distribution of information amongst units is performed through the channels of communication which are recognised as the means by which information passes from one individual to another. These channels consist of mass media (e.g., radio, television, newspaper, etc.), interpersonal channel represented in an individual connection with one or more individuals, and interactive communication, performed by the internet. Interpersonal communication constitutes the most effective persuasion channel that incentivises units making a decision towards an innovation (Lundblad, 2003). That is because the relationship between the interpersonal channel (an individual who perceived innovation) is communicating with other units in the social system who share similar socioeconomic status, education, or other essential aspects. The entire communication process can be satisfied by four elements; first, an innovation; second, a social system unit (e.g., individual) who has the knowledge and/or experience of the innovation. Third, a social system unit who has not acquired a knowledge of innovation yet; and fourth, communication channel connecting two units. By satisfying these elements in a social system, an innovation can be diffused or refused by the members of the social system.

Time of innovation adoption

Time is deemed as a variable that gives strength to the diffusion of innovation approach. Time has three factors that are participating in the innovation adoption process, the first factor is the innovation-decision process, the second is the innovativeness, and the third is the rate of adoption (Rogers, 2010). The innovation-decision process is the process where an individual or other decision-making units passes different phases starting from the first knowledge of an innovation to configure an attitude on an innovation to eventually a decision of adoption/rejection. This factor has three major elements in order; (i) the perceived knowledge towards an innovation; (ii) persuasion to adopt or reject; (iii) and the implementation of a decision made. Exceptions may occur as a result of unusual conditions, for example, an individual may adopt an innovation without passing the persuasion phase, as a result of, for instance, the implementation of new legislation by the social system (e.g., a company, or a government). The second factor is the innovativeness of an adopter, which refers to the earliness or lateness of innovation's adoption by an adopter in a social system (Shim and Kotsiopulos, 1994). This factor classifies adopters under five categories; (a) innovators; (b) early adopters; (c) early majority, (d) late majority; and (e) laggards, see Figure 6.1.

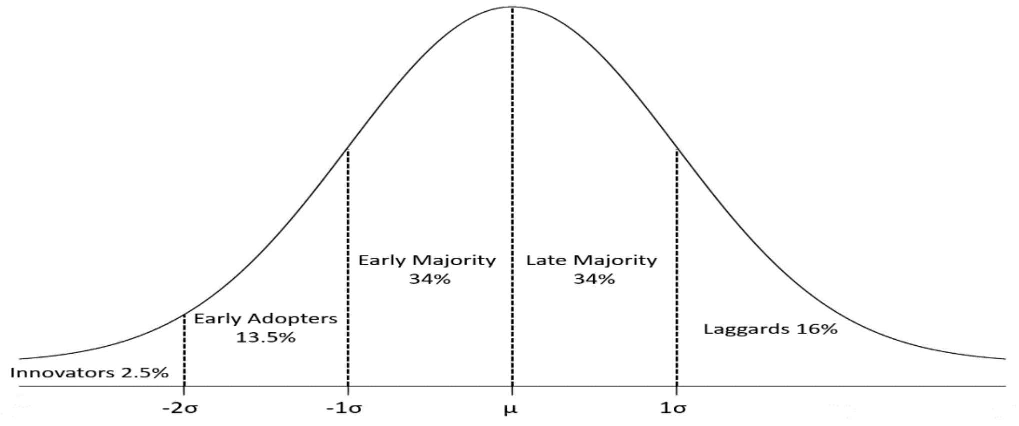

Figure 6.1: Types of innovation adopters
Source: Rogers (2002)

Innovators are the most active units in the social system seeking information about a new idea in which they are the earliest units to adopt an innovation. They tend to adopt an idea just because it is new, and because they accept risk more readily than others in the social system. They have high resilience in dealing with uncertainty about an innovation compared with other adoption categories. The second category is the early adopters where they tend to create opinions and have high degree in opinion leadership, which propel trends towards their side. They are not like innovators in how rapidly they take on a new idea, instead, they are more concerned about their reputation as being ahead of the curve. The third category is the early majority where any innovation enters this group of a social system, deviates to be widely adopted before long. The early majority have a unique location between early adopters and relatively late majority which gives them advantageous location in linking the diffusion process. When this group starts adopting an innovation, the rate of adoption takes off to reach the critical mass (self-sustained point) where the innovation become self-sustaining and will be diffused widely to reach other categories. The fourth category is the late majority where they share some attributes with the early majority, but they are more cautious before committing, needing more handholding as they adopt. The last category is the laggards, characterised by a slow adaption of new ideas, reluctance to change and who tend to adopt only when they are pressed to or because everyone else has already adopted the innovation.

The third factor is rate of adoption which refers to as the relative speed with which a social system unit adopts an innovation (Rogers, 2002). The rate of adoption starts at a modest increase (the first two adopter categories), shifts to a high-speed adoption rate when it reaches the critical mass (early majority). In this case, the behaviour of the rate of adoption changes from linear to exponential growth with accelerated speed until reaching the inflection point where the innovation has reached half of a social systems unit, see Figure 6.2. Then, the rate of adoption decreases to reach zero where the innovation has achieved the saturation point (laggard adoption). Here, the shape of adoption takes an S-shape curve where the adoption rate starts at a low speed (linear), then shifts to a high adoption speed (exponential), then returns to linearity as most of the units have adopted the innovation.

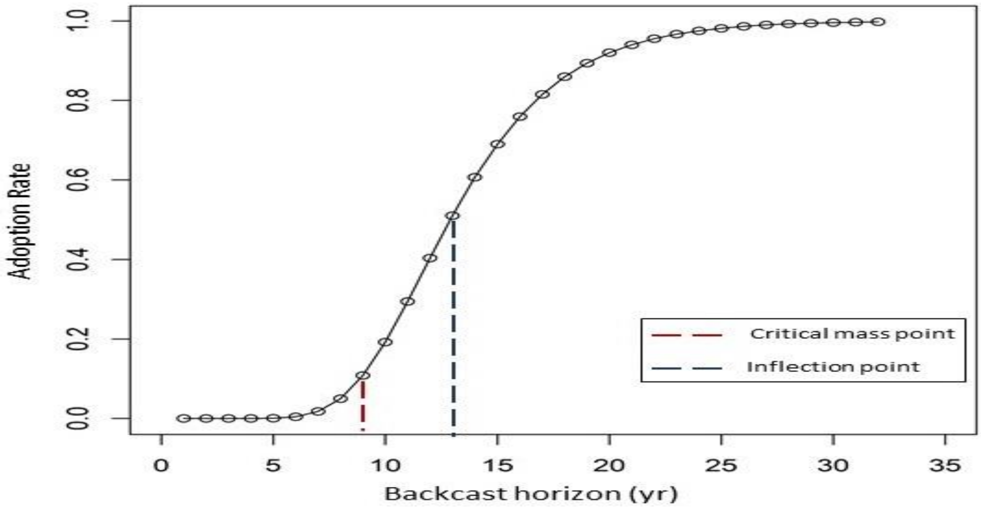

Figure 6.2: Diffusion of innovation curve

Social system

A social system is a group of interlinked units that are involved in joint problem solving to achieve a mutual target (Rogers, 2010). A social system may be particularised or generalised, for instance, targeting a social system of medical care employees (particularised) in a certain country or targeting all units in this country (generalised). The social system represents the boundaries within which the diffusion of innovation occurs, consequently, the social system has an influence on the way that an innovation is diffused. In this matter, the social system is a subject of how it affects innovations diffusion within its boundary that has three dimensions within it, which consist of; (i) the social structure, social norms; (ii) the role of opinion leaders (innovators and early adopters); (iii) types of innovation-decision. It is a causal relationship between an innovation and a social system that innovation occurs in it.

The social system's structure is referred to as the patterned arrangements of all units in a system. Since the units in a social system are not all identical in their behaviour individually, the social structure is a measure of the predominant collective behaviour tendency in any social system. The social structure gives individuals the regularity and stability to their behaviour in a system so that enabling to predict social behaviour with some degree of certainty and accuracy which in turn reduces the uncertainty in innovation diffusion. An example of a social structure is a bureaucratic organisation (e.g., a government institute) where all units in such a system have a hierarchical administrative system. The higher ranked positioned units give commands and orders to lower ranked positioned units, in this case, the relationship amongst units constitutes the social structure in a social system, where the social behaviour can be predicted within it. The nature of communication structure in the social structure in a social system can facilitate or impede the diffusion of innovation.

Another dimension of a social system are the norms, that to some degree directly affects the rate of adoption of innovation. Norms are defined as the developed behaviour pattern for the units of a social system. They are the guide which drives individuals to act and behave in a systematic way and lead to prediction of the behaviour of social units. Furthermore, opinion leadership is a dimension of the social system where the most innovative units in the social system (innovators and early adopters) take the risk to be the very first adopters for an innovation. Opinion leadership is the degree that the individual (opinion leader) is able to influence other individuals to configure or alert others attitude towards an innovation to a desired point in which they adopt or reject the innovation. Opinion leaders are positioned in the centre of the social structure communication, they tend to have active interpersonal communication networks; thus, their influence is crucial in the diffusion of innovation process.

The last dimension is the type of innovation-decision making, which plays a significant role in the diffusion of innovation. Innovation-decision making has two main types with which the diffusion of an innovation is stimulated, and which takes different diffusion patterns based on the type of decision. The first type of innovation is where an innovation-decision is made based on an individual basis, in the situation the adoption or rejection decision is optional, but it might be influenced by a social system's norms and the influence of the interpersonal and mass media channels. What distinguishes this is that the decision-making process mainly returns to the individual's desire instead of the social system. The second type is the collective or authority decision making where the decision is taken by a relatively small number of individuals who possess the power to implement resolutions. In this situation, individuals must implement the decisions made by the authority as they have little or no influence on the authority. In comparison, the speed of adoption rate of the collective and authority innovation-decision is higher than the optional individual innovation-decision.

Diffusion of innovation is a combination of social and economic methods that are simultaneously presented and executed. The diffusion of any innovation can go in several pathways as a response to the existing social and economic situation. It might be a governmental tool where; e.g., the government apply a policy to mandate the adoption of efficient water appliances. It might be as a result of the implementation of increasing the water tariff, in this matter, the customers seek to reduce the economic burden that results from water price change by adopting water efficient appliances. Adoption might be a result of the customer awareness of the cost of production that the government affords, the resultant pollution of the production operation, and/or awareness of how stressed the country is due to freshwater scarcity.

The detailed explanation of the DOI approach above delivers the understanding of how the backcasting MC model is developed and performed using the DOI approach. It showed how the adoption of efficient appliances is diffused amongst different population segments in Kuwait's household population. For example, higher-income households (household in villas) presumably respond to the mass media water conservation campaigns more than other segments as they are more exposed to mass media. Another example, increase water tariff may particularly incentivise the lower-income households (e.g., expatriates who live in traditional households) to reduce the extra costs resulting from the tariff change, and so forth. The employment of the DOI approach delivers a logical, robust, and systematic methodology that describes and interprets how the innovation is diffused. It shows how the impetus for change is started in the population of interest to reach the peak point in an in-depth deliberate manner.

6.3.1.1 Application of DOI: Household water sector

Liyanage and Vishwanathan (2020) have carried out an empirical study on the effect of water efficient appliances in reducing demand using the diffusion of innovation approach as a demarketing non-price strategy. The study addresses the pressing forces that affects freshwater availability and increases demand in Botswana, namely population growth, global warming, and expanding urban infrastructure. The adoption of water atomisation appliances technology has been used in this study, where the community of the Botho University in Botswana has been selected as a case study. The aim of the study is to uncover the effectiveness of the efficient water appliances on reducing demand without affecting consumption behaviour, with results scaled to cover all the population of Botswana. The study shows a demand reduction of 75% after two years from the diffusion of atomisation technology, and nationally demand could be reduced by 50% if this technology is diffused in Botswana over a ten-year time span.

Renwick and Archibald (1998) conducted an experimental study in California that revealed that installing low-flow toilets decreased consumption by 10%, showerheads by 8%, and efficient irrigation technologies up to 11%. Fielding *et al.* (2012) found that fitting low-flow toilets, efficient showerheads, and taps have reduced consumption to 12% in England and Wales. Beal *et al.* (2011) also found that replacing the traditional showerhead and tap with highly efficient ones would reduce water consumption by 75% and 65% yr^{-1}, respectively, compared to old appliances. In the UK, the diffusion of such efficient appliance has been achieved through introducing specific regulatory tool to promote and deliver incentives for water efficiency in new buildings and retrofitting programs for existing buildings. It has been estimated to reduce water demand by 30% to 50% (Inman and Jeffrey, 2006; DEFRA, 2008; Waterwise, 2017).

6.3.2 Economic: Water pricing and tariff structure

Water tariff is defined as a set of prices, charges, and taxes that are used to calculate customers water bills (Dinar *et al.*, 2015). It is an economic tool set out to pursuing different objectives, comprising financial, economic, and social objectives. This implies raising revenue and achieving cost recovery, maximising economic efficiency through incentivising conservation, and ensuring equity, fairness, affordability, and contributing to poverty alleviation (Meran *et al.*, 2021). Such multi-criteria highlight the complexity and difficulty of designing an effective tariff structure; this is the so-called “water pricing paradox”, for example, the paradox of raising revenue and delivering price affordability to customers, simultaneously (Grafton *et al.*, 2020).

Furthermore, there is a huge debate whether to keep water tariff low or raise it up to reflect the marginal cost value (Lam, 2015). Low tariff's proponents claim that; (i) keeping water pricing low would increase positive health externalities associated with piped water services which are paralleled with Pigouvian principles of taxing negative externalities and subsidising positive externalities; and (ii) piped water services are natural monopoly where marginal cost should be below the average cost (Berbel and Expósito, 2020). Whereas cost-reflective tariff's proponents claim that an effective tariff provides correct economic signals to water users about its relative value which in turn motivates wise consumption, raise sufficient revenue to, for example, maximise service quality, and invest in innovation programs. These contradictory arguments don't necessarily suit all water users and providers; rather, it depends on a country/region situation. For example, in Scotland, freshwater is abundant, and the cost of production and sanitation are relatively low, thus the opportunity cost is low (Hoque and Wichelns, 2013). While in Kuwait, freshwater is highly scarce and the cost production is relatively high, so the opportunity cost is consequently high. Therefore, it might be suitable to keep tariff low in the example of Scotland and raise it to cost-reflective value in the example of Kuwait where, for example, the opportunity and environmental costs are high. Hence, water tariff structure depends on the situation of the country/region, and to what is aimed to be achieved by policy and decision makers.

Water tariffs vary in design and type, and can include fixed and/or volumetric elements (see Table 6.1); one-part or two-part typed (Meran *et al.*, 2021). One-part tariff is distinguished by a single volumetric rate without a recurrent fixed rate or by a recurrent fixed rate without a volumetric price. A two-part tariff is characterised by a single volumetric rate, i.e., the price per volume of water consumed, plus a recurrent fixed rate, where the latter is independent of the consumption level, and usually paid monthly or yearly (Martins and Fortunato, 2007). The selection procedure of what tariff design and type are suitable depends on several factors, for example, the implementation of fixed tariff due to unmetered households (where volumetric tariffs are impossible to apply in this case), and selecting the two-part tariff to, for example, reduce revenue volatility (Hoque and Wichelns, (2013). Any revision to the water tariff associated with an increase in prices (no matter what goals intended to achieve) is almost always perceived as unfair and unjustified, thus a controversial topic (Whittington, 2003).

Traditional tariff designs have been discussed in the literature with an emphasis on their flaws and merits (Boland and Whittington, 2000; Arbués *et al.*, 2003; Fuente, 2019). The most controversial discussions went to the Increasing Block Tariff (IBT) structure, where its effectiveness has been debated. This is because it is employed in different countries, especially in developing countries (GWI, 2020). For instance, a debate on its social objectives; while IBT is designed to ensure that low-income households can obtain the water they needed at a low price (initial lifeline block), subsidies go to middle and upper-income households. For example, in many cities in developing countries, low-income households obtain water from a shared connection with shared meter. So, the water used can quickly exceed the volume of the initial block and moves to the highest-priced block. Whereas the middle and upper-income households get more benefit, as they tend to have private meters, hence lower consumption (Whittington *et al.*, 2015). In this case, the intent of IBT design has brought about counterproductive results and fall in the inclusion and exclusion errors[17], Dinar *et al.* (2015). Therefore, voices to adopt effective innovative tariff design have increased in academia, such as a tariff design based on per capita consumption (Liu *et al.*, 2003). In sum, water tariff structuring is about the effectiveness to meet the aimed objectives and positive responsiveness by customers to its design.

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[17] Inclusion error is to include rich households in subsides; exclusion error is to exclude poor households from subsides.

In Kuwait, the tariff design used is the volumetric uniform rate charge, sometimes named as the flat tariff. It was introduced at the beginning of the 1960s and has not changed since. Currently customers pay 0.58 US\$ per m^3, while production cost is estimated as 2 US\$ per m^3, delivery to end-user cost is 1 US\$ m^3, and aggregate cost is 3 US\$ m^3 (Al-Humoud and Jasem, 2008; Fadlelmawla, 2009). With revenue so far below production cost economic efficiency is very low. A change in tariff is needed to raise revenue and economic efficiency with considering other IWRM objectives (Table 2.1). Therefore, water pricing has been selected as an economic tool in the backcast MC-WEC modelling. Where the increase of water price has been used to reduce household demand to reach the backcast targets (structuring a tariff design is out of research scope; however, a design that meets IWRM principles is highly recommended to authorities). How price increase affects household water consumption has been measured by the degree of sensitivity and responsiveness of customers to price change obtained from literature in countries similar in the context of Kuwait.

Table 6.1: Water tariff design

Tariff design		**Description**
Volumetric	*Increasing Block Tariff (IBT)*	A unit charge for water increases as the volume rate rises with successively higher consumption blocks.
	Decreasing Block Tariff (DBT)	A unit charge for water decreases stepwise as the water volume rate increases to reach a successful lower consumption blocks.
	Constant Unit Tariff (CUT)/Uniform	A water unit charge is constant with all levels of consumption, where customers pay proportionally to their water consumption.
	Increasing Linear Tariff (ILT)	Unit charge increases linearly as water use increases; it has increasing block tariff with infinitely small blocks, which makes it hard to perceive by customers.
	Seasonal (peak)	Unit charge changes seasonally as a response to peak and off-peak seasons, it can be added to any other volumetric tariff.
Fixed	*Fixed/Flat*	A customer pays a monthly or annually fixed water bill, which is independent of the volume consumed.
	Minimum charge	A customer pays for a basic consumption allowance per month, allows a minimum amount of free consumption of water.

Source: Meran *et al.* (2021); Hoque and Wichelns (2013)

6.3.2.1 Price elasticity of demand

Customers' response to water tariff structure can be tested by the Price Elasticity of Demand (PED). PED defined as an econometric technique that measures the responsiveness of quantity demanded for a good or a service to a change in its price (Hyes and Drury, 2021). Price elasticity of water demand in the residential sector varies widely; however, there is a consensus of water price inelasticity to water demand in literature. The variation of elasticity is attributed to; first, estimation method used, whether linear regression (i.e., Ordinary Least Square (OLS), Two-Stage Linear Square (2SLS), and Three-stage Linear Square (3SLS)), or logarithmic regression (i.e., linear-log (Semi-Log), and log-log (Double-Log) models)). Second, type of dataset used, whether it cross-sectional, time-series, or panel data. Third, data disaggregation level, for example, temporal interval (daily, monthly, or yearly), and demographic, for example, aggregate-level or household-level (Espey *et al.*, 1997). Fourth, price specification whether using marginal or average price. To fix the difference between utilising average or marginal price, Nordin (1976) introduced the Difference (D) price to modelling price elasticity of demand where measures the difference between the marginal and average price. Also, Shin (1985) has introduced a price-perception parameter (Shin price) to measure whether the customer response to average or marginal price. Fifth, run period, long-run period tends to be more elastic than short-run. Sixth is the explanatory variables added to the model (e.g., household size, climate, and income that affect the price elasticity of demand (Sebri, 2014)). Seventh, the size of sample being modelled, smaller samples tend to vary in result (some extreme elastic or inelastic values), whereas larger samples tend to have convergent elasticity values (Marzano *et al.*, 2018).

Irrespective of the relatively inelastic behaviour of water demand, pricing remains a viable measure to include in water demand management strategies (Worthington and Hoffman, 2008). The inelasticity of water demand pricing is mainly due to the substitution effect (Hoyos and Artabe, 2017), whereby there are no ready substitutes for the water delivering the service demanded. Although water demand price elasticity tends to be price inelastic worldwide (Dhungel and Fiedler, 2014), this does not imply non-responsiveness; rather, it indicates responsiveness but simply at a lower rate than the increase of water given its importance. From parameters (stated above) that affect the price elasticity of water demand, the income level of a household is a crucial determinant for water demand, thus affecting the price elasticity of demand. The effect of income on water quantity demanded is gauged by the Income Elasticity of Demand (IED)[18] metric (Hayes, 2021). There is a positive relationship between income and water demand (Reynaud, 2015) in which an increase in a household's income would increase water quantity demanded as water is considered to be a normal economic good (but is this not always the case; see (Ščasný and Smutná, 2021) for more details). The income elasticity of demand tends to be lower than the proportional increase in income; for instance, if an IED is (0.26), this indicates that an increase of 100% in income would increase water demand by 26%. Income elasticity of demand as a variable that affects the demand on water, thus the price elasticity of demand, is also can be affected by different variables; for instance, the temporal dynamics (i.e., short and long run). In short-run the IED tends to be more elastic than in long-run, see (Havranek *et al.*, 2018) for further details. Price elasticity of water demand is also affected by consumer's responsiveness to average and marginal prices. Several studies found that consumers are more likely to react to average price than marginal price as consumers are more aware of average price; for example (Nieswiadomy and Molina, 1991; McRae and Meeks, 2016). Regardless of the contentious nature of price elasticity of water demand where several variables are responsible for consumer responsiveness to water price change, there is consensus that price elasticity is inelastic and water pricing is a critical conservation measure in water demand management policies (Olmstead and Stavins, 2009).

Literature in residential price elasticity of demand is sparse for Kuwait, the GCC, and even in the broader classification, for developing countries. In developed (industrialised) countries the literature is extensive (Nauges and Whittington, 2010). Table 6.2 shows valuable studies of the residential water price elasticity and the considerable studies in Kuwait and GCC. Relying on elasticity studies in Kuwait and GCC would increase the uncertainties in the backcast MC-WEC model (because the studies made are limited in quantity). Therefore, meta-analysis studies and a review of elasticities in developing countries have been used to lessen the uncertainty. How these elasticities are used in the modelling procedure is detailed later (section 6.4.2).

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[18] Income elasticity of demand is describing the sensitivity to changes in consumer income relative to the amount of a good that consumers demand.

Table 6.2: Price elasticity of residential water demand from literature in the GCC and regional valuable studies

Study	Region/country	Econometric model/techniques	Price specification	Price elasticity	Study summary/description
Al-Qunaibet and Johnston (1985)	Kuwait	OLS, Semi-Log, Double-Log Exponential, and Stone-Geary	Average and marginal price	Elasticities ranging between -0.77 to -0.97, an average of -0.88	The study drew on empirical studies from different arid regions to fit to Kuwait. The elasticities obtained pertain to the residential sector.
Milutinovic (2006)	Kuwait	OLS, Double-Log, and Stone-Geary	Average, marginal, and difference price	An average of -0.36 and a median of -0.33	Five models have been adopted from KSA, California (USA), Australia, Spain, and Tunis to fit to Kuwait.
Rizaiza (1991)	KSA	Double-Log	Average price	An average of -0.36	The study has been conducted in four major cities, Jeddah, Makkah, Madinah, and Taif. The parameters used are; (i) income; (ii) household size; (iii) temperature; and (iv) garden possession.
Al-Noaimi (2004)	Bahrain	Semi-Log	Average price	-0.07	The study comprised variables, income elasticity, household size, household characteristics, and temperature.
Srouji (2017)	Abu Dhabi, UAE	OLS	Marginal price	Elasticities range between -0.12 to -0.42, an average of -0.23 (nationals), and -0.33 (non-nationals)	A sample of 45,500 households was addressed. The parameters used are; (i) household status (national or non-national); (ii) household income; and (iii) household type (villa or flat).

Study	**Region/country**	**Econometric model/techniques**	**Price specification**	**Price elasticity**	**Study summary/description**
Espey *et al.* (1997)	USA	OLS, Semi-Log, and Box-Cox	Average, Marginal, Nordin (difference) price, and Shin price	Average of -0.51, and 90% of output ranged between 0 to -0.75	A meta-regression modelling of 24 journal articles published 1967 to 1993 using meta-analysis method.
Dalhuisen *et al.* (2003)	USA and Europe	OSL, Semi-Log, and Box-Cox	Average, Marginal, Nordin price, and Shin price	Average of -0.38	An extension of Espey *et al.* (1997), Modelling 51 studies published between 1963 to 2001.
Sebri (2014)	Several countries worldwide	WLS	Average, Marginal, and Shin price	Average of -0.36, and median of -0.29	Meta-regression modelling of 100 studies published between 2002 and 2012 using meta-analysis method.
Marzano *et al.* (2018)	Several countries worldwide	WLS	Average, Marginal, and Shin price	Average of -0.40, and median of -0.34	A meta-regression modelling of 124 studies published between 1964 and 2013 using meta-analysis method.
Nauges and Whittington (2010)	Developing Countries, e.g., KSA	A review of the econometric techniques in the original studies, e.g., OLS, 2SLS, and 3SLS	A review of the price specification in the original studies, i.e., average and marginal price	Most estimates are in the range from -0.3 to -0.6	A review of 19 studies from developing countries on modelling strategies used and issues related to data collection. A key finding is that elasticities are close to what is usually reported for developed (industrialized) countries.

6.3.3 Education: Public awareness and voluntary actions

Public education is an intervention measure often employed to educate a consumer to use water wisely, voluntarily (Nieswiadomy, 1992). Public education is used to alter a consumer's behaviour through a range of means (e.g., through TV advertising, posts sent with water bills to instruct customers on how to save water, awareness campaigns, and water bill rebate programs (Syme *et al.*, 2000)). Public education is usually used in short-term water demand strategies; e.g., when a drought heatwave strikes a region/country, thus a need for an immediate collective action to be in place to decrease water consumption (March *et al.*, 2013; Matikinca *et al.*, 2020). It can be a complement and/or adjunct to a long-term water demand management policy to maximise the effect of demand interventions (e.g., water pricing, marketing to WSDs, and water restrictions (Syme *et al.*, 2000; Fielding *et al.*, 2013)). Accordingly, in this case, public education is a long-term measure applied in parallel with different measures to promote the effectiveness of a policy adopted. A long-term public education approach involving behavioural change can be critical to shifting the way the public thinks about water use; e.g., perception of participation in demand conservation programs can lead to sustaining the environment, reducing life cycle cost, and reducing ecological footprint (Geller, 2002).

In this endeavour, a number of environmental psychology theories have emerged in an attempt to understand and explain why human behaviours change and how changes in behaviour can be driven to a particular condition. For instance, a person's consciousness of the environmental issues translated to adopt a behaviour change to help sustain the environment. Several studies in household water demand management have conducted these theories to understand personal and community behaviour; hence, a draw of effective interactive water conservation policies. The Theory of Planned Behaviour (TPB) is the most frequent theory applied in water demand literature to test the consumers' behaviour (Schifter and Ajzen, 1985). It is an extension of the Theory of Reasoned Action (TRA) developed by (Azjen, 1980). The TPB theory is constructed upon three beliefs; (i) behavioural “attitude”; (ii) normative “subjective norm”; and (iii) control “perceived behavioural control” (Hurlimann *et al.*, 2009). These beliefs can then translate to intention to behaviour change; however, intentions don't always translate to actual behaviour (Barr, 2006; Jensen, 2008; Dolnicar and

Hurlimann, 2010). The TPB can be incorporated with the Rational-Economic Choice Theory (RECT) to push behaviour to change more increasingly (Hassell and Cary, 2007); environmental and economic drivers. RECT states that to change conservation-based decisions, a customer needs only information relating to financial and performance benefits of choices to enable act accordingly. For instance, a decision to purchase efficient appliances to reduce water bill with same consumer behaviour (e.g., frequency and duration of consumption); or a change in consumer behaviour (e.g., less frequency and duration) to reduce water bill; or a combination of them concurrently to maximise benefits. In the first instance, the behaviour adopted is known as “efficiency behaviour”, referred to as purchase-related behaviour. The second instance is “curtailment behaviour”, which is referred to as maintenance-related behaviour (Gardner and Stern, 1996).

Application of environmental psychology theories to household water conservation programs has revealed that understanding the effect on water behaviour of education programs is a complex and challenging task. This is because of the interaction between education and other drivers, and due to customers' socioeconomic and sociodemographic variations (Medd and Shove, 2007; Browne *et al.*, 2013; Parker and Wilby, 2013); thus, it is hard to test and to quantify effects, i.e., the proportion of demand reduction that can be achieved through education. Nevertheless, some literature has quantified education's effect in water conservation programs (see Table 6.4); however, it is limited. Unfortunately, no study has yet gauged the effect of education in Kuwait and only one study exists for the GCC (Al-Zubari, 2014) although the impact of the education effect draws on findings from a study outside the GCC. Based on this situation, public education effect literature from other countries has been used in the backcast MC-WEC model (see section 6.4.3)

6.4 The development of backcast intervention measures

This section presents and justifies the parameters that have been used in the model. It shows how these parameters have been obtained, organised, and utilised. Starting with the adoption of innovative water appliances, then to the adoption of price elasticity and its implementation in the model, and finally presents representation of the education effect.

6.4.1 Efficient and high-efficient water appliances: Technology intervention performance

Technology has been employed in several demand management policies due to its effectiveness in reducing water consumption to substantial levels (Stavenhagen *et al.*, 2018). Studies have shown the potential for demand reduction of 30 to 40 percent in the residential sector; for example (Roccaro *et al.*, 2011), and others up to 50%; for example (Liyanage and Vishwanathan, 2020). As a result, the technology has been selected as a priority instrument to reduce household demand, and one that avoids pricing intervention which sometimes is problematic due to restrictions (e.g., radical price tariff could bring about a political dilemma (see section 8.2), it is not an acceptable measure amongst the public) (Grafton *et al.*, 2020). However, technology can also be used in conjunction with water pricing schemes where it alleviates the possibilities of applying extreme water tariff and/or can be added to water tariff to a achieve an optimistic and radical demand reduction.

In our backcast MC-WEC modelling, the uptake of efficient/high-efficient technology to the household population has been addressed using a Gompertz (sigmoid) function (Waliszewski and Konarski, 2005) wherein it aligns with the diffusion of innovation approach. The sigmoid function consists of three parameters, adoption rate, penetration rate, and time (backcasting horizon). Adoption rate is the households' uptake rate for a given technology in a given year in the backcasting horizon. The penetration rate is the accumulated adoption rates for a given technology to the target backcasting year (2050), which represents the saturation point of adoption. Adoption rate can be expressed as;

$$k = \frac{n_t}{N_t} * 100 \tag{14}$$

Where k denotes to the adoption rate; n denotes to the household population adopting a given technology (e.g., low flow toilet) for a given year t, N refers to the total household population for a given year in the backcast horizon t. Whereas penetration rate can be expressed as;

$$p = \sum_{t=0}^{31} tk \tag{15}$$

Where p denotes to the penetration rate, t is a given year (e.g., 2030) in the backcast horizon, where the backcasting period starts at 0 = 2019 and ends up by 31 = 2050; and k is the adoption rate.

It should be noted that distinguishing between efficient and high-efficient technologies (i.e., how much water an appliance uses per minute/cycle?) in the backcast MC-WEC modelling is based on a normalisation calculation. This means the innovative technologies used in a particular household end-use component have been summed up collectively, and the values of average and standard deviation calculated. Then, the manipulation of flowrate/volume values have been performed in a systematic manner, in which the values from average and above (e.g., 1σ) have been treated as efficient appliances, in the opposite, the values lower than average (e.g., -1σ) have been treated as high-efficient appliances. It can be manipulated easily and systematically, for example, applying a standard deviation lower than the average (high-efficient) to see the effect on demand reduction, and so forth. It implies that a given technological design for an efficient appliance is quite less important compared with the flowrate/volume that it produces per use. For instance, a low-flow single flush toilet or a low-flow dual flush toilet, here, the design of toilet is not as significant as water volume per flush since the volume per flush is the key point in the backcasting modelling. The type or the design of toilet is referred to customers' preferences, desires, circumstances, and needs. In this sense, different designs of technologies will be introduced to Kuwait's marketplace but with specified water volume per flush, efficient ones.

Data on innovative water saving appliances (i.e., litre per minute/load per cycle) has been collated from manufacturers that Kuwait imports appliances from (e.g., USA and UK; see section 5.3.2.3). A number of different technologies with different volumes (flowrate per minute/load per cycle) for each component have been collated; then, the normalisation calculation has been applied. Table 6.3 shows the number of plots for each appliance, maximum and minimum values, standard deviations, and as average values. Figure 6.3 shows the graphical normal distribution for each component applied in the backcast MC-WEC model.

Table 6.3: The volume of the innovative technology for each end-use component

Appliance	Litre per minute/load per cycle				Number of plots
	Maximum	Minimum	Average	Standard deviation	
Shower	9.5	3	6.2	1.87	23
Toilet	6	3	4.5	0.86	19
Washing Machine	86.1	26.4	57.4	15.32	27
Dishwasher	19	6	12	2.51	28
Tap	8.3	1.9	5.6	2.21	18
Hosepipe Nozzle	7.5	5.3	6.4	1.1	13

Source: plumbing manufacturers, comprising; Plumworld, EnergySaver, LG, BobVila, Neoperl, Nebia, Samsung, Victorian Plumbing, Niagara, Sterling, Delta, Mira, Bosch, Whirlpool, SaveWater, Nisbets, Pfister, Tapstore, Washrooms, and Aqualisa; and environmental and water agencies, comprising; Waterwise, WaterSense, EPA, WaterSafe, UKWIR, and Ofwat.

6.4.1.1 Innovative appliances: Indoor components

Shower

As a result of lifestyle and habits changes, showering has been used more frequently by the households' members (Butler and Memon, 2005). For instance, it has been reported that water consumed in showering has steady increased to reach 45% in a number of UK households (Bello-Dambatta *et al.*, 2014). In Kuwait's households, showering contributes to 60% of the total household consumption; the high share of demand is related to; (i) high temperature in summer and dusty winds throughout the year; (ii) low tariff; (ii) and changing lifestyle, where people tend to take care of their hygiene more than ever.

Water use in showering is dependent on several factors, consisting of water pressure, water flowrate (see section 5.3.2.3), water flow style (e.g., spray, atomised), and heating mechanism. These factors come collectively to shape the amount of water consumed (litre per minute) in the shower component. The heating mechanism is defined by the plumbing system fixed in a household, whether it is a high-pressure, combi, unvented system or a low-pressure gravity-fed system (section 5.3.2.3). The type of the plumbing system defines what a shower type is suitable to be installed; for instance, a power shower is not fixable for combi systems (Chard, 2020). Conversely, water flow style can define the volume (flowrate) of water consumed in the showering component; for example, laminar streamline pattern consumes more water than the atomised (aerated) streamline pattern (Danco, 2016). The flowing style of water is defined by showerhead nozzle outlets. Those two factors, the shower type and the flow style has been discussed in the context to emerge the understanding of how these factors differentiated in terms of water consumption and how it has been utilised and developed to reduce water volume.

There are four types of showering available in the marketplace, comprising mixer showers, power showers, digital showers, and electric showers. Mixer shower blend hot and cold water (e.g., cold tank and boiler) by using a tempering valve, and this type of shower can be fixed in high/low pressure systems (Aqualisa, 2019). Mixer showers come with versatile faucet options, for example, single lever mixer, sequential mixer, and dual control mixer. Power showers use the same mechanism as mixer shower plus adding a pump (usually, electric pump) to boost flowrate which in turn delivers an invigorating shower, it is only compatible with the low-pressure system. As well, digital showers use the same functionality of the mixer shower but with the application of the latest technology that assists to improve the shower experience. Digital showers use a built-in thermostat to control water temperature and flowrate precisely and remotely (e.g., controlled by using a smartphone), and it is applicable to any plumbing system. Conversely, an electric shower does not mix hot and cold water but heats water by passing it through an electric-heating unit instantaneously as required. These showers are available in a range of kilowatt ratings; the higher the kilowatts the more powerful it will be, and water flow will increase accordingly. In general, power showers are considered a wasteful shower type since it uses a pump to boost flowrate. Conversely, electric showers are a water-saving type as water flow falls as it is getting more heat. However, water flow can be regulated to specific rate range with any shower type in any plumbing system. This can be achieved by innovative shower gadgets including low-flow showerhead, water flow restrictor and regulator (Critchley and Phipps, 2007).

The showerhead (nozzle outlet) alters flow patterns depending on the nozzle's shape, size, and water flowrate (Okamoto *et al.*, 2015). Showerhead design has improved in recent decades so that the flowrate per minute has been reduced without affecting showering performance; in addition, different types of showers' streamline patterns have been enhanced in which several showerheads have been introduced to the marketplace (Nolan, 2021). In design, there are two types of showerheads, fixed (rain shower) and handheld showerheads, the first type is plumbed in permanently and it can't be moved around, the second is attached to a hosepipe allowing removable from its wall bracket or ceiling. These can be available collectively (dual showerhead) or separately (single showerhead). Dual showerhead delivers more flexibility in having a shower in which provides a range of streamline settings, for example, rainfall shower (drenching full body spray) or using the handheld shower to bath pets, washing children, or targeting a specific side of a body. Innovative showerheads have been designed to enhance the shower experience, and more importantly to save water to a particular limits to which a consumer can conserve water, save water bill, save energy, and eco-friendly.

Innovative low-flow showerheads are categorised under two categories: (i) aerated spray streamline; and (ii) laminar spray streamline (Stickly, 2021). Aerated spray showerhead is aerated showerheads that blend air with water to atomise droplets of water forming a misty spray that provides the appearance and feeling of more water than there is (Phipps *et al.*, 2009). Aerated nozzle showerhead is considered an ultra-low flow shower that is highly efficient, which can produce an effective shower with approximately three litres per minute. For instance, the innovative Nebia aerated showerhead creates millions of tiny droplets using different nozzle geometries (micro nozzles), resulting in more efficient water use and better performance (Bouchot and Delatour, 2016). Furthermore, this kind of showerheads have a wider surface area coverage than the standard ones, optimising efficiency (Mecc, 2018). Laminar-flow showerheads are the showerhead that produces individual streams of water (Gray, 2021). A laminar-flow showerhead is a better choice in a humid climate because it will not produce as much steam and moisture as an aerating showerhead.

A shower flow regulator or so-called Pressure Reducing Valve (PRV) is an alternative conservation method used in a shower, which restricts the amount of water passing through the outlet (Ryan, 2019). Some regulator valves have built-in shut-off valves, in which a shut-off lever can manipulate water flow to the desired point. These plumbing retrofits are usually installed in old and inefficient high-pressure showers; it is an efficient alternative to enable a customer who does not aim to replace the existing shower, rather, installing a regulating device. On average, flow regulators can provide a flowrate of 6 litres per minute for high pressure showers. Accordingly, the shower component in the backcast MC-WEC model has ranged between 3 (minimum) to 9.5 (maximum) litres per minute and an average of 6.2 litre per minute. Values less than 6.2 are considered a high-efficient shower, whilst values of 6.2 and above are efficient shower. Figure 6.3 shows the normalised values of innovative shower plus the other innovative appliances that have been used in the model.

Toilet

Toilets have been the primary consuming component in households for several countries (e.g., UK and USA), reaching 30% of a household's consumption (Bello-Dambatta *et al.*, 2014). Therefore, innovative technologies have rapidly been developed, where various toilet technologies have been introduced with very low-flow flush volume without trading off the flushing pattern's performance, even delivering a superior performance (Anand and Apul, 2011). This is a consequence of the target of reducing toilet volume per flush by several plumbing manufacturers. It has been stated by the WaterSense agency – USA, a household with state of innovative art technology can get a water reduction up to 60% of toilet flushing volume compared with inefficient toilets. This is equivalent to a water-saving of 50 cubic metres a year, saving 140 US$ yr^{-1} in water cost and 2,900 US$ over a toilet's lifespan (EPA, 2014).

Different efficient technologies are introduced to the marketplace, allowing customers to choose their preferences (Feng, 2020). These technologies comprise of the toilet types (tank or tankless toilets), types of flushing (e.g., single or dual flush), and the trapway design, whether a siphonic or washdown trapway. The innovative advancement has provided these technologies with a variety of low-flow and ultra-low-flow flushing volumes paralleled with good flushing performance. The research scope is out of investigating the technology design and mechanism; what needed is the volume of each flush. How much water these technologies can save compared with the inefficient and traditional toilets, and the consequences of the water-saving, in term of economic and environmental implications. However, it is better to deliver a brief definition and description of these technology types to gain a better vision and understanding of their functionality.

Types of toilets are divided into two main categories, tank and tankless technologies. A tank toilet is a toilet that has a cistern tank that sits above the toilet's bowl to store and allow water flushes down to the bowl (Woodford, 2021). Conversely, a tankless toilet is a toilet that doesn't need a tank to store water; rather, it’s directly joined to the household plumbing system and flushes water from the plumbing pipes or an electric pump (Parker, 2021). There are different types of tank toilets comprising gravity-fed, vacuum assist, and pressure assist, whilst tankless toilets comprising a flushometer toilet uses a flushometer valve to operate (Johnson *et al.*, 2013). Furthermore, toilets can be differentiated from the trapway design; there are two types of trapway, the siphonic and washdown trapways. The siphonic toilet is the siphonic action to force water discharging from the bowl in which creates a siphon in the bowl's trapway. The siphonic action helps pull waste from the bowl into the household drain (Koeller and Gauley, 2013). In contrast, the washdown toilet a process when water flushes from the tank into the bowl and pushes the waste down to out of the trapway (Hu *et al.*, 2014). In comparison, the siphonic toilet, water is pulled to trapway, whilst the washdown toilet water is discharged by pushing water from the bowl to the trapway; the siphonic trapway is narrow, whereas the washdown trapway is wide (ibid). Toilets can be differentiated by the flushing type, there is a handle (lever) valve flush or button flush (single and dual flush). On the other hand, there is also toilet technology that is a water-free – the composting toilet or dry toilet (Anand and Apul, 2014). This type of toilets has been rejected to be an innovative technology used in backcasting modelling for two reasons; the first, it is not wildly acceptable amongst customers; the second reason is that the cultural background of Kuwait's population refuses these kind of technologies.

Each type and design of any toilet is dependent on different amount of water to flush; however, these toilets do not exceed the volume of being efficient or highly efficient toilet. Manufacturers in the last three decades have developed the industry of toilets as a response to economic and environment raising issues (e.g., increasing CO_2, and water tariff changes (Lee *et al.*, 2011)). As well, it is a response to new implemented regulations, for instance, USA federal law in 1992, which indicates the flushing volume of a toilet should not be more than 6 litres per flush (EPA, 2002). Recent innovative toilets flushes vary depending on the type of a toilet, for example, low-flow gravity-fed toilet can flushes 6 litres per flush and a bit lower, whilst an ultra-low-flow toilet such as pressure assist toilet (power flush toilet) can uses 3 litres per flush.

Thus, in the backcast MC-WEC modelling it has been assumed that new innovative toilets are varies between 3 to 6 litres per flush, and assuming 4.5 litres per flush (average) is the threshold of being efficient or high-efficient toilet performance. It means, the toilet uses

4.5 to 6 litres per flush is an efficient toilet, whereas toilets use less than 4.5 litres per flush is a high-efficient toilet.

Washing Machine

Washing machines have developed significantly in the last three decades, not only in water efficiency but also in performance and energy efficiency (Boyano *et al.*, 2020). The new and innovative washing machine can wash garments with much less water than conventional washers, reaching about 80% less water (Söderström, 2020). There are different washing machine designs, encompassing washer-dryer (combo washing machine), stackable, and unitised washing machines (Wilde, 2019). Also, it comes with different types, including front load washer or top load washer; as with different mechanisms and systems, namely, agitator or impeller mechanisms and vent or condenser (ventless) systems (ibid). Furthermore, washing machines manufactured with a variety of load/drum capacity sizes, starting from five kilograms (small machine) up to twelve kilograms per load (extra-large machine). Different kinds of washing machines have resulted in using different amounts of water to operate; however, manufacturers have developed these machines for better performance than old models. For comparison, the top load washer consumes more water than the front load water, as well, agitator machine consumes more water than the impeller one (Carey, 2021). Top loading washers wash garments by having them float around in water while front loader wash garments by picking them up and dropping them into the wash water repeatedly; therefore, top loaders consume more water. Agitator washers' clean stains by spinning and rubbing against the garments to loosen stains. In contrast, impellers spin well, but in different mechanism since they are centred at the bottom of the drum, they work by causing articles of clothing to rub against each other, not against the device (Palermo, 2021). Impeller washers have larger capacity, faster spinning, gentle wash, and more efficient in terms of water consumption, oppositely, agitator washers have less capacity, better in cleaning stains, and consume more water than impellers (Whirlpool, 2021). Consequently, most highly efficient washing machine use impellers for better efficiency. Another reason that may affect water consumption is the technical factor; if the wash setting has chosen incorrectly (e.g., cotton, silk, synthetic, etc.), it may result in more water used in the washing cycle (West, 2021).

Efficient washing machines use built-in innovative functions in order to optimise the machine's functionality. Some innovative washing machines apply the mathematical process, fuzzy logic function (Akram *et al.*, 2014). This allows the washing machine to determine wash load quantity in the machine, adjusting the water intake and detergent intake and wash cycle. Other machines have a half load setting (button) in which a user determine the use of half capacity to save water, as well, some efficient washers provide a fast wash setting, where water is used at a minimum. The range of water used in the efficient washers is falling between 6 to 13 litres per kilogram. A number of different efficient washing machine designs have been investigated; thus, a value of 26.4 litres/load has been determined as the highest efficient load per cycle in the backcast MC-WEC model, while a value of 80 litres/load is the lowest efficient load machine, with an average of 57.4 litres/load.

Tap

Water usage by tap components to wash floors and dishes has a considerable proportion in the base model and its derivatives. Old and traditional taps can consume above 15 litres per minute in some tap models (Roberts, 2019). Technology has served to save water and consume responsibly while using the tap component. Innovative technology has allowed to use less water without compromising a strong rinse that keeps things clean (Englart and Jedlikowski, 2019). Tap aerators have been manufactured to reduce water in traditional appliances to efficient flowrate and flow style without affecting the water pressure. A tap aerator is a small attachment that either fits onto the end of the tap or inserted inside the existing spout (Drake, 2019). It controls the volume of water that flows through the spout as it mixes the water with air the produce atomisation, acting as a sieve. It separates a single flow of water into several small streams, which present the air into the water flow; additionally, as there is less room for the water to flow through, the water flow is lessened, resulting in water savings (ibid). Aerators create a larger and whiter stream that is soft and gentle to the touch, non-splashing and does not bounce. On average, tap aerators can decrease the flow to as little as 6 litres per minute with traditional ones (EUI, 2018).

Besides aerators, several tap nozzles use different mechanisms for efficient and effective performance. First, the laminar stream nozzle produces a straight streamline and delivers crystal-clear and non-splashing water; it does not mix air with water (non-aerated).

Second, a spray stream nozzle is used when the flowrate is very low to create an aerated or laminar stream; a spray nozzle device is utilised to produce a miniature shower pattern to deliver full coverage to hands during washing. Third, a rain spray stream nozzle uses numerous little outlets join forces to generate an extensive, ample, and pleasingly stream of water just as a shower sensation (Bader and Abu-Hijleh, 2011). Parallel to tap nozzles manufacturing, plumbing manufacturers have developed a number of highly efficient taps, for instance, Neoperl plumbing has developed a dual flow setting tap where an atomised aerator saves up to 98% of the flow of a regular tap. The second setting is the regulated spray jet that uses 4.5 litres per minute with high performance (Neoperl, 2021).

Dishwasher

Dishwashers have been developed in recent decades, becoming more efficient where water usage per cycle has dramatically fallen (Nguyen *et al.*, 2018). Additionally, energy and performance efficiency has increased, which is an attractive factor to encourage householders to purchase. Dishwashers have been manufactured mainly as portable (compact) and standard dishwashers (Major and Zorta, 2018). A standard dishwasher is a built-in washer that connected to the household's plumbing system (commonly kitchen sink) and is fixed permanently. Portable dishwashers are attached to a tap temporarily (Casciano, 2021). The standard dishwashers are either; (i) freestanding; (ii) fully integrated to the kitchen cupboard; (iii) semi-integrated; or (iv) a customised drawer dishwasher (Buech, 2020). Portable and built-in dishwashers can be manufactured to promote efficient water use. A soil sensor is a device operating fuzzy logic function to allow dishwashers to behave like an intelligent appliance that can test how dirty utensils are, and optimise water use and cleaning performance (e.g., the amount of water to use (Atef *et al.*, 2021)). Manufacturers have also improved water filtration and style of the jet flow to using water efficiently throughout the washing cycle. Furthermore, an anti-flooding innovative device is a sensor device can shut off water if a leak has occurred because of a technical malfunction (Fletcher, 2021); in general, there are several functions to attain efficient and effective dishwasher operation (e.g., photoelectric turbidity sensor (Xu, 2021)). A number of efficient dishwashers have been investigated to determine the volume of water use in the backcast MC-WEC model; thus, 19 litres per cycle has been set as the highest volume in an efficient dishwasher and 6 litres per cycle is the lowest, in the most efficient washer, with an average of 12 litres per cycle.

6.4.1.2 Innovative appliances: Outdoor component

Efficient hosepipe nozzles: Car Washing

Car washing is a key component in our backcast MC-WEC modelling as water is used for car washing daily, as there a relatively high number of cars per household (average of four cars per Kuwaiti households) given the preference for private transportation (see section 5.3.2.2 for more detail) and because of high levels of ambient dust. There are different methods in use including the pressure washer gun (Zhang *et al.*, 2019) that can have different nozzles to vary hosepipe flow, including use of jet blasts (McCallum, 2021). The nozzle design allows the water pass through with high pressure and low flowrate (much lower than the hosepipe flowrate). There are different types of pressure washer nozzles based on the nozzle degree, starting from 0 to 40 degree. The degrees between 25 to 40 are suitable for car washing and detergent rinsing, lower than 25 degree can damage a car's surface and paint (Haas, 2016). Flowrates of nozzles degree range between 25 to 40 starts with 5.3 litres per minute as a minimum, 7.5 litres as maximum, and an average of 6.4 litres per minute.

Dripping and sprinkler irrigating systems

The methods used in irrigating a garden/lawn in Kuwait's villas are already efficient since Kuwait's municipality bans inefficient practices. Therefore, the methods and flowrates used in the base model to this component are unchanged. It means that this component has not been applied in MC-DOI modelling, but it has been applied in MC-WEC measures (via education and water pricing interventions).

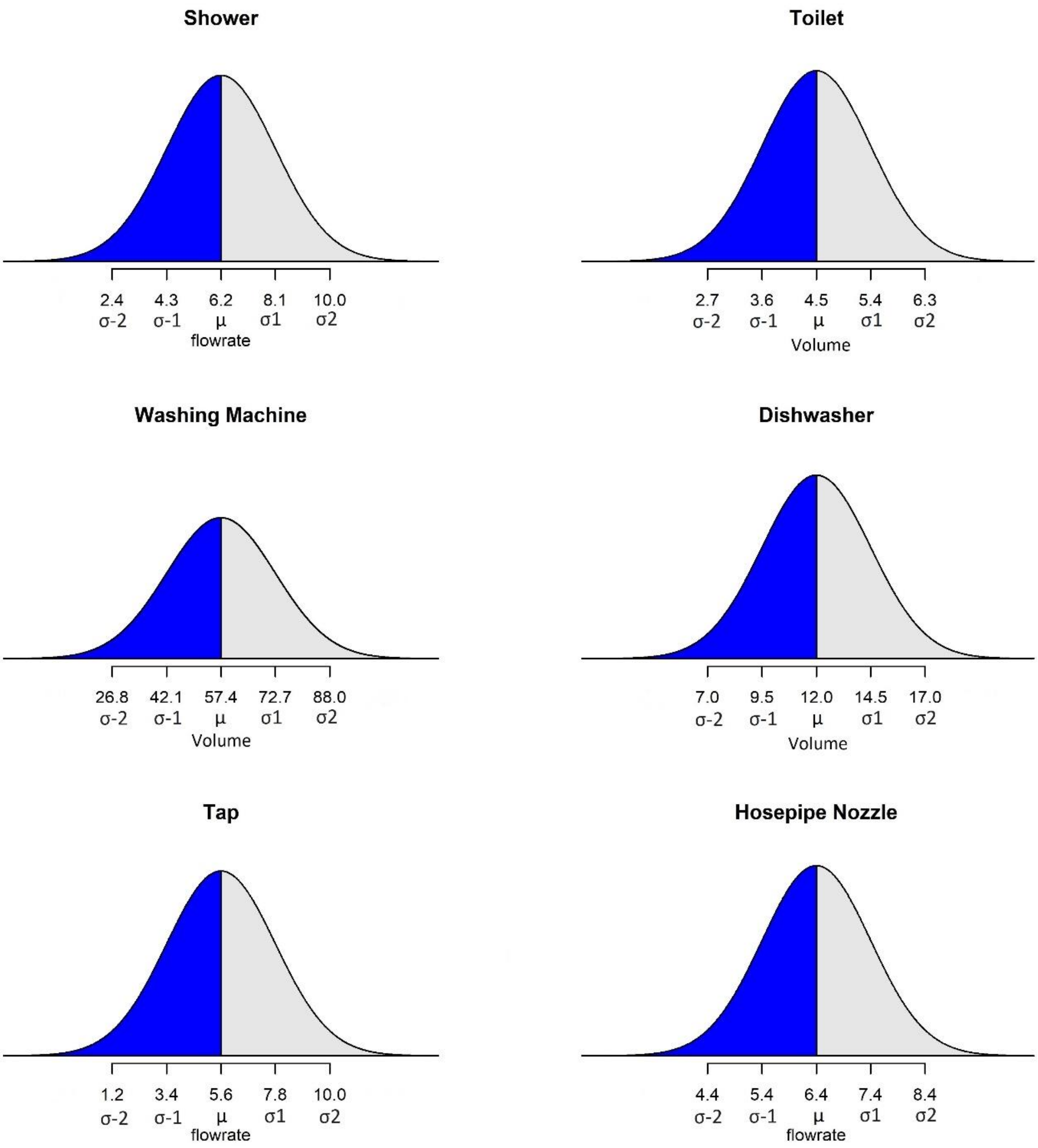

Figure 6.3: Volume and flowrate distribution of efficient and high-efficient appliances (volume: litre per cycle; flowrate: litre per minute)

Note: These normal distribution graphs are drawn on data collated from plumbing industry manufacturers provided in Table 6.3 and exclude more traditional technology that is not considered water efficient. The mathematical and utilisation processes are explained on p.203.

6.4.2 Water demand elasticity: Pricing intervention performance

The review of elasticities presented in Table 6.2 informed the application of elasticity values in the backcast MC-WEC model. The model emphasises the elasticity values of Rizaiza (1991) and Srouji (2017), as these elasticities represent empirical evidence from countries similar in context to Kuwait; it must be noted that these elasticity values used in the model are indicative/speculative values where the values are adopted from other studies. However, we do not adopt these exact elasticity parameters in the model but manipulate values close to it across a range, that are reasonable, achievable, and acceptable. The application of elasticity has been proportionally applied; for instance, a price elasticity of -0.30 applies from the year 2035, so the elasticity has been divided by the remaining backcast years (2050 – 2035 = 15; -0.30/15 = -0.02). The result (-0.02) has been applied for each year in a cumulative manner so that the target year 2050 the elasticity parameter is (-0.30). Consequently, water price increases gradually until the backcast endpoint year so that a 100% price increase is implemented. The structure of the price intervention has been presented in section 6.5.1.2.

6.4.3 Public education: Intervention performance

The education intervention performance has followed the same performance of the price intervention. As discussed in section 6.3.3, no study has investigated the effect of education to reduce household demand in Kuwait or GCC, the only one is attributed to is (Al-Zubari, 2014) which has been adopted from other study. Therefore, Table 6.4 shows the education effect from different regions, which has been used in the backcast MC-WEC modelling.

Table 6.4: The education effect in the household demand

Study	**Demand reduction** (%)
UKWIR (1998)	7.6
Syme *et al.* (2000)	10 to 25
Renwick and Green (2000)	8
Fielding *et al.* (2013)	14.2
March *et al.* (2013)	5 to 20
Al-Zubari (2014)	10

6.5 Backcast MC intervention applications: Building the structure

The backcast interventions discussed above have been employed to achieve the desired targets and develop backcast future scenarios. These interventions have been presented individually and collectively in the modelling processes, i.e., where some backcast parameters have not been used in some scenarios, and some have been introduced partly. So as the introduction of water pricing for non-Kuwaiti households in the *Intermediate* scenario and the application of technology for some components in the MC-WEC modelling, for example, the penetration of high-efficient showerhead appliances in the *Light* scenario (see section 7.2.1.1). The variation of interventions applied in the backcast scenarios depends on; (i) the severity of the demand reduction sought, i.e., the more demand reduction, the more interventions are applied; and (ii) the socioeconomic background of the state of Kuwait, i.e., citizens are always at the top priority in the state's policies (e.g., getting more subsidies than non-Kuwaitis).

6.5.1 Backcast MC-WEC modelling structure

The absence of empirical evidence regarding the synergy effect of demand intervention measures on conservation actions and consumer behaviour has brought difficulties to developing backcast intervention packages. No literature on water demand management investigates the effect of demand interventions synergistically, for example, how much an increase of water tariff would affect consumer consumption if an awareness campaign had been in place, and vice versa. Instead, demand intervention measures have been investigated individually, for example, the effect of education or of water pricing signalling on consumer consumption. Given such a situation, a discursive manner has been adopted to develop backcast intervention packages. It indicates that each intervention is introduced individually and has no effect on the other introduced interventions. It should be noted that the introduced interventions must be compared in degree with observed data that are taken from countries/cities that are similar in the context to Kuwait (e.g., GCC or arid countries). For instance, a comparison with an introduced demand reduction resulting from water price elasticity (e.g., -0.21 demand reduction in the backcast model) with an observed demand reduction resulted from price tariff change (e.g., -0.30 price elasticity, see Table 6.2).

Here, we can gauge the proposed demand reduction with an observed reduction, which then can be discussed with professional stakeholders in terms of acceptability and feasibility.

Backcast MC scenario packages

Based on backcast MC-WEC modelling achieved (see chapter seven), two intervention packages have been developed for each scenario, comprising six packages in total (Table 6.5). These packages have treated the socioeconomic and sociodemographic disparities in Kuwait's households and have addressed different scenarios possible to achieve, using interventions adopted in the study.

Table 6.5: The measures adopted in the backcast scenarios

Scenario	**Reduction target** (%)	**Package**	**Measures**
Light	32	P.1.1	An efficient showerhead penetration
		P.1.2	Efficient showerhead and washing floor tap penetration
Intermediate	48	P.2.1	A high-efficient showerhead and efficient toilet and washing floor tap penetration
		P.2.2	a) Efficient showerhead, toilet, and washing floor tap penetration; b) Price intervention for non-Kuwaiti households
Optimistic	64	P.3.1	High-efficient appliances penetration for all household components
		P.3.2	a) Efficient appliances penetration for all components; b) price intervention (Kuwaiti and non-Kuwaiti); c) education intervention (Kuwaiti and non-Kuwaiti)

For the *Light* scenario, two packages were developed: P.1.1 and P.1.2. The P.1.1 package has employed the efficient showerhead to achieve the no new water target. The reason behind selecting the Shower component is that; first, the proportion of Shower component in the base model and first and second derivatives is over 60%, accounting for more than half of households' consumption. Thus, investment in this component would achieve a substantial demand reduction. Second, the Shower component has been the main target in several household demand management actions (see section 6.3.1.1), for instance, the USA Environmental Protection Agency (EPA) introduced legislation in 1992 to ban the use of traditional showerhead and replace it with efficient ones. Third, is to show policymakers and authorities in the state how the use of technology is a promising and effective measure in reducing household demand. In the P.1.2 package, Shower and Washing Floor components have been modelled using efficient showerhead and washing floor tap appliances. The reason to use these components is that they occupy the highest distribution proportions of demand in the base model and derivatives. It represents an alternative to P.1.1 where the penetration rate is very high. So, the diffusion of shower and washing floor appliances would achieve the same output but with a lower penetration rate. No other interventions have been introduced with technology in the two packages. The target is light; hence, no further incentives are needed to introduce in the *Light* scenario.

In the *Intermediate* scenario, two further packages have been developed. In P.2.1, a mixture of high-efficient and efficient appliances is in place, with three components selected to be modelled, Shower, Toilet, and Washing Floor components, as these occupy the highest proportional demand distribution in the base model and derivatives. High-efficient showerhead and efficient toilet and washing floor tap appliances has been employed. P.2.1 shows how a mixture between high-efficient and efficient appliances could help to achieve moderate target (*Intermediate* scenario). For P.2.2, a combination of technology and price interventions have been introduced. It comprises penetration of efficient appliances (Shower, Toilet, and Washing Floor components), and introduction of price effect to non-Kuwaiti households. Regardless that the non-Kuwaiti demand constitutes less than 30% of total household population demand, it has been selected for the price intervention. This is as a result of the current and past practices in Kuwait and other GCC countries. For instance, in Qatar, citizens household consume water for free, whereas expatriates pay as they consume. In UAE, citizens were consuming water for free before 2015, whilst expatriates were paying as they consume; after 2015, the UAE government has introduced two tariff structures, one with relatively high subsides assigned to citizens, and another with lower subsidies assigned to expatriates. In the *Optimistic* scenario, P.3.1 introduces high-efficient appliances for all components in the base model and derivatives, whilst P.3.2 introduces efficient appliances for all components plus introduction of price and education interventions for all household population segments.

6.5.1.1 Technology adoption structure

Several equations have been developed in the backcast MC-WEC model to model the penetration of technology in households. They have been designed to; (i) ensure the prevention of penetration overlapping; (ii) differentiate household segments (e.g., the second derivative of non-Kuwaiti distribution after technology penetration); (iii) quantify the households adopting and not adopting the technology; and (iv) to quantify the exact aggregate and disaggregate household demand. The equations have been set in ascending order. The equations have been introduced separately but are linked to each other in the MC-WEC spreadsheet modelling, in which any manipulation in the first equation has been resulted in the last equation.

The first equation is a Gompertz function designed to model the uptake and penetration rate curve (DOI curve). The equation structure is;

$$U_t = U_0 \exp\left(r/\lambda\{1 - \exp(-\lambda t)\}\right) \tag{16}$$

Where U_t is the penetration rate of the household population adopting a certain technology at time t; U_0 is the value of penetration rate at time zero (2019); r is a constant determining the maximum value of U that can be reached; and λ is a constant determining the rate of growth of the curve. The constant r can be manipulated to reflect the market penetration of efficient and high-efficient appliances. The result of this equation has been used to build the second equation, where the households adopting technology have been calculated.

The second equation structure is;

$$HAT_{kpj} = k_t * p_t * j_t \tag{17}$$

Where HAT refers to households adopting (“O” element) technology; k is the technology penetration rate at time t; p is the aggregate household population at the same time t; and j is the proportional distribution of the characteristics of each household in the household matrix[19] (i.e., household size, dwelling type, and household status) at time t. The outcome of the equation has delivered the number of households adopting technology for each household size in the household matrix, so that the number of households adopting the technology has been differentiated for the number of households not adopting the technology at a certain time t. Here, two household population matrices have been developed, the ("backcast" household matrix) showing household population adopting technology, and the ("initial" household population) showing the initial population number before backcast modelling (i.e., initial – backcast = households not adopting technology).

The result of this equation has been used to determine the proportion of each model specification (base model, 1st and 2nd derivative) and the proportion of households using dishwasher or kitchen sink tap (washing by hand) in the Washing Dishes component. The developed equation is as following;

$$BDM_{kpjw} = (\{k_t/p_t * p_t * j * w) \tag{18}$$

Where BDM refers to the backcast households by dwelling type and by the model specification; k is the calculated household adopting technology in the backcast household matrix (the output of the equation 17) divided by p the initial aggregate population by a certain dwelling type specification (e.g., flat), to get the proportion of each household size in the dwelling type's vector (1-12 household sizes). This function enables a check to see if the penetration rate of the backcast population is identical to that developed in equation (16); this is relevant as the sum of proportions in a dwelling vector must be identical to penetration rate of equation (16). After the examination function, the number of the backcast households in the dwelling vector (of the backcast matrix) has been multiplied by the model specification coefficient j. The model specification coefficients are varied depending on household dwelling type and household status (see section 5.3.2 for coefficients details). For instance, base model specification is assigned only to villas with garden/lawn attachments; and the second derivative is assigned to non-Kuwaiti households not possession a car. Then the

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[19] It is the final household population water demand forecast matrix that has been developed from chapter three through chapter five where the calibrated MC model (chapter five) has been linked to the base household demand forecast scenario (chapter four) that has been used in the backcast MC-WEC modelling (chapter seven).

output has been multiplied by the coefficient of the washing dishes method used w (dishwasher or kitchen sink tap); the coefficients are varied depending on the household status (see section 5.3.2.1). At this point, the backcast household matrix has been differentiated based on the washing dishes method used (wash by hand and dishwasher), so that the Water Efficiency Calculator (WEC) has two samples, one for household using kitchen sink tap (wash by hand) and another for dishwasher. The used coefficients for Washing Dishes component have been constant throughout the backcast horizon in the *Light* and *Intermediate* scenarios (packages: P.1.1, P.1.2, P.2.1, and P.2.2) as efficient/high-efficient dishwashers/kitchen sink taps have not been modelled in the Washing Dishes component. In the *Optimistic* scenario, where the Washing Dishes component has been modelled using efficient/high-efficient dishwasher/kitchen sink tap, the constant (static) coefficient parameters have been compensated by penetration rate (dynamic) parameters (see section 7.2.1.3 for in-depth discussion).

At this stage, the backcast household population is now ready to be used in the MC-WEC model to calculate the consumption reduction resultant from adopting technology (detection of a disaggregate PHC reduction). An equation has been developed to link the backcast household population to the MC-WEC; the equation structure is as the following;

$$DHC_{s,t,m,f,c,w} = (\{s-t\} + \{t-m\} + \{m-f\} + \{f-c\} + \{c-w\} + w) \tag{19}$$

Where DHC refers to the disaggregate household consumption (“O” and part of “V” elements = litre per minute or volume per cycle of adopted technology); s is the number of households adopting technology in Shower component; t is the number of households adopted technology in Toilet component; m for the technology adopted on the Washing Machine component; f is the technology adopted in the Washing Floor component; c refers to the technology adopted in the Car Washing component; and w is donated to the technology adopted in the Washing Dishes component. This equation has been fixed in the MC-WEC model to calculate the household adopting technology with the penetration rate for each technology, in which disaggregate (PHC by micro-component), and aggregate (total number of PHCs) demand can be calculated. The final output of the equation is that; (i) the aggregate water demand and aggregate households adopting certain technology by similar household characteristics (i.e., model specification, household size, household status, and dwelling type); and (ii) disaggregate PHC demand by a micro-component level (e.g., Shower component and OVF elements).

The principle of employing this equation is that, rather than obtain the weight of technology adopted in each component which will bring about the difficulties in controlling the model structure (i.e., every model manipulation will need to develop new weights); therefore, subtraction/addition function has been adopted. The function assumes that the highest adopted technology will be subtracted to lower adopted technology until reaching the lowest adopted technology; this has enabled; first, a dynamic manipulation (e.g., easily to shift positions if the proportions of technology changed). Second, it prevents any population overlapping; each technology adopted has been developed with separate household matrix to get the exact population adopted this technology; therefore, adding these population together will result in overlapping population; this equation has addressed this issue. This equation has not been used in the *Light* scenario (P.1.1) as the technology adopted is only (s) the efficient showerhead; for package P.1.2 the technologies used $(\{s - f\} + f)$; to *Intermediate* scenario, P.2.1 and P.2.2, the technologies used $(\{s - t\} + \{t - f\} + f)$, see the example in Figure 6.4. The equation has received special treatment in the *Optimistic* scenario as the Washing Dishes component has two technologies used (discussed and addressed in section 7.2.1.3).

An example is presented to clarify the functionality of this equation: a full penetration (100%) for Shower (s) component of (100 households), a penetration of (80%) for Toilet (t) component of (80 households), and a penetration (60%) for Washing Floor (f) component (60 households). When applied the equation output will be as follows; 60 households adopted $(s + t + f)$ technologies; 20 households adopted $(s + t)$ technologies; and 20 households adopted (s) technology; in total, 100 households. At this level, backcast demand and household adopting and not adopting technology can be calculated. To calculate the grand aggregate household adopting technology and grand aggregate backcast demand for a certain year in the backcast horizon, two equations have been developed. The first equation is;

$$GAHAT = \sum_{t=i} (cj_{\{b+f\}} + e_{j\{b+f+s\}}) \tag{20}$$

Where $GAHAT$ refers to the grand aggregate households adopting technology; cj is the Kuwaiti households by dwelling type in b base model and f first derivative; ej is the non-Kuwaiti households by dwelling type in b base model and f first and s second derivatives at time t. The second equation is:

$$GABD = \sum_{t=i} (\{cj^{-d}_{(b+f)} + ej^{-d}_{(b+f+s)}/10^{-9}\} * yr^{-1}) \tag{21}$$

Where $GABD$ refers to the grand aggregate backcast demand; cj is the Kuwaiti demand by dwelling type in b base model and f first derivative, litres per d day; ej is the non-Kuwaiti demand by dwelling type in b base model and f first and s second derivatives, litres per d day, divided by a billion (litres in MCM) multiplied by a yearlong (365 days) at time t.

It should be noticed that the spatial household distribution (by state's governorates) has not been included in the backcast MC-WEC model. This is as; (i) the spatial distribution has no effect on demand; and (ii) adding the geography would add further complexity to the model's structure. Spatial distribution can be estimated after calculating water demand using a proportional distribution function.

6.5.1.2 Economic intervention structure

The economic (price) intervention has been applied in the *Intermediate* scenario (P.2.2), and *Optimistic* scenario (P.3.2). The price elasticity has been introduced gradually from a certain time in the backcast horizon to the end year. The price effect has been applied for each component in each PHC-MC table (see section 5.4.1.1). The equation of price effect on duration is as following;

$$P_d = (\{1 - p_t\} * d) \tag{22}$$

Where P refers to the price intervention; p is the price elasticity at time t; and d is the duration (part of “V” element) of each component has duration factor (i.e., Shower, Washing Dishes (wash by hand), Washing Floor, Car Washing, and Garden/Lawn Irrigating components). To explain this equation; for example, a shower duration of 20 minutes for each member in a household, and a price elasticity for a given year is -0.3 (e.g., an increase of 100%

of water price). To calculate the effect of price, then; ({1-0.3}*20) equals 14 minutes (a reduction of 30% of total duration).

The equation of price effect on frequency is the following;

$$P_f = 1 - f_t \tag{23}$$

Where P refers to the price intervention; f is the frequency (“F” element) of a certain component subtracted by one at time t. This equation has not applied in Toilet component as the visit frequency is dependent in the biological needs and in Shower component where the frequency has been previously set as one time a day for each member of a household which has not been modelled, for lifestyle and hygiene reasons (i.e., the frequency is not affected by backcast intervention).

6.5.1.3 Education intervention structure

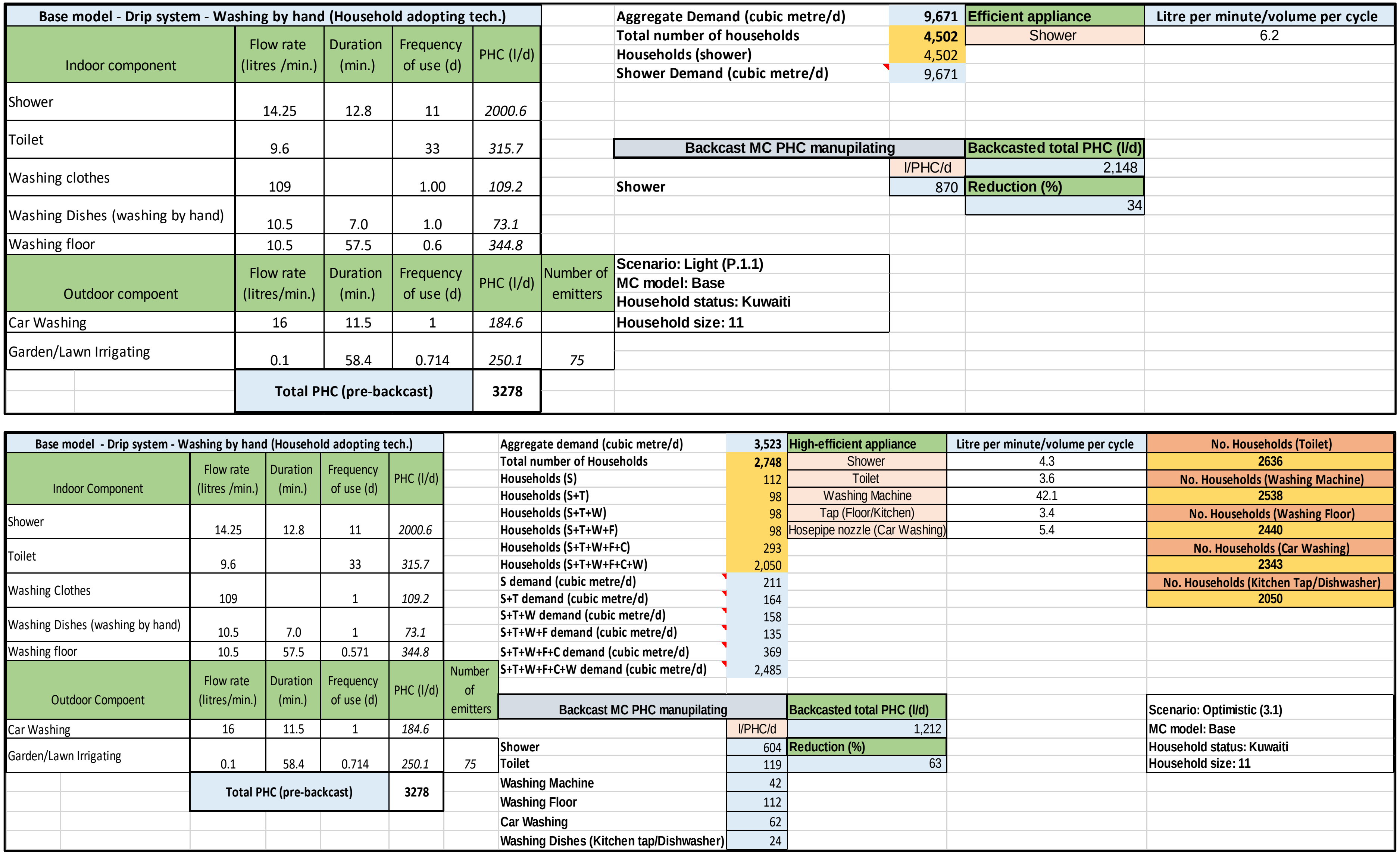
The education effect application has followed the same functionality of price intervention equation, where the education intervention equation is;

$$E_d = (\{1 - e_t\} * d) \tag{24}$$

Where E refers to the education intervention; e is the education effect at time t; and d is the duration of for each component has duration factor. The equation of education effect on frequency is the following;

$$E_f = 1 - f_t \tag{25}$$

Where E refers to the price intervention; f is the frequency of a certain component subtracted by one at time .



Base model - Drip system - Washing by hand (Household adopting tech.)					
Indoor component	Flow rate (litres /min.)	Duration (min.)	Frequency of use (d)	PHC (l/d)	
Shower	14.25	12.8	11	*2000.6*	
Toilet	9.6		33	*315.7*	
Washing clothes	109		1.00	*109.2*	
Washing Dishes (washing by hand)	10.5	7.0	1.0	*73.1*	
Washing floor	10.5	57.5	0.6	*344.8*	
Outdoor compoent	Flow rate (litres/min.)	Duration (min.)	Frequency of use (d)	PHC (l/d)	Number of emitters
Car Washing	16	11.5	1	*184.6*	
Garden/Lawn Irrigating	0.1	58.4	0.714	*250.1*	*75*
	Total PHC (pre-backcast)			3278	

Aggregate Demand (cubic metre/d)	**9,671**
Total number of households	**4,502**
Households (shower)	4,502
Shower Demand (cubic metre/d)	9,671

Efficient appliance	**Litre per minute/volume per cycle**
Shower	6.2

Backcast MC PHC manupilating		**Backcasted total PHC (l/d)**
	l/PHC/d	2,148
Shower	870	**Reduction (%)**
		34

Scenario: Light (P.1.1)
MC model: Base
Household status: Kuwaiti
Household size: 11

Base model - Drip system - Washing by hand (Household adopting tech.)					
Indoor Component	Flow rate (litres /min.)	Duration (min.)	Frequency of use (d)	PHC (l/d)	
Shower	14.25	12.8	11	*2000.6*	
Toilet	9.6		33	*315.7*	
Washing Clothes	109		1	*109.2*	
Washing Dishes (washing by hand)	10.5	7.0	1	*73.1*	
Washing floor	10.5	57.5	0.571	*344.8*	
Outdoor Compoent	Flow rate (litres/min.)	Duration (min.)	Frequency of use (d)	PHC (l/d)	Number of emitters
Car Washing	16	11.5	1	*184.6*	
Garden/Lawn Irrigating	0.1	58.4	0.714	*250.1*	*75*
	Total PHC (pre-backcast)			3278	

Aggregate demand (cubic metre/d)	**3,523**
Total number of Households	**2,748**
Households (S)	112
Households (S+T)	98
Households (S+T+W)	98
Households (S+T+W+F)	98
Households (S+T+W+F+C)	293
Households (S+T+W+F+C+W)	2,050
S demand (cubic metre/d)	211
S+T demand (cubic metre/d)	164
S+T+W demand (cubic metre/d)	158
S+T+W+F demand (cubic metre/d)	135
S+T+W+F+C demand (cubic metre/d)	369
S+T+W+F+C+W demand (cubic metre/d)	2,485

High-efficient appliance	**Litre per minute/volume per cycle**
Shower	4.3
Toilet	3.6
Washing Machine	42.1
Tap (Floor/Kitchen)	3.4
Hosepipe nozzle (Car Washing)	5.4

No. Households (Toilet)	**2636**
No. Households (Washing Machine)	**2538**
No. Households (Washing Floor)	**2440**
No. Households (Car Washing)	**2343**
No. Households (Kitchen Tap/Dishwasher)	**2050**

Backcast MC PHC manupilating		**Backcasted total PHC (l/d)**
	l/PHC/d	1,212
Shower	604	**Reduction (%)**
Toilet	119	63
Washing Machine	42	
Washing Floor	112	
Car Washing	62	
Washing Dishes (Kitchen tap/Dishwasher)	24	

Scenario: Optimistic (3.1)
MC model: Base
Household status: Kuwaiti
Household size: 11

Figure 6.4: An example of the backcast MC-WEC model

6.6 Conclusion

The structure of the backcast MC-WEC model has been set out. Started with the definition of three backcast targets (to 2050) obtained from literature surveying (see 6.2.1). Three backcast scenarios have been defined (scenario for each target) each of which has two backcast intervention packages. Three conservation measures interventions have been selected to be applied in the backcast MC-WEC model in developing backcast scenarios, comprising non-pricing measures (technology and education) and pricing measure (water pricing). Diffusion of innovation approach has been adopted to model the technology uptake and penetration rates (through Gompertz function), whilst the water price elasticity of demand has been used to test the change in water price in reducing demand. While past observations demand reduction rates through public education measures have been utilised to test the effect of education in reducing Kuwait's household demand. Several equations have been developed to fit these variables (conservation measures) in the model with the consideration of the socioeconomic and sociodemographic variations in Kuwait household population. At this point, the model is now ready for the backcast MC-WEC manipulation exercise to define the measures needed to reach backcast targets (e.g., What market penetration rate is needed to reach the *Light* scenario, first package P.1.1?). The following chapter shows and discusses the output of the backacst MC-WEC modelling; the measures needed to reach backcast targets (manipulation output); the demand reduction resulting from applying conservation measures; and the wider appraisal of backcast scenarios impact.

Chapter 7 Backcast modelling output: Backcast scenarios

7.1 Introduction

This chapter applies the backcast MC-WEC conservation intervention measures modelling to the household water demand and subsequently evaluates backcast scenario impacts (i.e., economic and environmental appraisal). The chapter constitutes the peak of the research where the fundamental question (section 1.4) of the study has been explored. The chapter starts with backcast MC-WEC model manipulation, where different figures for each parameter (e.g., technology = market penetration rates) has been manipulated until reaching the backcast targets. Thus, exploring the measures needed to reach the targets – also, showing how these measures have influenced demand for different household population segments (What segment has received more demand reduction? What dwelling type have most/least effect on demand after measures application? etc.); hence, drawing the key findings. A summary of the measures needed to reach the three backcast targets is presented in Table 7.9. For each intervention package, a summary of how these specific measures have been manipulated in the backcast MC-WEC spreadsheet model is provided. Finally, the wider appraisal of the backcast conservation intervention measures addressing the economic and environmental impact of the developed scenarios is presented. Planned feasibility and acceptability appraisal has not been possible as a result Covid-19 outbreak (see section 7.2.3.3).

7.2 Backcast MC-WEC model output

7.2.1 Backcast scenarios

Backcast manipulation modelling was implemented to achieve the demand reduction targets from the base year (2018). Three backcast scenarios and two packages for each scenario have been developed (justified in section 6.5.1). This section presents and discusses the results of the backcast modelling for each scenario.

7.2.1.1 No new water target: Light scenario

The target of this scenario is to add no more water into service from the base year demand which is equivalent to a reduction of 1% yr^{-1}. Unfortunately, the annual proportional demand reduction throughout the backcast horizon (i.e., keeping demand constant as in the base year) is not applicable. This is a consequence of; (i) the application of DOI-Gompertz modelling where exponential growth is presented (which is against linearity approach modelling where constant growth can be presented); (ii) the interventions applied in P.1.1 and P.1.2 are light, hence demand reduction proportions start at low values (lower than a reduction of 1% yr^{-1}). Thus, the target no new water added into service has been altered to be '*no more water to be added to at least from the mid-point of the backcast horizon*' (= 2035).

First package: P.1.1

The first package comprises adoption of efficient showerhead appliances (mean values = µ) applied for all household population segments with a similar penetration rate of 95% by 2050. This penetration rate (95%) is the output of the backcast MC-WEC model manipulation process where this rate of technology penetration is considered to achieve the target of *Light* scenario. Section 7.2.2 discusses the process of obtaining the needed conservation measures (parameters) in the backcast MC-WEC model to reach backcast targets. This penetration rate has been applied equally to all household population segments as a result of no incentives introduced to vary the penetration amongst household segments. Thus, the modelling process in this package is modest.

A key finding of this package is that adopting efficient showerhead appliances is able to reduce grand aggregate (i.e., the demand of the entire household population), aggregate (i.e., Kuwaiti or non-Kuwaiti households demand), PHC, and PCC[20] demand up to reaching the target of the *Light* scenario (32% demand reduction). On grand aggregate demand, household demand has increased from base year to reach 494.2 MCM in 2025[21] (due to low technology diffusion) then demand has dropped to reach a trough of 437.3 in 2043, afterward demand has slightly escalated to achieve 443 MCM at the end of the backcast horizon. The increasing period (2043 – 2050) after decreasing period is driven by an increase in Kuwaiti household demand, whilst non-Kuwaiti demand has continued to decline until backcast endpoint (see Figure 7.1). Grand aggregate demand rebound is a consequence of three reasons; (i) a

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[20] Backcast PCC values have been derived from backcast PHC values (= PHC divided by the household size).

[21] Backcast household demand has decreased (3.1%) compared with BAU demand, but the backcast demand has increased (7.6%) until 2025 in comparison with the base year 2018.

continuous increase of Kuwaiti population till backcast endpoint, although non-Kuwaiti population started decreasing from 2045; (ii) Kuwaiti demand has much weight (on average 76%) of total household demand thus more effect on grand aggregate demand; and (iii) the nature of Gompertz curve, where the increase rate is decreasing dramatically when reaching the saturation point, which is lower than the increase rate of Kuwaiti population.

In terms of demand by dwelling type, on average of demand share, Kuwaiti villa has the highest demand share proportion of 53.8% of grand aggregate demand; whilst the lowest demand share went to floor or flat in a villa of non-Kuwaiti household with demand share proportion of 1%. Villa dwelling type occupies the highest demand share with 70.7% of total Kuwaiti demand, whilst it is flat dwelling type for non-Kuwaiti demand with 60.1% of total non-Kuwaiti demand. In contrast, the lowest Kuwaiti demand share went to flats with a proportion of 4.3% of Kuwaiti demand, while it is floor or flat type for non-Kuwaiti with a share of 4.2% of non-Kuwaiti demand. On demand by model specification, on average, the first derivative of Kuwaiti households occupies the highest demand share of 50.7% of grand aggregate demand; in the opposite, the lowest share went to the base model of non-Kuwaiti with a share of 0.6% of total demand, see Figure 7.2 and Figure 7.3.

On disaggregate demand, the average Kuwaiti and non-Kuwaiti PHC/PCC has been reduced to meet a reduction of 35% by backcast endpoint 2050. For example, the average PHC in Kuwaiti villa in the base model has been reduced to achieve 2,227 l/d compared with the observed PHC of 3,399 l/d. So as other PHC/PCC categories have been reduced to achieve a reduction of 34% to 36% at the endpoint of the backcast horizon. To compare between the backcast PHC and observed PHC, Table 3.10 shows the PHC demand matrix (observed PHC), and Table 7.1 showing the average backcast PHC/PCC by dwelling type, model specification, and household status.

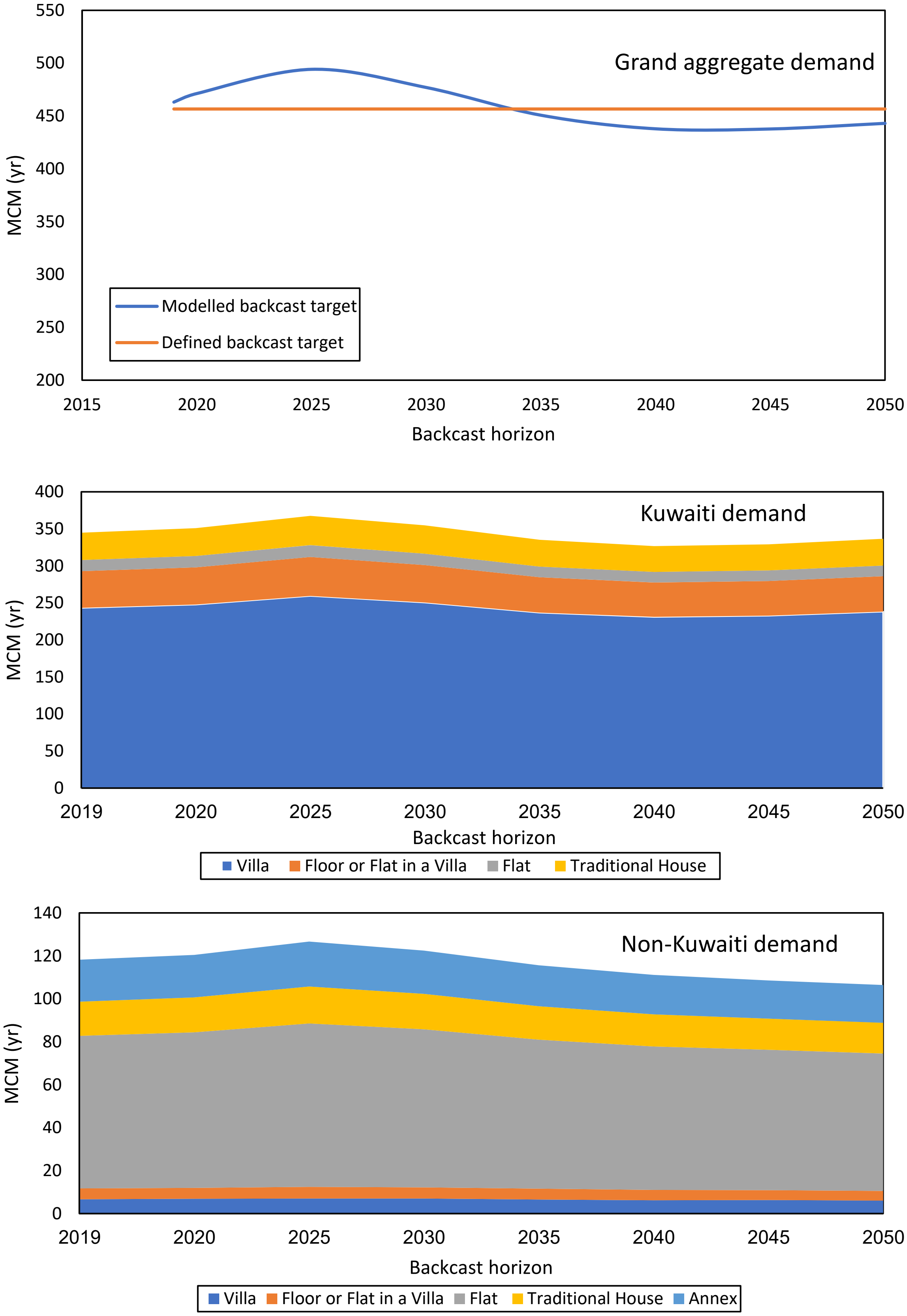

Figure 7.1: Aggregate demand and demand by dwelling type in the Light scenario: P.1.1

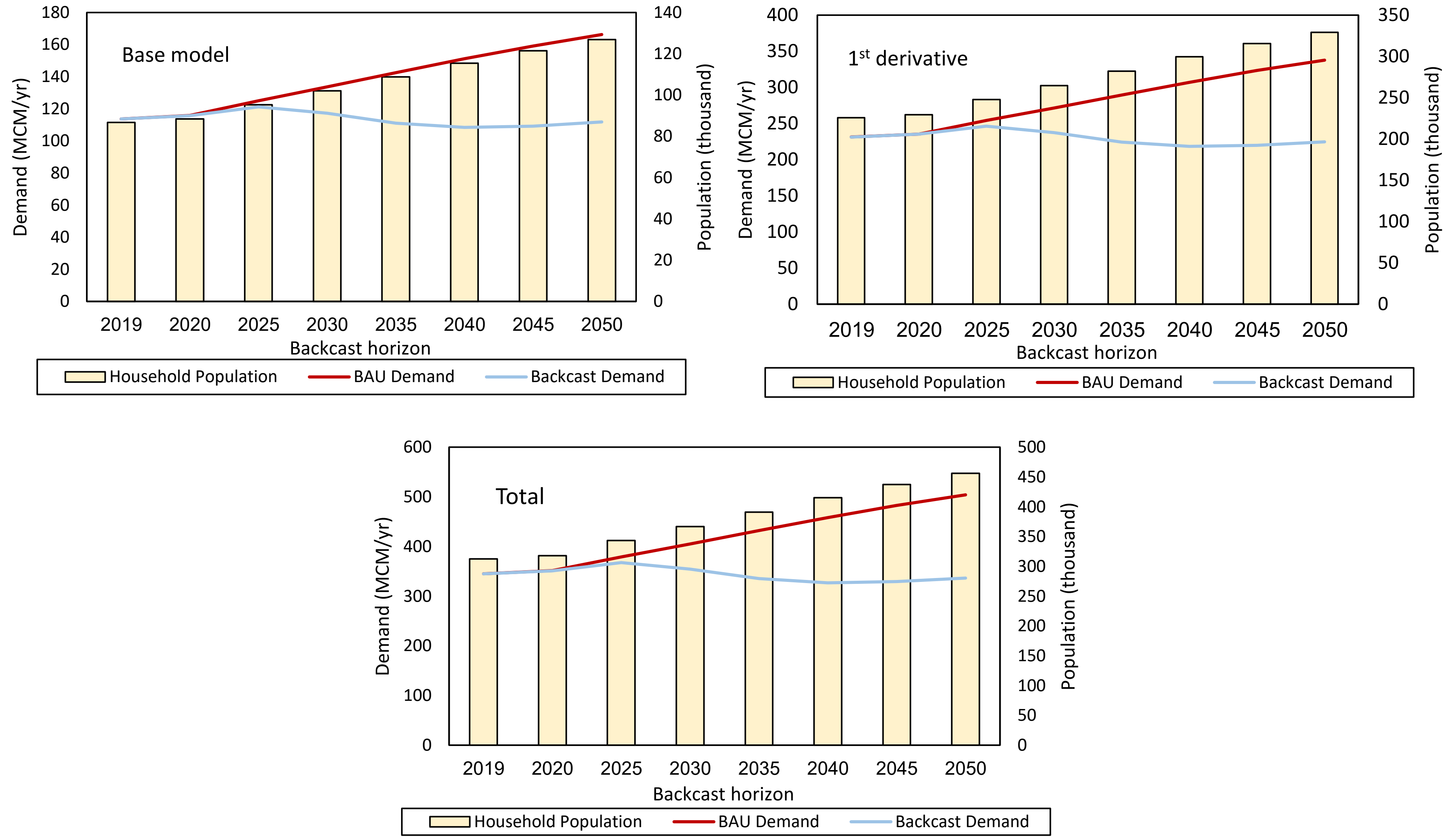

Figure 7.2: Demand by model specification in the Light scenario: Kuwaiti P.1.1

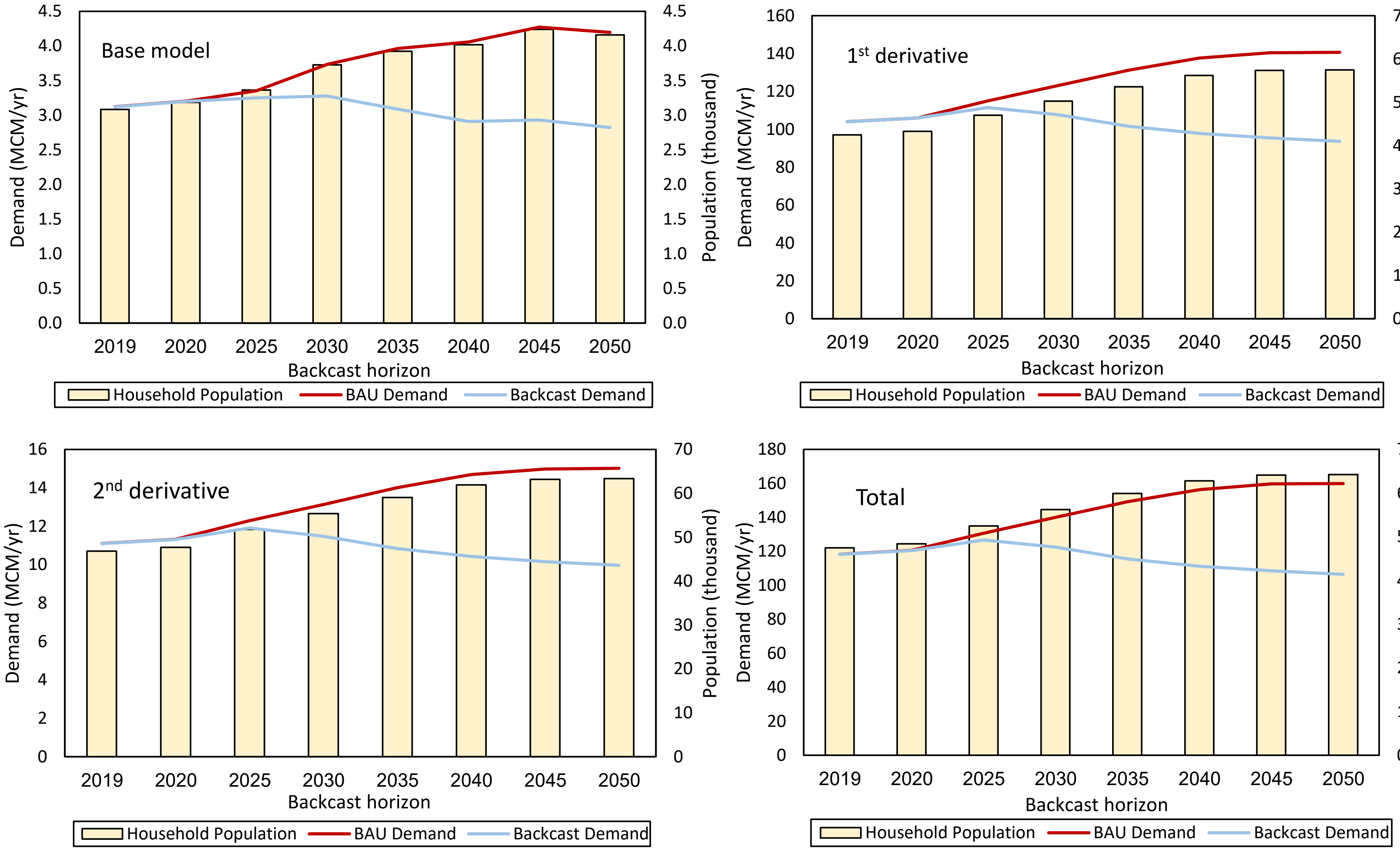

Figure 7.3: Demand by model specification in the Light scenario: non-Kuwaiti P.1.1

Table 7.1: Average PHC and PCC under the Light scenario in 2050: P.1.1

Average PHC/PCC (Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	2,227	550
1st	Villa	2,203	544
	Floor or flat in a villa	1,463	319
	Flat	931	220
	Traditional house	1,890	458
Aggregate average (1st derivative)		1,622	385
Aggregate average (base and 1st derivative)		1,743	418
Average PHC/PCC (non-Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	1,857	358
1st	Villa	1,837	354
	Floor or flat in a villa	834	151
	Flat	548	113
	Traditional house	1,150	226
	Annex	548	108
2nd	Floor or flat in a villa	824	150
	Flat	541	112
	Traditional house	1,137	223
	Annex	538	106
Aggregate average (1st derivative)		983	190
Aggregate average (2nd derivative)		760	148
Aggregate average (base and 1st and 2nd derivative)		981	190

Second package: P.1.2

This backcast package employs the market penetrations of efficient showerhead and tap (Washing Floor component) appliances (= μ). After a series of backcast MC-WEC model manipulation, we find that the market penetrations to reach the backcast target are 82% for efficient showerhead and 67% for efficient taps.

On grand aggregate demand, the output is very similar to what has been quantified in P.1.1., see Figure 7.4, Figure 7.5, and Figure 7.6. The difference has occurred in the disaggregate demand PHC/PCC, where the backcast PHC/PCC in P.1.2 is lower than that in P.1.1. This is because of; (i) the adopting of two efficient appliances; and (ii) the effect of subtraction/addition equation (19). For instance, the average PHC in Kuwaiti villa in the base model has been reduced to achieve 1,997 l/d compared with the backcast PHC of 2,227 l/d in P.1.1. This accounts for a reduction of 10.3%, see Table 7.2 for more investigation.

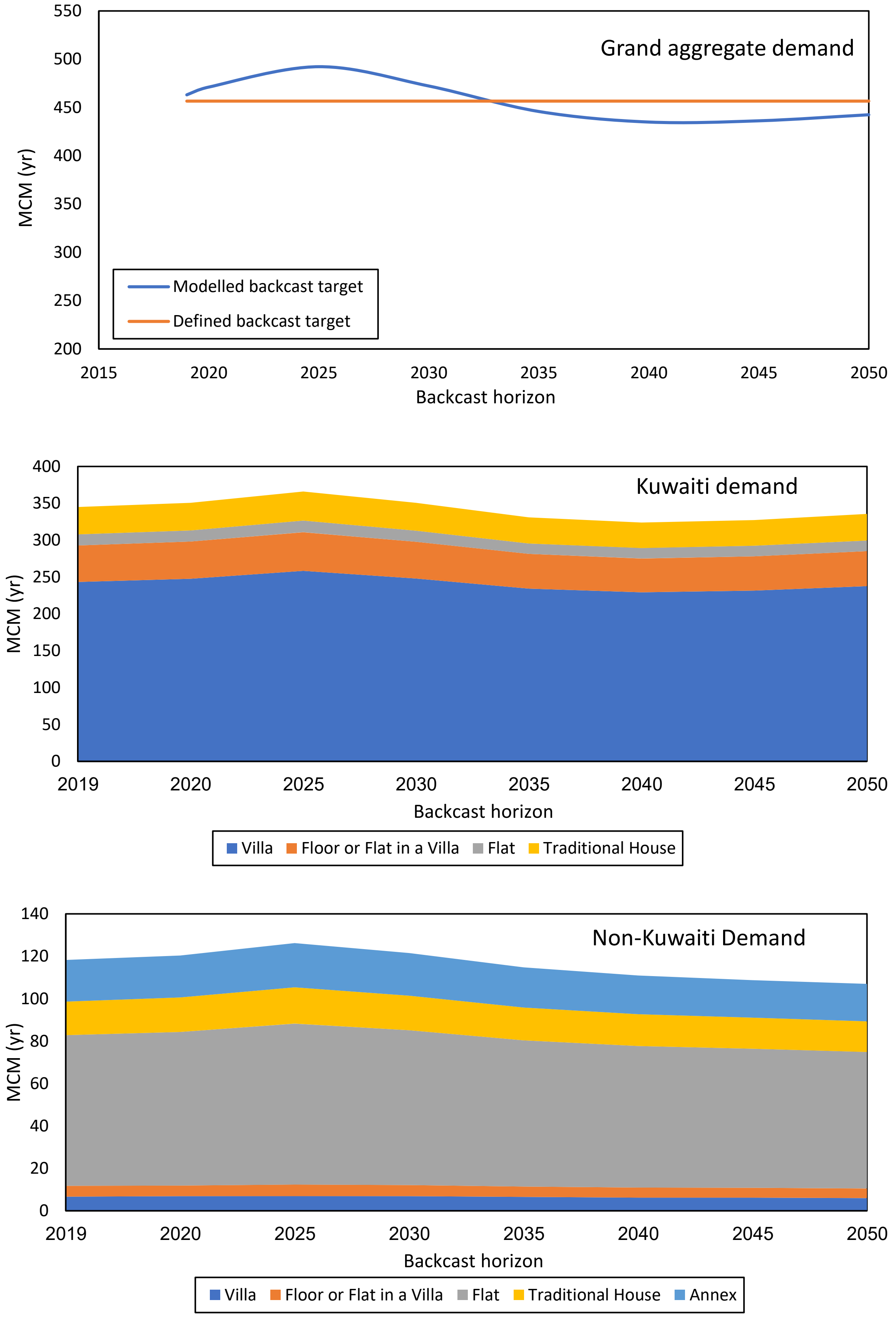

Figure 7.4: Aggregate demand and demand by dwelling type in the Light scenario: P.1.2

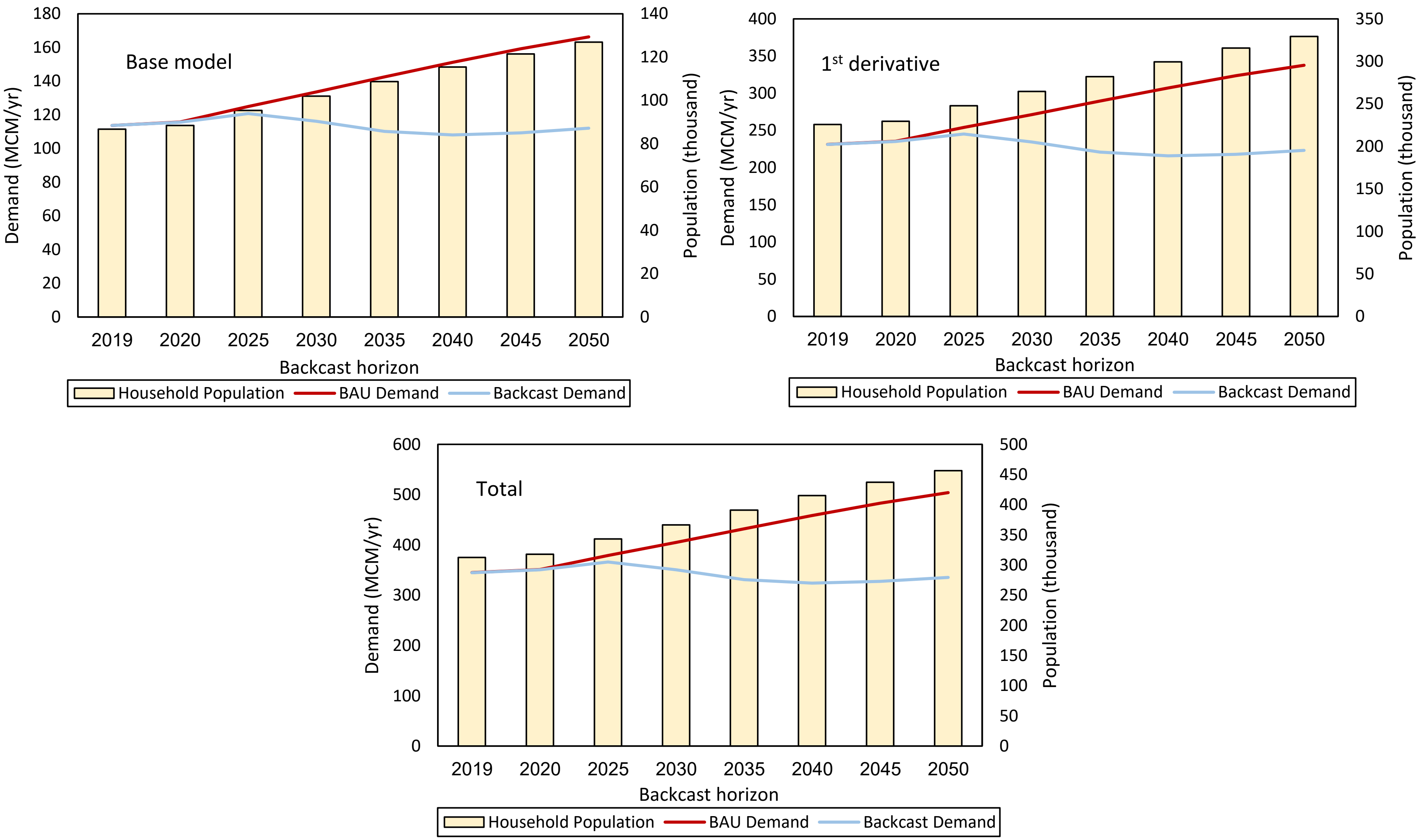

Figure 7.5: Demand by model specification in the Light scenario: Kuwaiti P.1.2

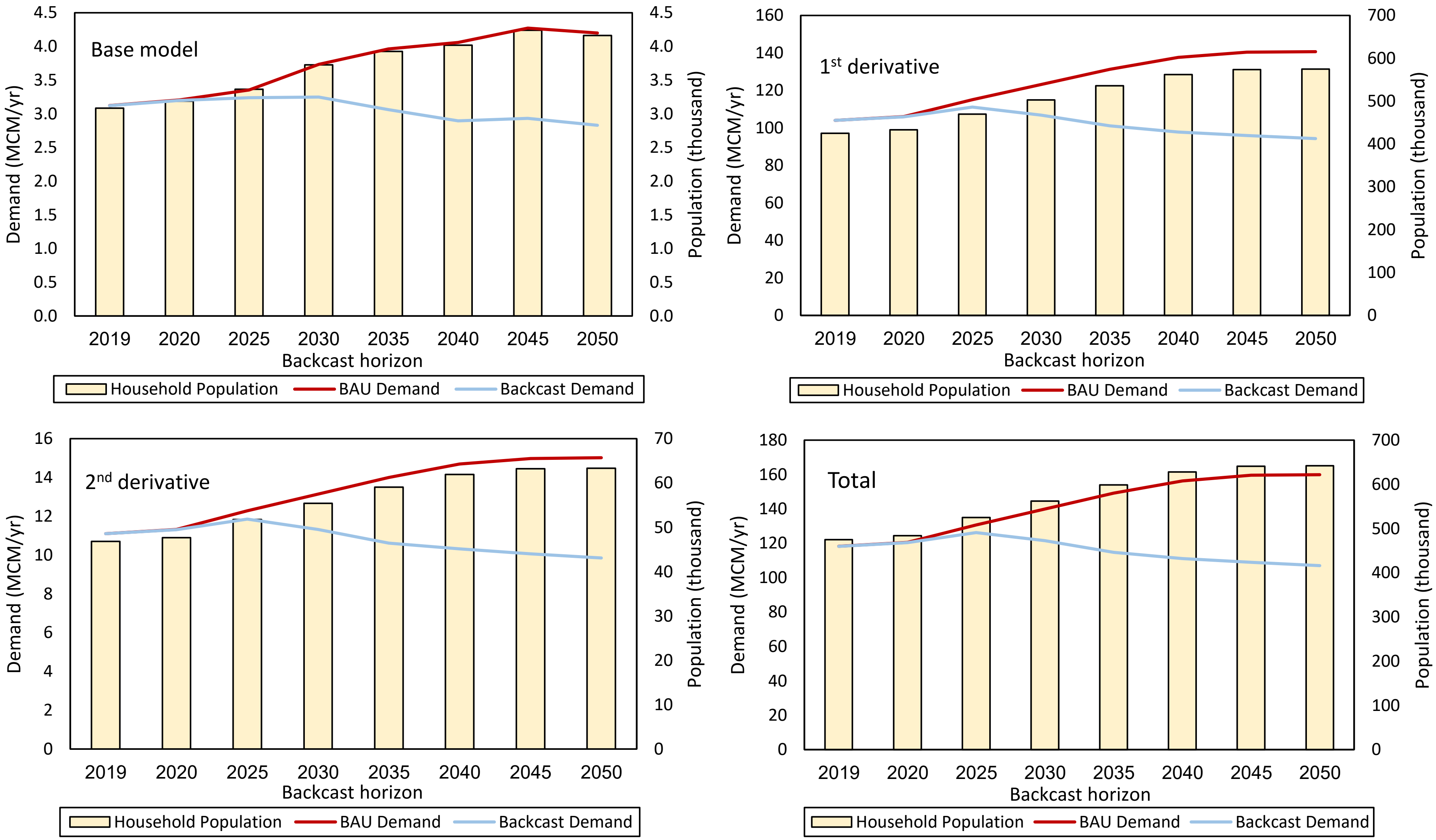

Figure 7.6: Demand by model specification in the Light scenario: non-Kuwaiti P.1.2

Table 7.2: Average PHC and PCC (l/d) under the Light scenario in 2050: P.1.2

Average PHC/PCC (Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	1,997	489
1st	Villa	1,933	474
	Floor or flat in a villa	1,307	280
	Flat	844	196
	Traditional house	1,669	400
Aggregate average (1st derivative)		1,438	338
Aggregate average (base and 1st derivative)		1,550	368
Average PHC/PCC (non-Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	1,674	320
1st	Villa	1,617	308
	Floor or flat in a villa	764	138
	Flat	502	103
	Traditional house	1,038	201
	Annex	504	98
2nd	Floor or flat in a villa	742	133
	Flat	478	98
	Traditional house	1,005	195
	Annex	492	96
Aggregate average (1st derivative)		885	170
Aggregate average (2nd derivative)		679	130
Aggregate average (base and 1st and 2nd derivative)		882	169

7.2.1.2 Moderate target: Intermediate scenario

First package: P.2.1

The package employs the adoption of high-efficient showerhead (= -1σ) and efficient toilet and washing floor tap appliances (= μ). The output of the backcast MC-WEC model manipulation have ended up with a required market penetration rate of 88% for showerheads, 84.5% for toilets, and 75% for washing floor taps; these rates are considered the threshold to achieve the target of the *Intermediate* scenario. As well, these rates have been applied equally for all household population segments. It is a result of no incentives introduced to vary the penetration amongst household segments (similar to the *Light* scenario).

On grand aggregate demand, household demand has increased from base year to reach 485.3 MCM in 2025[22] (due to low technology diffusion; similar performance with *Light* scenario). Then demand has dropped to 345.3 MCM to meet the backcast target; the intensity of technology intervention diffused has prevent any demand rebound (Figure 7.7). On demand by dwelling type, Kuwaiti villa has the highest demand share proportion of 53.8% of grand aggregate demand; whilst the lowest demand share went to floor or flat in a villa of non-Kuwaiti household with demand share proportion of 1%. Villa dwelling type occupies the highest demand of total Kuwaiti demand share of 70.7%, whilst it is flat dwelling type for non-Kuwaiti demand with 60.1% of total non-Kuwaiti demand. In contrast, the lowest Kuwaiti demand share went to flat with a proportion of 4.3% of Kuwaiti demand, while it is floor or flat type for non-Kuwaiti with a share of 4.3% of non-Kuwaiti demand. On demand by model specification, on average, the first derivative of Kuwaiti demand occupies the highest demand share of 50.1% of grand aggregate demand; in the opposite, the lowest share went to the base model of non-Kuwaiti with a share of 0.7%, see Figure 7.8 and Figure 7.9.

On disaggregate demand, the average Kuwaiti and non-Kuwaiti PHC/PCC has been reduced to achieve a 56% reduction in backcast endpoint 2050. For example, the average PHC in Kuwaiti villa in the base model has been reduced to reach 1,554 l/d compared with the observed PHC of 3,399 l/d. So as other PHC/PCC categories have been reduced by a range of 54% to 58% at the endpoint of the backcast horizon. To compare between the backcast PHC and observed PHC, Table 3.10 shows the PHC demand matrix (observed PHC), and Table 7.3 showing the average backcast PHC/PCC by dwelling type, model specification, and household status.

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[22] Backcast household demand has been decreased compared with BAU demand, but the backcast demand has been increased until 2025 in comparison with the base year 2018.

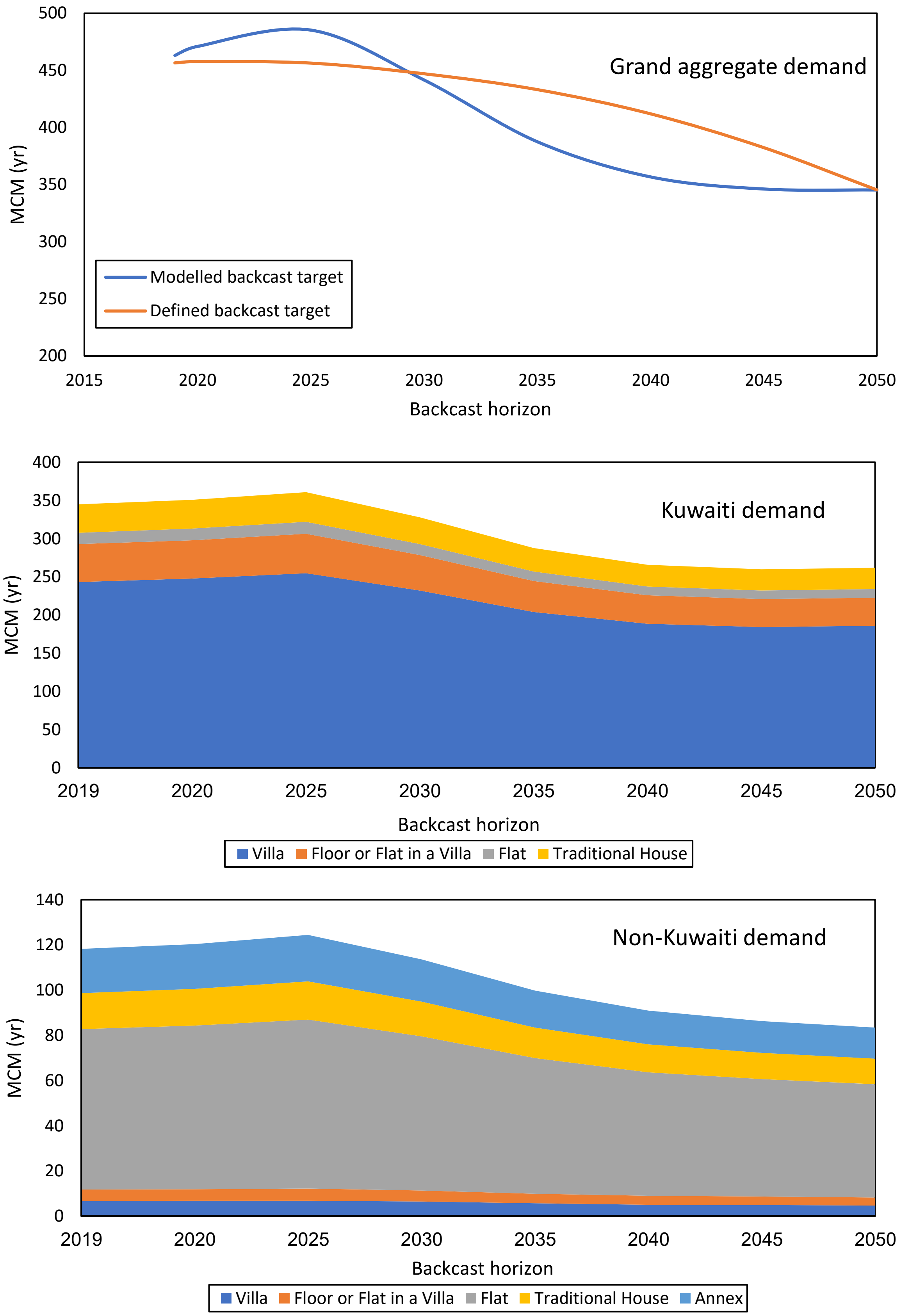

Figure 7.7: Aggregate demand and demand by dwelling type in the Intermediate scenario: P.2.1

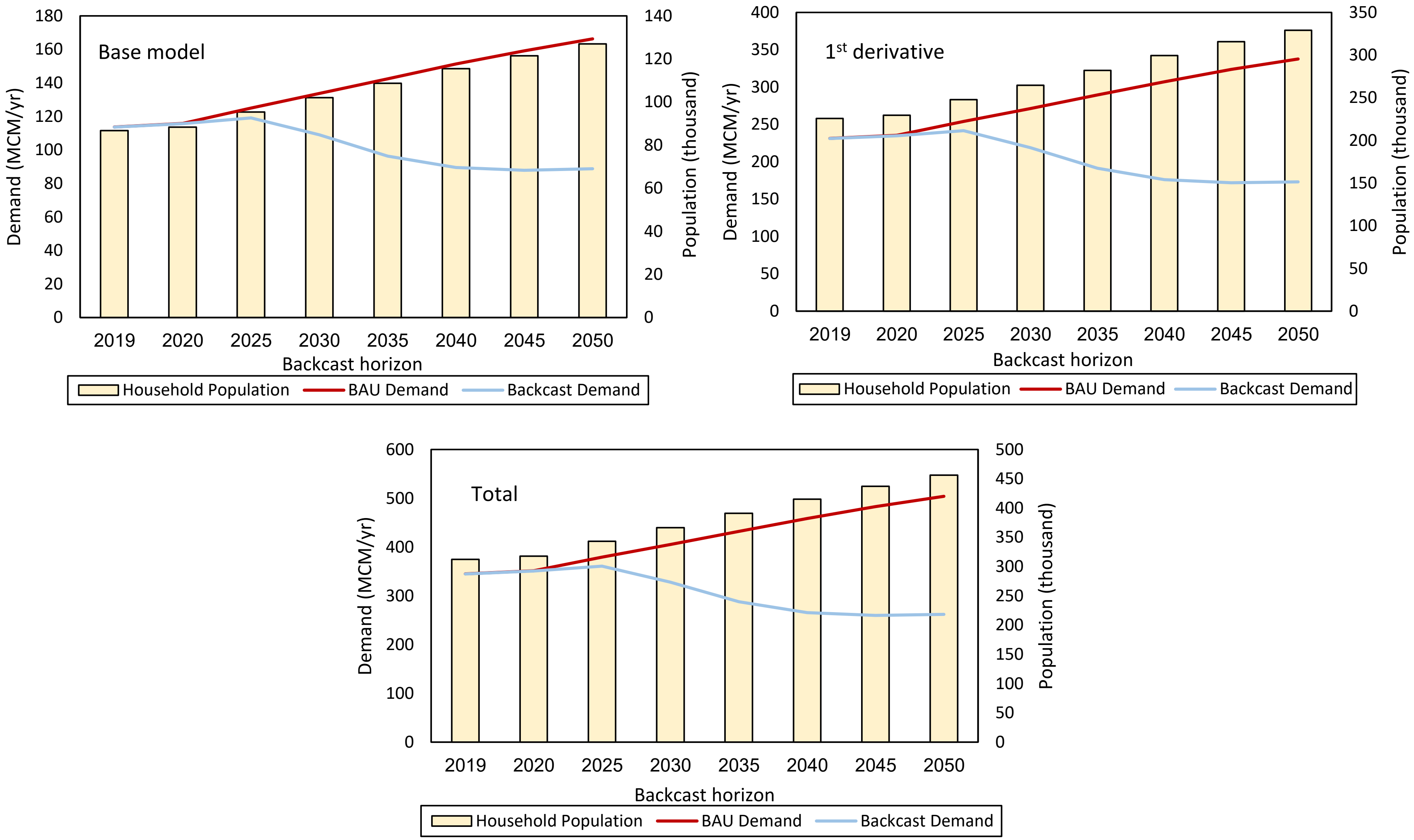

Figure 7.8: Demand by model specification in the Intermediate scenario: Kuwaiti P.2.1

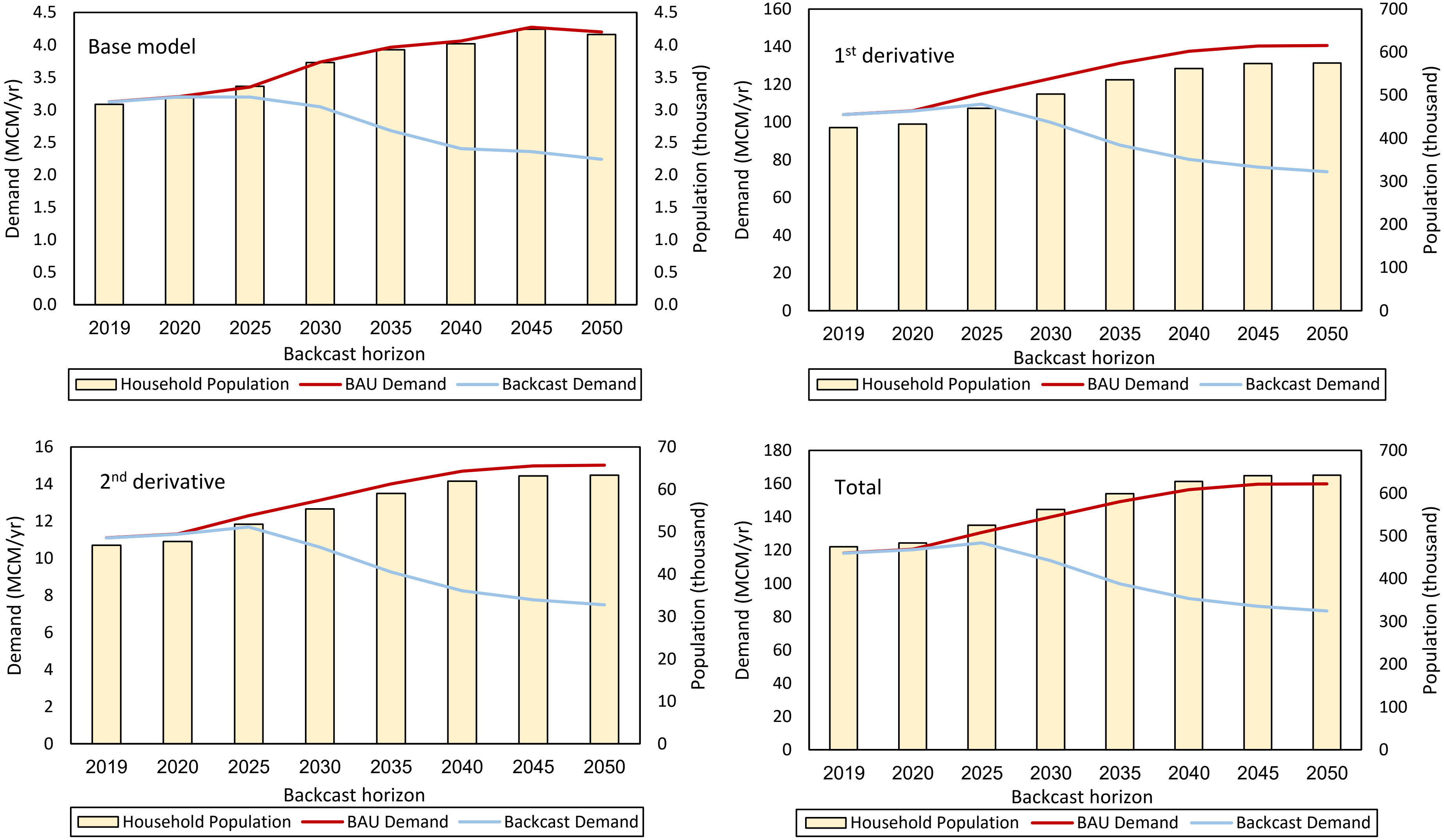

Figure 7.9: Demand by model specification in the Intermediate scenario: non-Kuwaiti P.2.1

Table 7.3: Average PHC and PCC (l/d) under the Intermediate scenario in 2050: P.2.1

Average PHC/PCC (Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	1,554	379
1st	Villa	1,463	358
	Floor or flat in a villa	995	213
	Flat	646	149
	Traditional house	1,266	302
Aggregate average (1st derivative)		1,092	255
Aggregate average (base and 1st derivative)		1,185	280
Average PHC/PCC (non-Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	1,304	249
1st	Villa	1,228	234
	Floor or flat in a villa	600	107
	Flat	386	79
	Traditional house	793	153
	Annex	387	75
2nd	Floor or flat in a villa	553	99
	Flat	355	73
	Traditional house	745	144
	Annex	365	71
Aggregate average (1st derivative)		679	130
Aggregate average (2nd derivative)		504	97
Aggregate average (base and 1st and 2nd derivative)		671	128

Second package: P.2.2

The package performance diverts from what was presented in the previous packages because of introducing the economic (water pricing) intervention with technology intervention. The water pricing intervention has been only applied to the non-Kuwaiti household population where the price elasticity of demand has been introduced from the year 2035[23]. Here, the price effect has been manipulated through the duration and frequency elements. In duration manipulation, two price elasticity parameters have been presented in the model (but with same price increase 100% applied gradually from the start year 2035 = an increase of 6.3% per annum) based on the household segments; the first parameter is applied in first and second derivatives; the second is applied in the base model. The elasticity of the first and second derivatives is higher than the elasticity of the base model. This is

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[23] Several model manipulations employed, hence, year 2035 selected as suitable point to start the economic intervention.

because that the households of first and second derivatives are assumed to have higher sensitivity (median and low-income households) to water price change than the base model households (high-income), see Figure 7.21. In frequency manipulation, a reduction of one time in each component (except Shower and Toilet)[24] in 2035 and 2045, which has been applied equally to all population segments. Because the frequencies are already relatively low in comparison with Kuwaiti frequencies; thus, the effect is assumed not to be high as duration so that it can be differentiated amongst household segments.

Water pricing intervention has been performed as the key driver in changing a consumer's behaviour by; (i) change consumption habits (curtailment behaviour); and (ii) seek alternatives to reduce water bills (purchasing efficient appliances = efficiency behaviour). Thus, non-Kuwaiti households have been assumed to adopt more efficient appliances than Kuwaiti households (mean values = μ). Within non-Kuwaiti households, the penetration rates have been differentiated by the model specification where, for example, the second derivative (low-income households) has higher penetration rates, see Table 7.9. This is because low-income households are the most vulnerable population segment to price change, thus seeking alternatives to reduce water bills more often than other households.

The equation (22) and (23) have been applied, the maximum reduction resulting in the duration of micro-component use (part of “V” element) is 24% in first and second derivatives and 16% in the base model. The frequency “F” in each component has been reduced once in 2035 and 2045. The aggregate price effect of the two equations has reached the maximum reduction (29.5%) in the first derivative and lowest reduction (22.9%) in the base model. The grand aggregate reduction is 29.2% where the first derivative has put the largest effect (weight) because of the large population number fall in this derivative (Table 7.5).

The effect of all interventions has shown that, on grand aggregate demand, household demand has increased from base year to reach 485.3 MCM in 2025 (decreased against BAU demand). Then demand has rapidly dropped to 345.3 MCM to reach the backcast target. The price intervention has put moderate effect on grand aggregate demand where

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[24] The frequency in Toilet component has not been modelled, referred to as a biological need; in Shower component, the frequency has been previously set as one time a day for each member of a household which has not been modelled, for lifestyle and hygiene reasons.

demand reached a trough by 312.3 MCM, then the demand rebounded to backcast endpoint 345.3 MCM. This demand rebound is as a result of the low intensity of technology diffusion/adoption in Kuwaiti household (heavy rebound) and non-Kuwaiti households (damped rebound), see Figure 7.10, Figure 7.11, and Figure 7.12.

On demand by dwelling type, Kuwaiti villa has the highest demand share proportion of 58.9% of grand aggregate demand; whilst the lowest demand share went to floor or flat in a villa of non-Kuwaiti household with demand share proportion of 0.67%. Villa dwelling type occupies the highest demand of total Kuwaiti demand share of 70.9%, whilst it is flat dwelling type for non-Kuwaiti demand with 59.3% of total non-Kuwaiti demand. In contrast, the lowest Kuwaiti demand share went to flat with a proportion of 12.3% of Kuwaiti demand, while it is floor or flat type for non-Kuwaiti with a share of 4% of non-Kuwaiti demand. On demand by model specification, on average, the first derivative of Kuwaiti demand occupies the highest demand share of 55% of grand aggregate demand; in the opposite, the lowest share went to the base model of non-Kuwaiti with a share of 0.5%.

On disaggregate demand, as a result of introducing the price intervention, the non-Kuwaiti PHC/PCC has been differentiated into two groups; (i) households adopting technology (backcast household matrix), and; (ii) household not adopting technology (= initial household matrix - backcast household matrix). Each group has been classified into two categories based on the method used to wash dishes; (i) PHC/PCC of wash by hand (kitchen sink tap) sample; (ii) PHC/PCC of dishwasher sample. This differentiation is a result of manipulating the Wash Dishes component, the duration (wash by hand) and frequency (dishwasher and wash by hand) elements in all non-Kuwaiti households (adopting/not adopting technology).

On average, Kuwaiti PHC/PCC has been reduced to achieve a 48% reduction by backcast endpoint 2050. For non-Kuwaiti, the grand aggregate average PHC/PCC has been reduced by 46% of this, 28.5% by non-Kuwaiti households not adopting the technology (wash by hand/dishwasher), whilst it is 64.5% by households adopting technology. Table 7.4 shows the average backcast PHC/PCC by dwelling type, model specification, and household status.

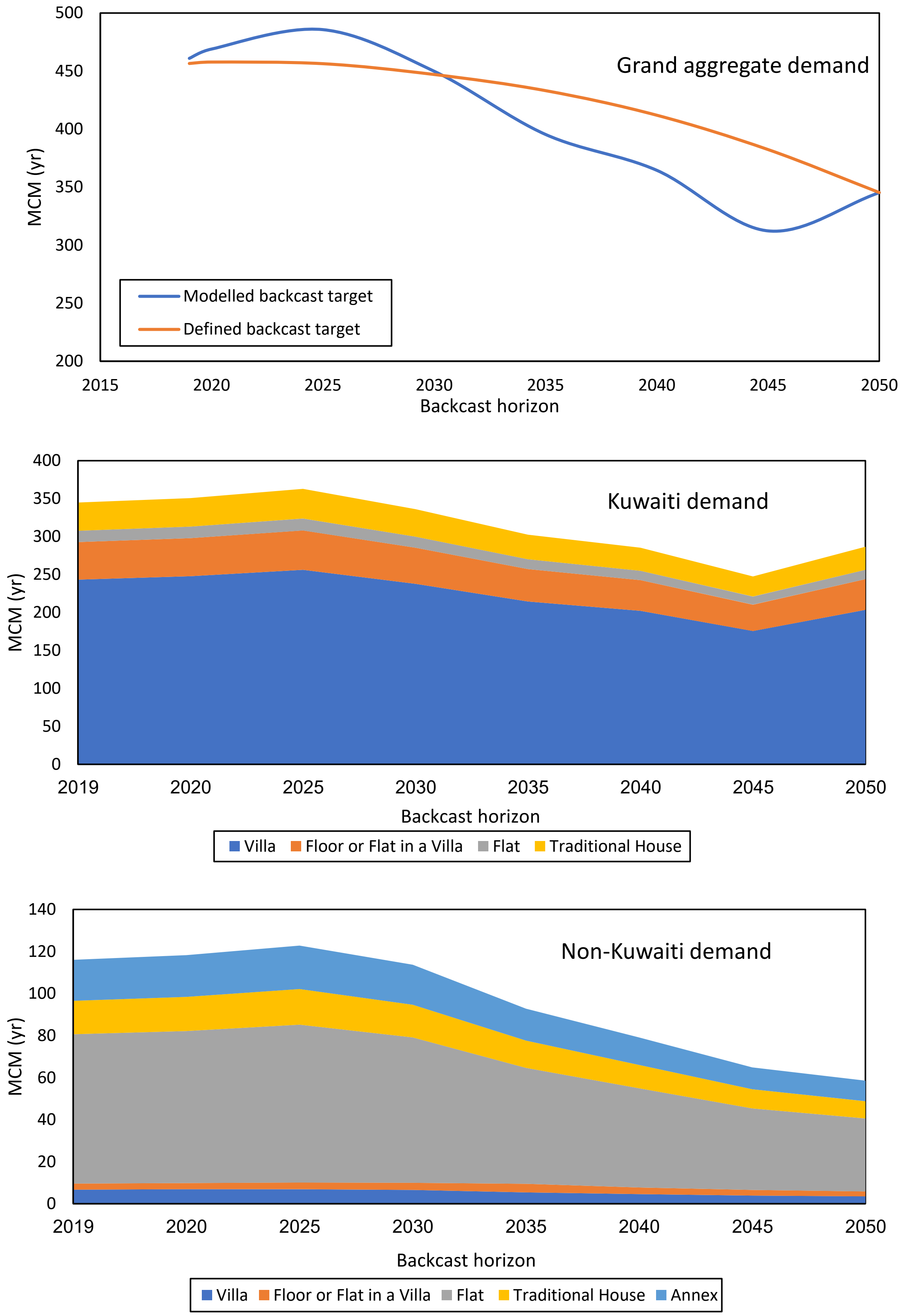

Figure 7.10: Aggregate demand and demand by dwelling type in the Intermediate scenario: P.2.2

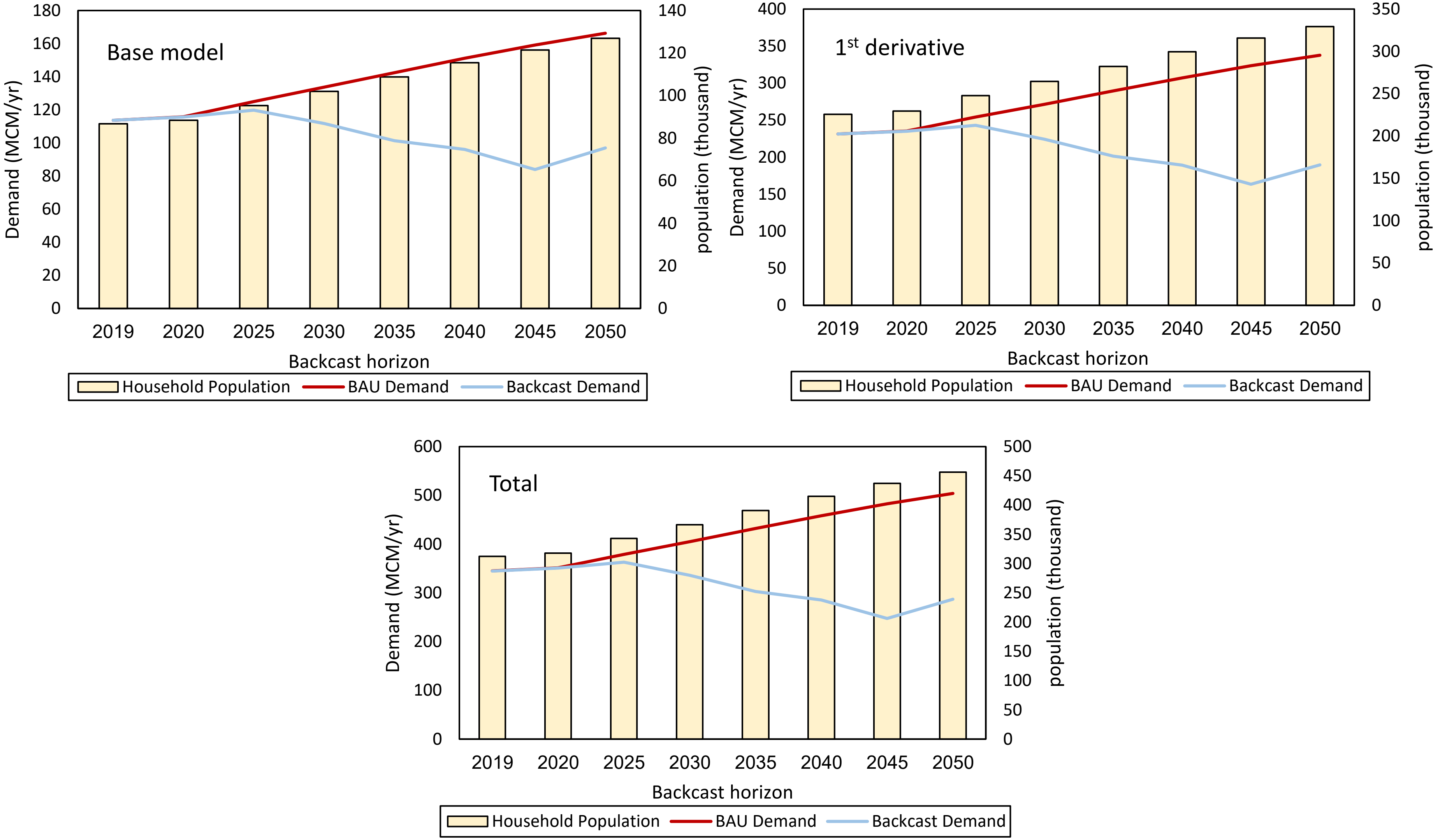

Figure 7.11: Demand by model specification in the Intermediate scenario: Kuwaiti P.2.2

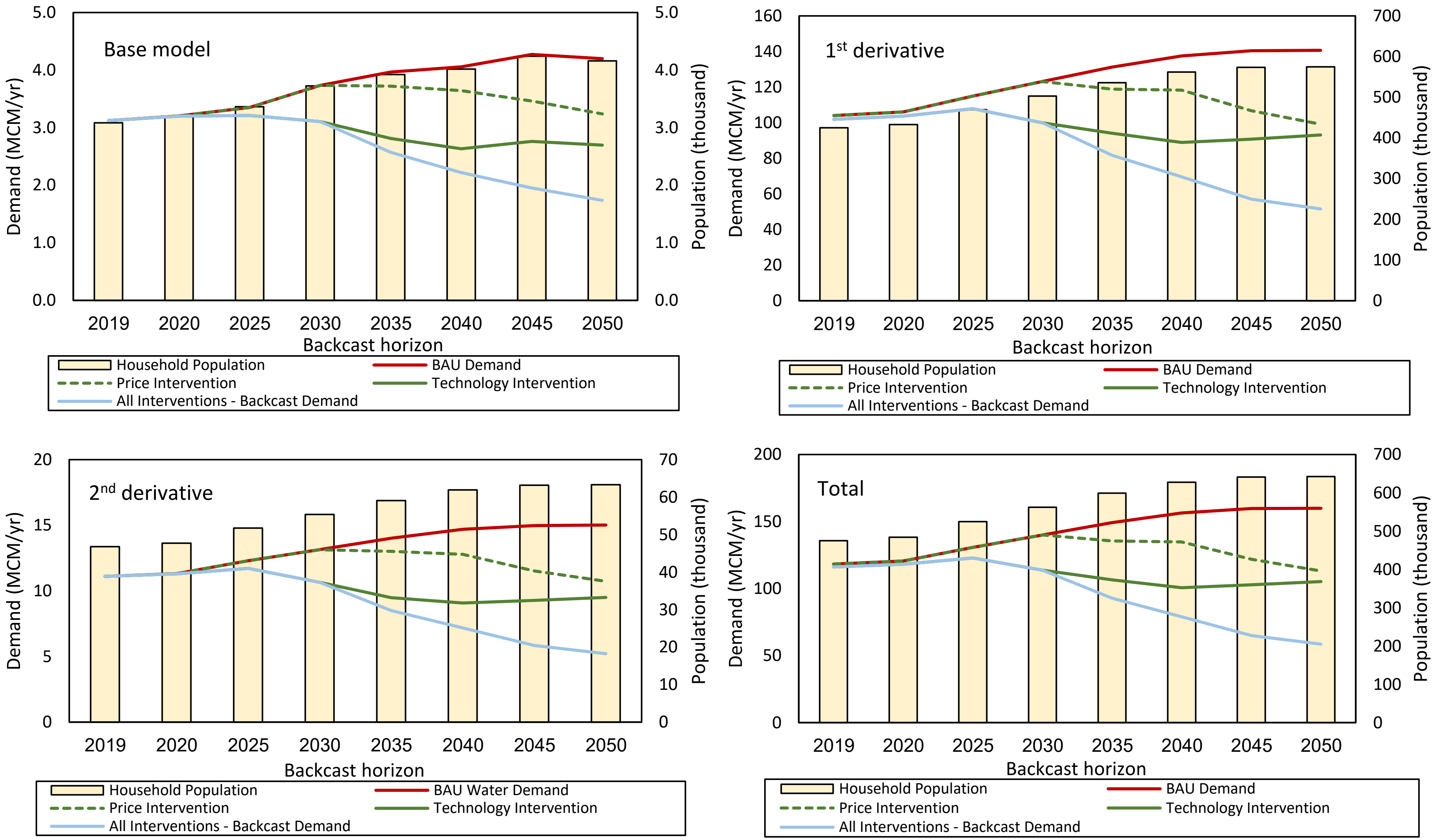

Figure 7.12: Demand by model specification in the Intermediate scenario: non-Kuwaiti P.2.2

Table 7.4: Average PHC and PCC (l/d) under the Intermediate scenario in 2050: P.2.2

Average PHC/PCC (Kuwaiti)			
Model	**Dwelling type**	**PHC**	**PCC**
Base	Villa	1,831	448
1st	Villa	1,746	427
	Floor or flat in a villa	1,183	253
	Flat	765	177
	Traditional house	1,508	361
Aggregate average (1st derivative)		1,300	305
Aggregate average (base and 1st derivative)		1,406	333

Average PHC/PCC (non-Kuwaiti)									
Model	**Dwelling type**	**Adopting technology (Wash by hand)**		**Adopting technology (Dishwasher)**		**Not adopting technology (Wash by hand)**		**Not adopting technology (Dishwasher)**	
		PHC	**PCC**	**PHC**	**PCC**	**PHC**	**PCC**	**PHC**	**PCC**
Base	Villa	1,112	211	1,125	213	2,180	419	2,194	421
1st	Villa	1,003	188	1,034	194	2,046	391	2,077	396
	Floor or flat in a villa	429	77	438	78	870	158	879	159
	Flat	301	62	306	62	591	122	595	123
	Traditional house	641	122	658	124	1,266	247	1,282	250
	Annex	305	60	309	60	595	117	599	117
2nd	Floor or flat in a villa	464	82	480	84	928	168	944	170
	Flat	287	58	294	60	600	124	607	125
	Traditional house	627	119	654	124	1,285	251	1,313	256
	Annex	300	59	307	60	600	119	607	120
Aggregate average (1st derivative)		536	102	549	104	1,073	207	1,086	209
Aggregate average (2nd derivative)		419	80	434	82	854	165	868	168
Aggregate average (base and 1st and 2nd derivative)		547	104	560	106	1,096	212	1,110	214

Table 7.5: Demand reduction resulting from the effect of price intervention on non-Kuwaiti demand in 2050 under Intermediate scenario P.2.2: price effect on duration and frequency

Demand reduction (%)						
Model	Villa	Floor or flat in a villa	Flat	Traditional house	Annex	Total
Base model	22.9	N/A*	N/A	N/A	N/A	22.9
1st derivative	27.8	32.5	29.8	28.4	29.0	29.5
2nd derivative	N/A	28.1	29.2	27.4	27.1	28.6
Grand total	25.5	32.1	29.7	28.3	28.8	29.2

* Not/Applicable (N/A)

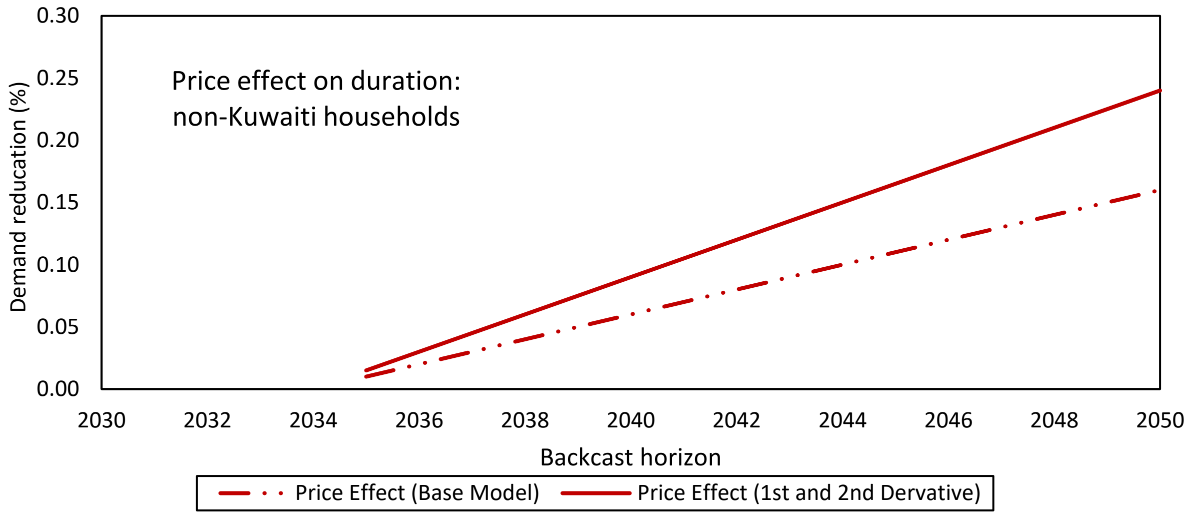

Figure 7.13: The price effect on duration in non-Kuwaiti households by model specification: P.2.2

7.2.1.3 Aggressive target: Optimistic scenario

A demand reduction of 64% under the *Optimistic* scenario implies an aggressive reduction where backcast interventions are highly intensified. This is resulted in the first package P.3.1 where adoption of high-efficient appliances (= -1σ) with high penetration rates has been manipulated and applied to all micro-components in the MC-WEC model. As well to second package P.3.2 where efficient appliances (= μ) manipulated and applied to all micro-components with lower penetration rates but associated with the introduction of price and education interventions manipulated and applied to all population segments.

As a result of comprising Washing Dishes component in the modelling, two equations have been developed before applying the equation 19, to fit MC-WEC model in the *Optimistic* scenario's packages. The Washing Dishes component has a special treatment because; (i) the component uses two methods (wash by hand and dishwasher) and; (ii) methods used are fixed with constant coefficients throughout BAU scenario and previous backcast modelling. To convert the constant coefficients to dynamic efficient/high-efficient of kitchen sink tap/dishwasher adoption, the dishwasher sample has been treated at first, as it the key to convert the component to dynamic status. The following equation has been applied;

$$DDD = (\{c - r_t\} + dp_t) \tag{26}$$

Where DDD is dynamic diffusion of dishwashers; c is the constant coefficient of dishwasher (2.9% Kuwaiti, and 1.2% non-Kuwaiti households); r is the rate of coefficient reduction per annum (i.e., 0.29% Kuwaiti, and 0.12% non-Kuwaiti households) at time t, where t is the time horizon of coefficient reduction (2019 to 2028)[25]. By 2028, all traditional dishwashers have been replaced with efficient/high-efficient ones. At this stage, the dishwasher sample of MC-WEC has been fully dynamic which is directly affected by the penetration rate dp of efficient/high-efficient dishwasher at a certain time t. Consequently, from 2028 up to reach the backcast endpoint, all households adopting efficient/high-efficient dishwashers have been equally presented (see an example in Figure 7.14: dishwasher sample). Second, the result of previous equation (households adopting efficient/high-efficient dishwasher) has been deducted from each component of the backcast household matrix (equation 17) through the application of the following equation;

$$DA = (jp_t - dp_t) \tag{27}$$

Where DA is dishwasher adoption; jp is the penetration of a certain technology of micro-component in the MC-WEC; dp is the penetration of dishwasher at time t (this has been applied for all MC-WEC components against Washing Dishes component; i.e., as other components should have higher penetration rates. This equation has been developed to differentiate the dishwasher method and wash by hand (kitchen sink tap: efficient/high-efficient and traditional taps) method in the Washing Dishes component of the backcast household matrix. After applying this equation, dishwasher and wash by hand methods have been calculated and differentiated. Third, wash by hand method has been differentiated to

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[25] The average lifespan of dishwasher is ten year; hence, it has been assumed that it started from 2019. Source: Santanachote, Perry. 2019. *How to make your dishwasher last longer.* [Online]. Available from: https://www.consumerreports.org/dishwashers/how-to-make-your-dishwasher-last-longer/

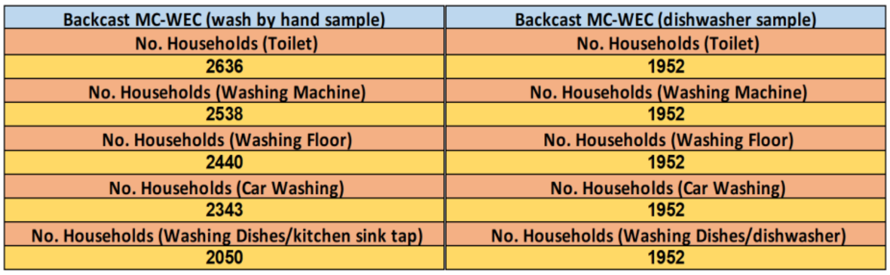
calculate the households using efficient/high-efficient and traditional kitchen sink tap through applying equation 19 (i.e., as some households still using traditional kitchen sink tap in the backcast household matrix), see an example in Figure 7.14: wash by hand sample. It should notice that the penetration rates of dishwasher and wash by hand methods should be 100% at maximum when adding them together as it presented in one component, so it is;

$$Wp = dp + kp = \leq 1 \tag{28}$$

Where Wp is the penetration rate of washing dishes component; dp is the penetration of efficient/high-efficient dishwashers; kp is the penetration of efficient/high-efficient kitchen sink tap. Here, through utilising the equations above, it can be found in the backcast household matrix; (i) the households adopting efficient/high-efficient dishwashers; (ii) the households adopting efficient/high-efficient kitchen sink tap, and; (iii) the households adopting traditional kitchen sink tap. Accordingly, what remains is, to calculate the households adopting traditional kitchen sink tap in the initial household matrix, to do so, this equation has been developed;

$$TKIHM = 1 - jp_t \tag{29}$$

Where $TKIHM$ is the number of households adopting traditional kitchen sink tap in the initial household matrix; jp_t is the highest penetrated technology in the MC-WEC model of the backcast household matrix (i.e., it is Shower (S) component in our model = all resulted elements of Washing Dishes component are included = backcast matrix + initial matrix = 1). At this point, the number of households adopting the traditional kitchen sink tap has been calculated; thus, the model has now fitted the *Optimistic* scenario's packages where manipulation exercise has been implemented and packages have been developed.



Backcast MC-WEC (wash by hand sample)	Backcast MC-WEC (dishwasher sample)
No. Households (Toilet)	No. Households (Toilet)
2636	1952
No. Households (Washing Machine)	No. Households (Washing Machine)
2538	1952
No. Households (Washing Floor)	No. Households (Washing Floor)
2440	1952
No. Households (Car Washing)	No. Households (Car Washing)
2343	1952
No. Households (Washing Dishes/kitchen sink tap)	No. Households (Washing Dishes/dishwasher)
2050	1952

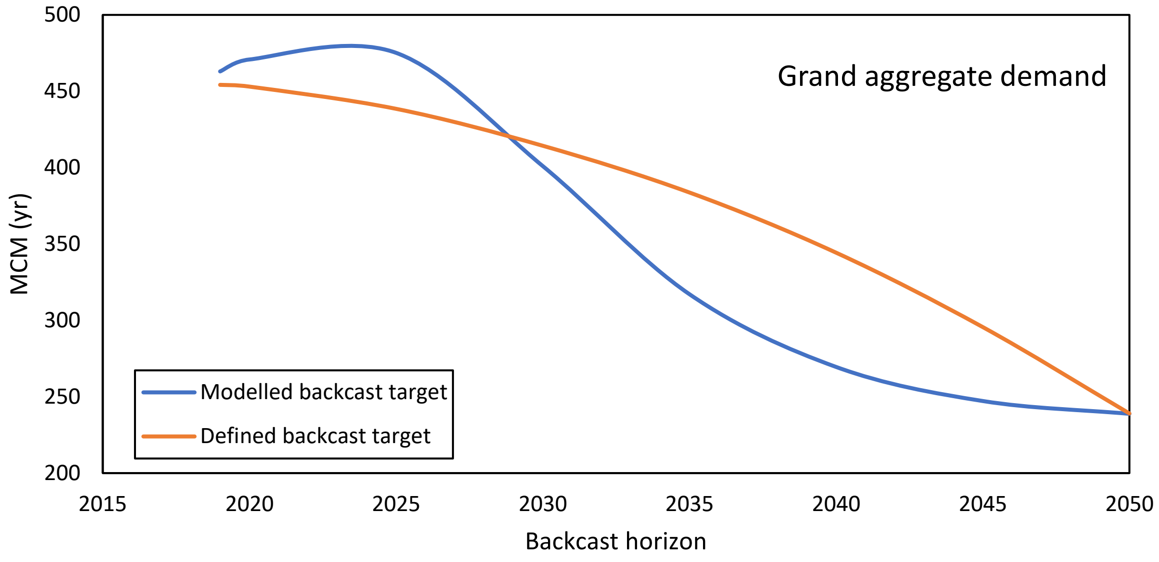
Figure 7.14: An example of the MC-WEC model samples in the backcast household matrix

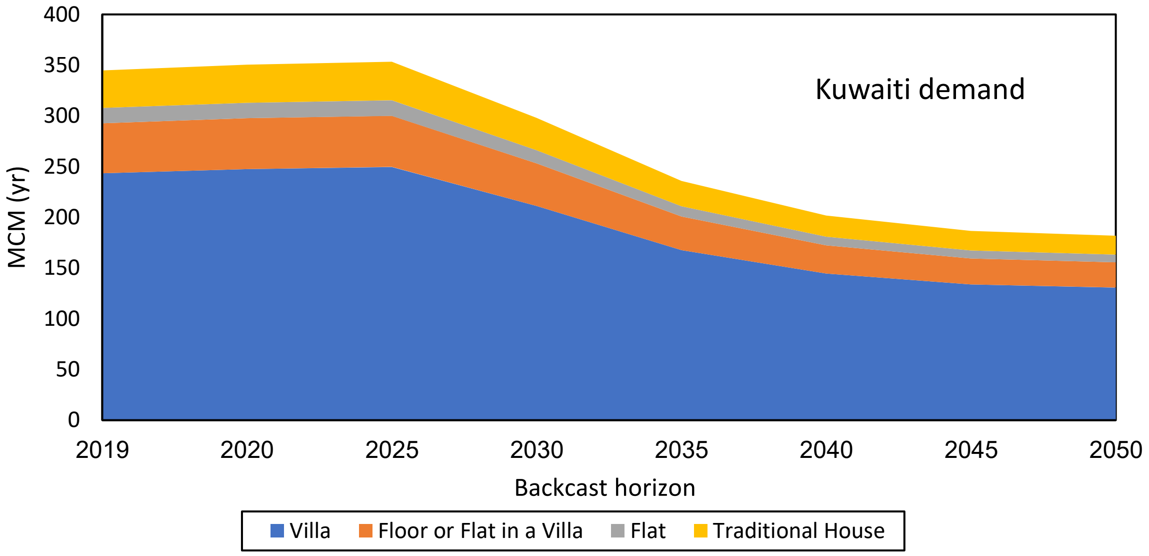
First package: P.3.1

The package assumes adopting high-efficient appliances for all micro-components in the backcast MC-WEC model with high penetration rates. Consequently, a series of model manipulation has been applied and rates of technology penetrations have been obtained to achieve the aggressive target, see Table 7.9. As what have been applied in P.1.1, P.1.2, and P.2.1, the penetration rate for each component has been manipulated and applied equally for all household population segments. Where no incentives applied to differentiate the adoption of technology amongst households' segments (see section 7.2.2 for a detailed discussion on how these rates have been manipulated).

On grand aggregate demand, household demand has slightly increased from base year to reach 475.2 MCM in 2025 (decreased in comparison with BAU). Then demand has dramatically dropped to 238.8 MCM to achieve the aggressive backcast target. On demand by dwelling type, Kuwaiti villa has the highest demand share proportion of 54.7% of grand aggregate demand; whilst the lowest demand share went to floor or flat in a villa of non-Kuwaiti household with demand share proportion of 1%. Villa dwelling type occupies the highest demand of total Kuwaiti demand share of 72%, whilst it is flat dwelling type for non-Kuwaiti demand with 60% of total non-Kuwaiti demand. In contrast, the lowest Kuwaiti demand share went to flat with a proportion of 4.2% of Kuwaiti demand, while it is floor or flat type for non-Kuwaiti with a share of 4.3% of non-Kuwaiti demand, Figure 7.15. On demand by model specification, on average, the first derivative of Kuwaiti demand occupies the highest demand share of 48.7% of grand aggregate demand; in the opposite, the lowest share went to the base model of non-Kuwaiti with a share of 0.7%, see Figure 7.16 and Figure 7.17.

On disaggregate demand, as a result of including the Washing Dishes component in the backcast MC-WEC modelling, the PHC/PPC has been categorised under two categorisations; (i) PHC/PCC of wash by hand sample, and; (ii) PHC/PCC of dishwasher sample, see Table 7.6. The grand average Kuwaiti and non-Kuwaiti PHC/PCC has been reduced by 68% in backcast endpoint 2050. Table 3.10 shows the observed PHC, where a comparison can be made.





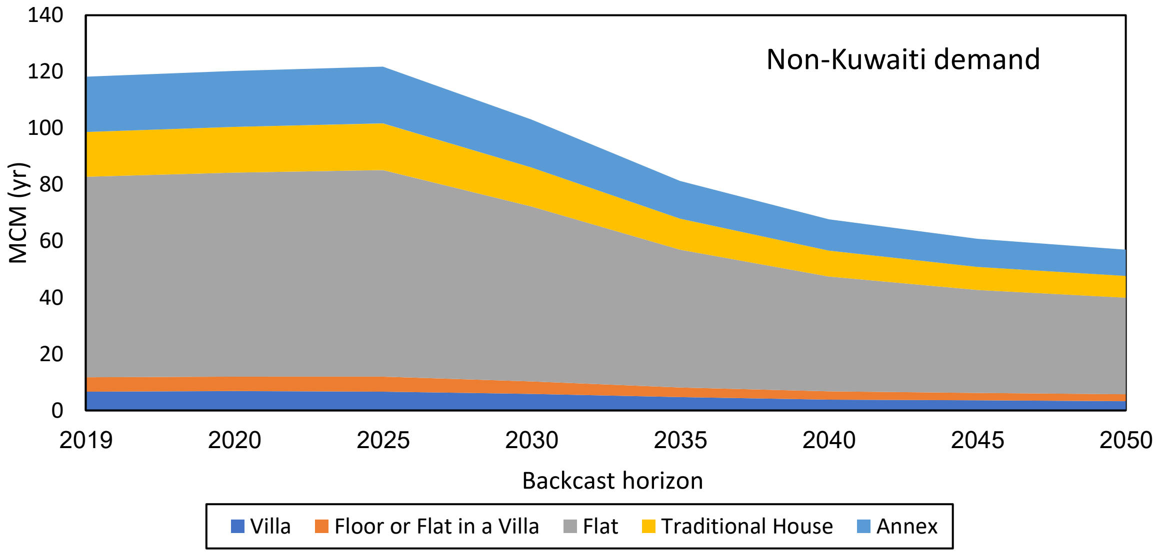


Figure 7.15: Aggregate demand and by dwelling type in the Optimistic scenario: P.3.1

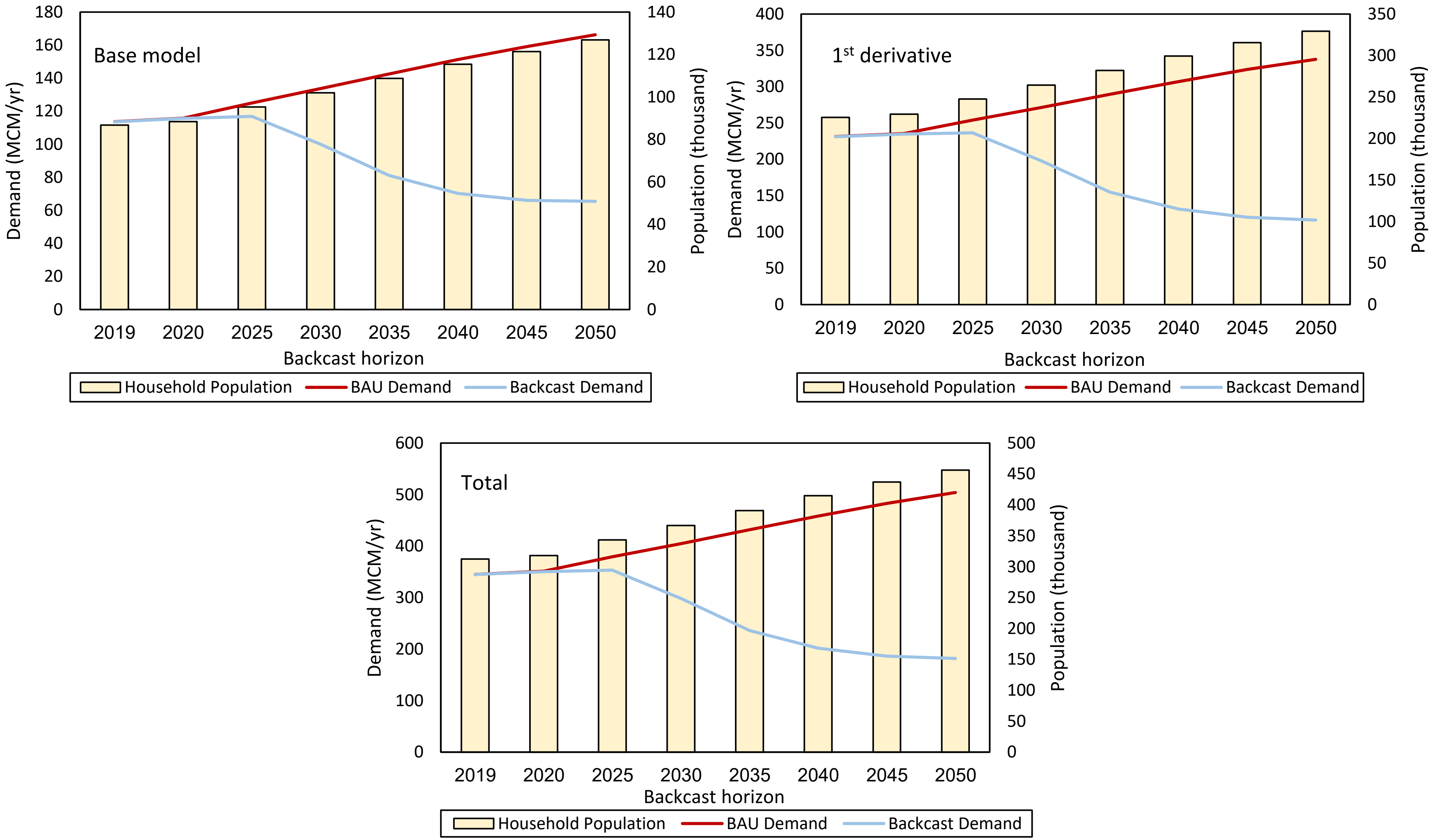


Figure 7.16: Demand by model specification in the Optimistic scenario: Kuwaiti P.3.1

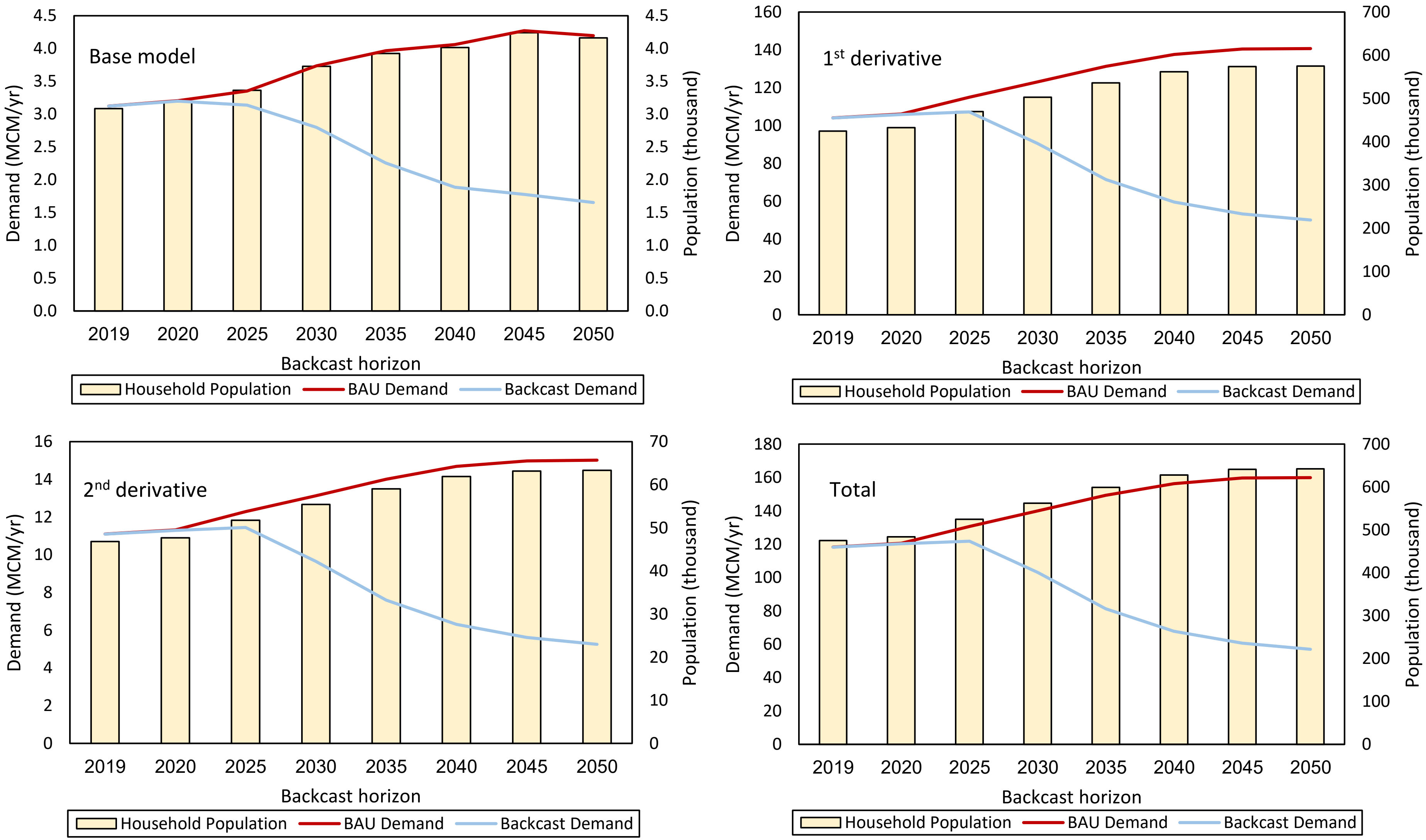


Figure 7.17: Demand by model specification in the Optimistic scenario: non-Kuwaiti P.3.1

Table 7.6: Average PHC and PCC (l/d) under the Optimistic scenario in 2050: P.3.1

Average PHC/PCC (Kuwaiti)					
Model	**Dwelling type**	**(Wash by hand)**		**(Dishwasher)**	
		PHC	**PCC**	**PHC**	**PCC**
Base	Villa	1,210	296	1,205	295
1st	Villa	1,009	247	992	243
	Floor or flat in a villa	701	150	692	148
	Flat	457	105	452	104
	Traditional house	880	210	866	207
Aggregate average (1st derivative)		762	178	750	175
Aggregate average (base and 1st derivative)		851	202	841	199
Average PHC/PCC (non-Kuwaiti)					
Model	**Dwelling type**	**(Wash by hand)**		**(Dishwasher)**	
		PHC	**PCC**	**PHC**	**PCC**
Base	Villa	1,017	194	984	201
1st	Villa	851	164	817	168
	Floor or flat in a villa	417	75	393	76
	Flat	273	55	261	58
	Traditional house	560	108	541	111
	Annex	275	53	265	55
2nd	Floor or flat in a villa	414	74	388	75
	Flat	265	54	251	56
	Traditional house	551	107	529	110
	Annex	273	53	259	54
Aggregate average (1st derivative)		475	91	455	94
Aggregate average (2nd derivative)		376	72	357	74
Aggregate average (base and 1st and 2nd derivative)		490	94	469	96

Second Package P.3.2

The package represents the peak of backcast conservation measures intervened, in which all measures have been used, comprising technology, economic, and education measures, manipulated and applied to the entire household population. The pricing and education interventions have been introduced from 2030[26], simultaneously. In pricing intervention, the price elasticity of demand of Kuwaiti households has been assumed as lower than elasticity of non-Kuwaiti households (but with same price increase 100% applied gradually from the start year 2030 = an increase of 4.8% per annum). Within Kuwaiti households, the elasticity has been assumed as the same in base and first derivative (as all Kuwaitis have a higher income than non-Kuwaitis; thus, lower sensitivity to price change). In

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[26] 2030 was selected as an appropriate point to start the economic and education interventions after the manipulation exercise.

contrast, non-Kuwaiti households have been assumed to differentiate by price change by household segments where households in base model have lower price elasticity (high-income households) than households in first and second derivatives (median and low-income households). Figure 7.21 and Figure 7.22 show the price effect on duration to household segments (plus education effect). The approach of manipulating and applying the price effect on duration and frequency is similar to P.2.2 approach (e.g., the frequency of toilet visits has not been modelled). In frequency manipulation, a reduction of one time in each component in 2030 and 2040, which has been applied equally to all population segments.

In education intervention manipulation, Kuwaiti households are assumed to have more response to education's incentivising channels (e.g., public awareness and TV advertisements). As they tend to have higher income and more educated (there is a positive relationship between income level and education level, i.e., high-income = higher education); thus, more sensitive to public education campaigns[27]. Whilst non-Kuwaiti households, the base model and first derivative are assumed as same as Kuwaiti households' responsiveness (educated). But in the second derivative, households are assumed to have lower effect by education intervention, where households have lower income; thus, lower education which means lower responsiveness to public education campaigns. The approach of manipulating and applying the education effect on duration and frequency is similar to the price effect approach. In frequency manipulation, a reduction of one time in each component in 2040 has been applied equally to all population segments. Based on the variation of households' responsiveness to price and education effect, different penetration rates have been manipulated, see Table 7.9.

The effect of all interventions has shown that, on grand aggregate demand, household demand has increased from base year to reach 486 MCM in 2025 (decreased against BAU demand). Then demand has rapidly dropped to 238.6 MCM to achieve the aggressive target. The price and education interventions have put moderate effect on aggregate Kuwaiti demand, but aggressive on aggregate non-Kuwaiti demand, see Figure 7.21 and Figure 7.22. Overall, demand reached 285.2 MCM in 2040, then rebounded to reach 293.2 MCM in 2045;

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[27] Educated individuals are more aware of environmental and economic issues (e.g., CO_2 emissions); thus, they tend to seek to participate to reduce adverse environmental and economic impacts (e.g., reducing CO_2 emissions and increasing economic efficiency).

eventually, demand reduced to reach 238.6 in 2050 where reduction is driven by price and education effects. The demand rebound (2040 – 2045) is driven by Kuwaiti demand (i.e., more weight in grand aggregate demand) where the technology penetration is much lower than non-Kuwaiti households.

On demand by dwelling type, Kuwaiti villa has the highest demand share proportion of 56.6% of grand aggregate demand; whilst the lowest demand share went to floor or flat in a villa of non-Kuwaiti household with demand share proportion of 0.87%. Villa dwelling type occupies the highest demand of total Kuwaiti demand share of 71.2%, whilst it is flat dwelling type for non-Kuwaiti demand with 59.5% of total non-Kuwaiti demand. In contrast, the lowest Kuwaiti demand share went to flat with a proportion of 4.2% of Kuwaiti demand, while it is floor or flat type for non-Kuwaiti with a share of 4.2% of non-Kuwaiti demand. On demand by model specification, on average, the first derivative of Kuwaiti demand occupies the highest demand share of 53.1% of grand aggregate demand; in the opposite, the lowest share went to the base model of non-Kuwaiti with a share of 0.64%.

On disaggregate demand, as a result of introducing the price and education interventions, PHC/PCC has been differentiated into two groups; (i) households adopting technology (backcast household matrix), and; (ii) household not adopting technology (initial household matrix). Households adopting technology has been classified into two categories based on the method used to wash dishes; (i) PHC/PCC of wash by hand (kitchen sink tap) sample; (ii) PHC/PCC of dishwasher sample. Whilst households not adopting technology has only wash by hand sample's category as no more traditional dishwasher is used by 2050. On average, the grand aggregate average of Kuwaiti PHC/PCC has been reduced by 63% of this, reduction by 40% of households not adopting technology, and 75% of households adopting technology in 2050. For non-Kuwaiti, the grand aggregate average PHC/PCC has been reduced by 65% of this, 46% by non-Kuwaiti households not adopting the technology, whilst it is 75% by households adopting technology. Table 7.8 shows the average backcast PHC/PCC by dwelling type, model specification, and household status.

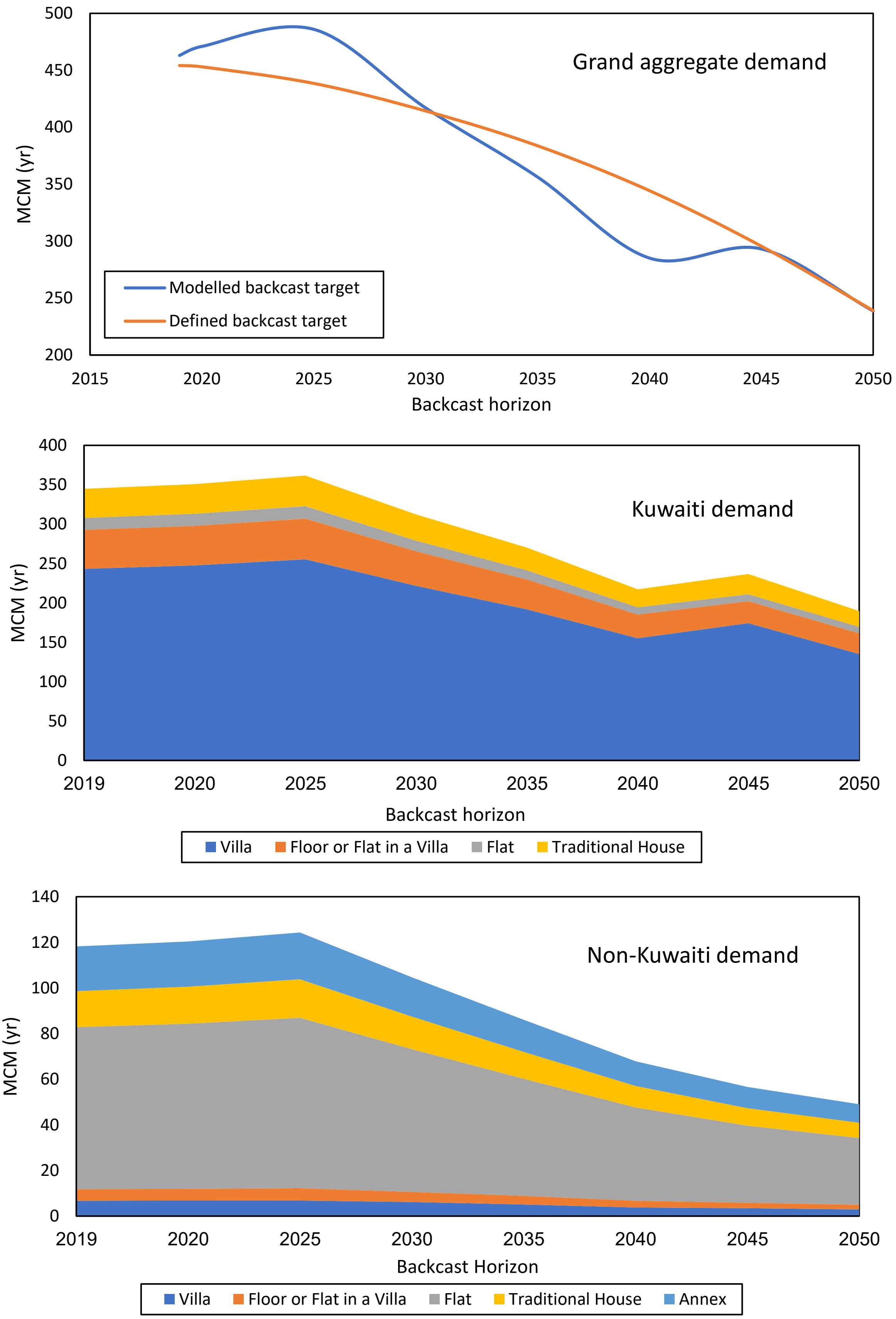

Figure 7.18: Aggregate demand and demand by dwelling type in the Optimistic scenario: P.3.2

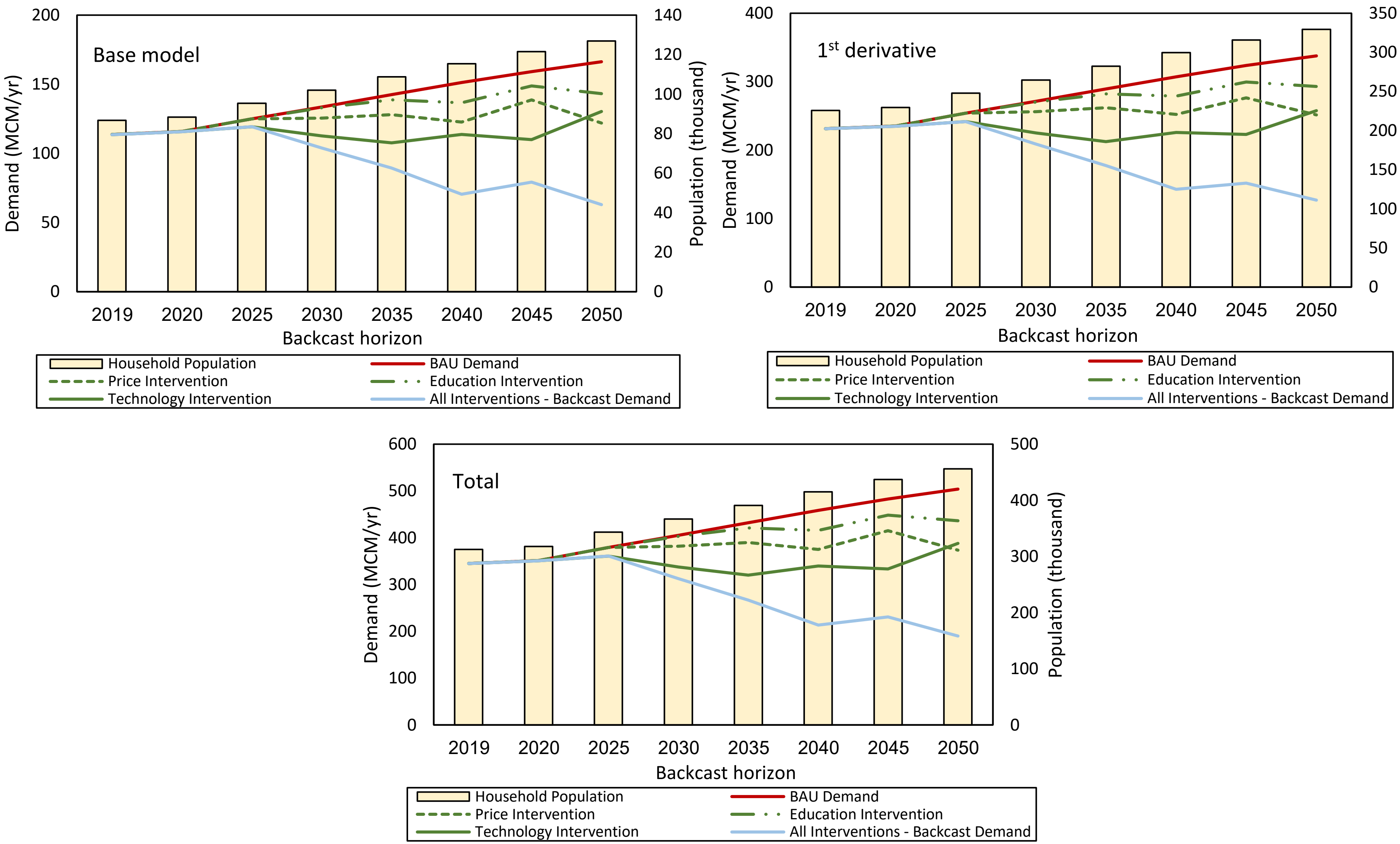

Figure 7.19: Demand by model specification in the Optimistic scenario: Kuwaiti P.3.2

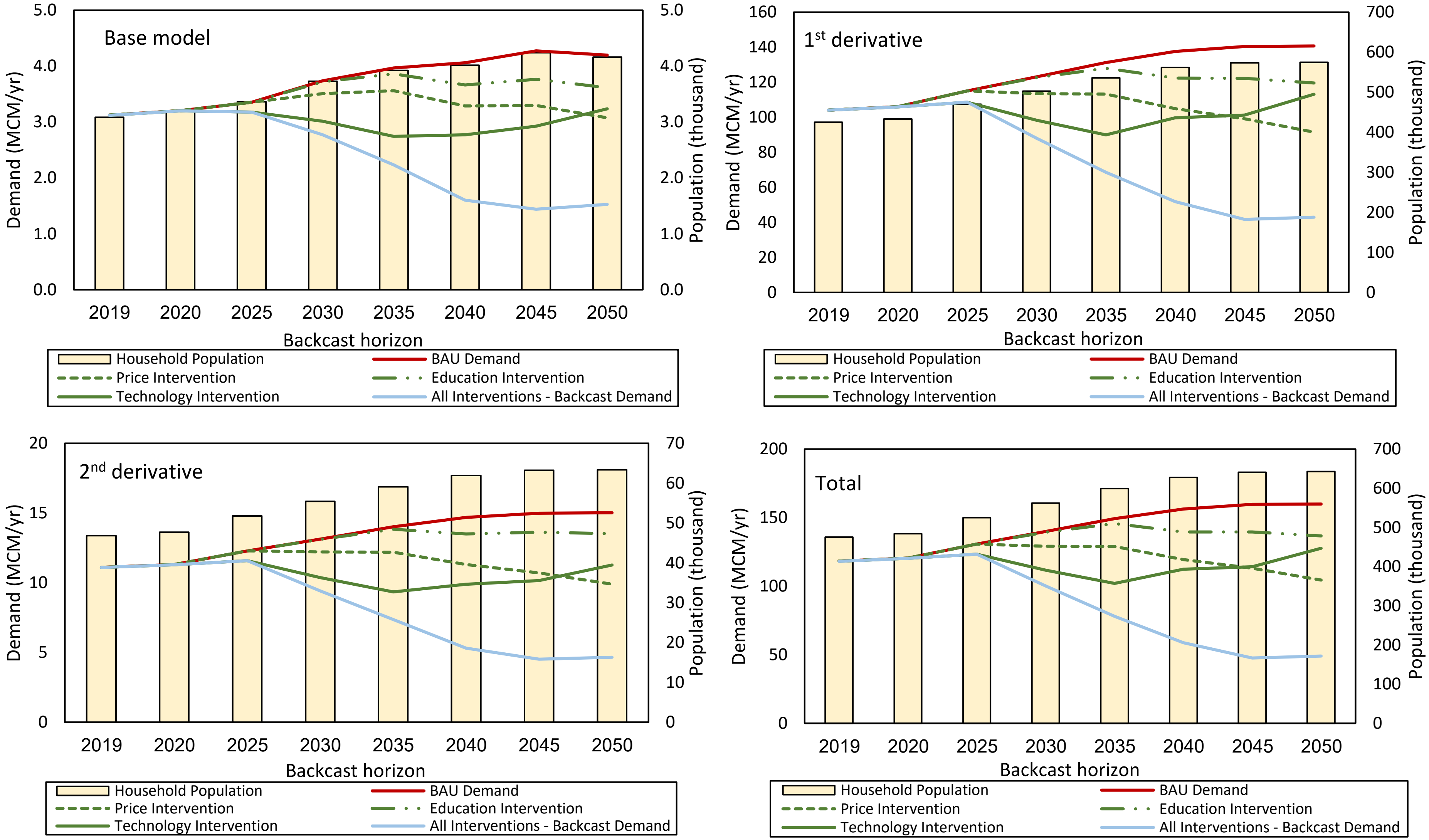

Figure 7.20: Demand by model specification in the Optimistic scenario: non-Kuwaiti P.3.2

Table 7.7: Price and education effect in demand reduction under Optimistic scenario: P.3.2

Price effect (%) **– Kuwaiti**					
Model	Villa	Floor or flat in a villa	Flat	Traditional house	Total
Base model	27.5	N/A[*]	N/A	N/A	27.5
1st derivative	25.7	27.7	27.2	27.2	26.5
				Grand total	26.8
Education effect (%) **– Kuwaiti**					
Model	Villa	Floor or flat in a villa	Flat	Traditional house	Total
Base model	13.8	N/A	N/A	N/A	13.8
1st derivative	12.9	13.6	14.1	13.3	13.2
				Grand total	13.4
Price and education effect (%) **– Kuwaiti**					
Model	Villa	Floor or flat in a villa	Flat	Traditional house	Total
Base model	41.4	N/A	N/A	N/A	41.4
1st derivative	38.6	41.3	41.3	40.4	39.7
				Grand total	40.2

Price effect (%) **– non-Kuwaiti**						
Model	Villa	Floor or Flat in a villa	Flat	Traditional house	Annex	Total
Base model	26.8	N/A	N/A	N/A	N/A	26.8
1st derivative	33.5	34.9	35.4	34.1	34.5	35.0
2nd derivative	N/A	33.6	34.8	33.0	32.6	34.1
Grand total	30.4	34.7	35.3	34.0	34.3	34.7
Education effect (%) **– non-Kuwaiti**						
Model	Villa	Floor or flat in a villa	Flat	Traditional house	Annex	Total
Base model	13.9	N/A	N/A	N/A	N/A	13.9
1st derivative	13.2	14.0	15.4	13.6	15.0	15.0
2nd derivative	N/A	9.4	10.5	9.0	9.4	10.0
Grand total	13.5	13.6	14.9	13.1	14.5	14.5
Price and education effect (%) **– non-Kuwaiti**						
Model	Villa	Floor or flat in a villa	Flat	Traditional house	Annex	Total
Base model	40.7	N/A	N/A	N/A	N/A	40.7
1st derivative	46.7	48.9	50.8	47.7	49.5	49.9
2nd derivative	N/A	43.0	45.2	41.9	42.0	44.1
Grand total	43.9	48.3	50.2	47.1	48.8	49.1

[*] Not/Applicable (N/A)

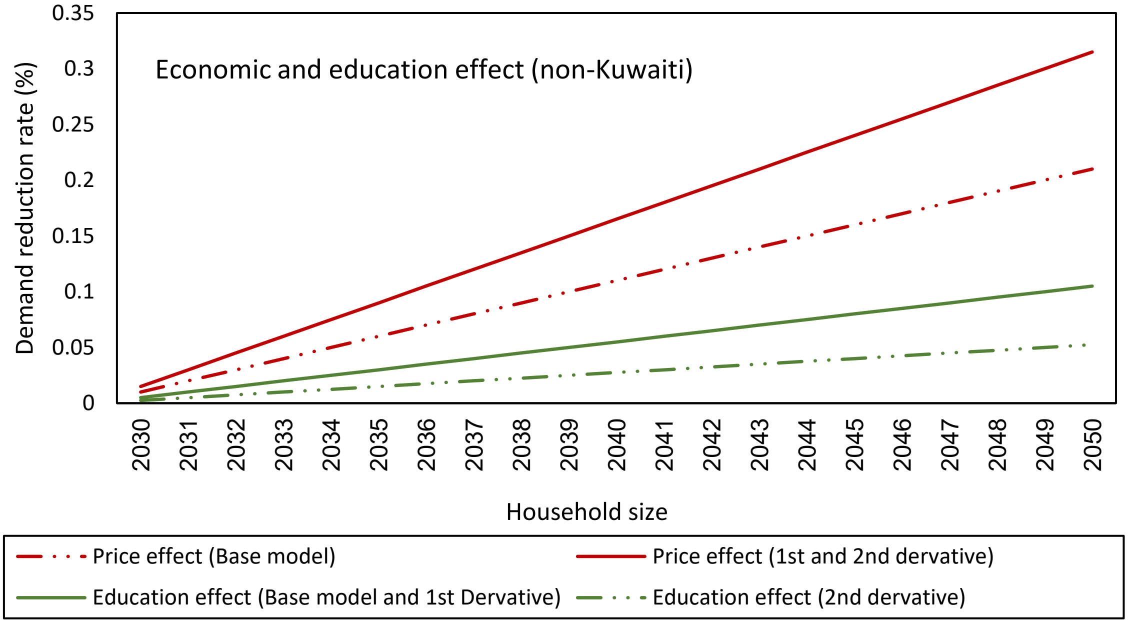

Figure 7.21: The price amd education effect on duration in non-Kuwaiti households by model specification: P.3.2

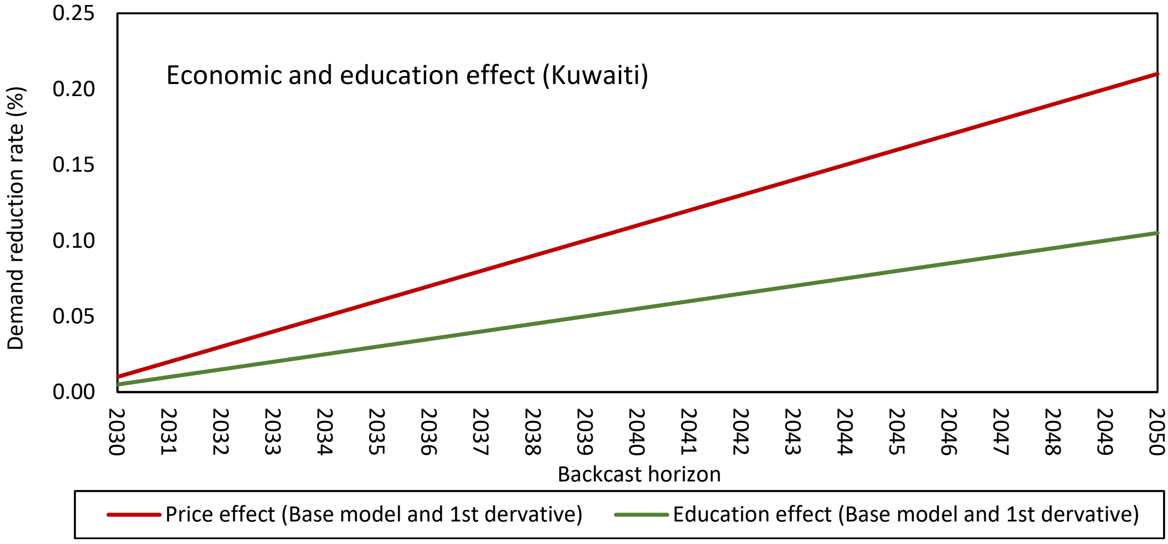

Figure 7.22: The price and education effect on duration in Kuwaiti households: P.3.2

Table 7.8: Average PHC and PCC (l/d) under the Optimistic scenario in 2050: P.3.2

Average PHC/PCC (Kuwaiti)							
Model	**Dwelling type**	**Adopting technology (Wash by hand)**		**Adopting technology (Dishwasher)**		**Not adopting technology (Wash by hand)**	
		PHC	**PCC**	**PHC**	**PCC**	**PHC**	**PCC**
Base	Villa	870	181	873	182	1,968	419
1st	Villa	836	174	831	173	2,061	453
	Floor or flat in a villa	592	115	593	115	1,377	278
	Flat	389	88	388	87	878	206
	Traditional house	726	153	724	152	1,748	379
Aggregate average (1st derivative)		636	132	634	132	1,516	329
Aggregate average (base and 1st derivative)		683	142	682	142	1,606	347

Average PHC/PCC (non-Kuwaiti)							
Model	**Dwelling type**	**Adopting technology (Wash by hand)**		**Adopting technology (Dishwasher)**		**Not adopting technology (Wash by hand)**	
		PHC	**PCC**	**PHC**	**PCC**	**PHC**	**PCC**
Base	Villa	784	150	785	150	1,740	335
1st	Villa	646	121	647	121	1,570	299
	Floor or flat in a villa	318	57	318	56	695	126
	Flat	207	42	207	42	453	94
	Traditional house	425	80	427	80	966	188
	Annex	209	41	209	41	456	90
2nd	Floor or flat in a villa	348	62	348	61	763	138
	Flat	215	44	214	44	493	102
	Traditional house	460	88	463	88	1,058	207
	Annex	227	44	225	44	493	98
Aggregate average (1st derivative)		361	68	362	68	828	160
Aggregate average (2nd derivative)		313	59	312	59	702	136
Aggregate average (base and 1st and 2nd derivative)		384	73	384	73	869	168

7.2.2 The measures needed to achieve backcast targets

The backcast MC-WEC model inputs are considered as the backcast output representing the measures needed to reach backcast targets. These inputs have been defined after a series of model manipulation processes. This includes manipulating parameters' time introductory, intensity, and parameters mixture that has been used to achieve the targets. Table 7.9 shows the needed measures, potential actions required, and potential feasibility.

Due to the complexity in the model structure, a "*constrained backcasting*" approach has been applied rather than an explicit backcasting approach. This means realistic measure (realistic to the context of Kuwait) options have been adopted rather than a very wide range of options that in practice are unrealistic (e.g., 500% price increase). This is still within the backcasting nature in which radical but reasonable measures are the target (see section 6.2). For instance, regardless of the Kuwaiti household population demand representing more than 70% of the total household demand, the water price increase couldn't be higher than non-Kuwaiti households (less than 30% of total demand) or apply water price increase measure to Kuwaiti only. This is a result of the socioeconomic context in the country and previous political practices that are very hard to change (see section 8.2).

7.2.2.1 Model manipulation process

To packages P.1.1, P.1.2, P.2.1, and P.3.1, where the technology measure has been applied solely, the manipulation process was to apply the technology diffusion parameters equally to all household population segments as no incentives were introduced. For packages that have more than one appliance diffused, a maximum variation between one appliance to other is 15% (adopted from (Billings and Jones, 2011)). For example, in package P.3.1, the penetration rate in Shower component is 96.3%, followed by penetration of 94% for Toilet component and 92% for Washing machine component. The difference between one appliance to another is not exceeding 15%. The manipulation starts at 2050 as it represents the endpoint of the backcasting horizon. From there (2050), the manipulation starts from the highest market penetrated appliance (showerhead: Shower component in our model) to the lowest one (dishwasher: Washing Dishes component), in ascending order. To accomplish the modelling in a systematic and efficient manner; three spreadsheets have been developed; the first sheet is for Kuwaiti household population; the second is for non-Kuwaiti household population; and third is an external spreadsheet that is linked (via absolute reference function) to Kuwaiti and non-Kuwaiti population spreadsheets. The link is to the last equation (20) in the model (see section 6.5.1.1) where the aggregate demand (e.g., villa dwelling in Kuwaiti households) is developed. The output for each dwelling for Kuwaiti and non-Kuwait is then summed up where the grand aggregate demand can be found. Here, we can manipulate the penetration rates until reaching the target that we need. Once achieve the target, the Gompertz equation (16) is utilised to find the uptake and penetration rates (2019 – 2050).

To package P.2.2, the price intervention has been added to the technology intervention in the model and applied only to the non-Kuwaiti population. Here, the technology diffusion has been differentiated amongst the household population segments as the price intervention influences each population segment (section 7.2.1.2). The manipulation process starts with the technology intervention for non-Kuwaiti population segments in which the population in the second derivative has higher technology market penetration, then lower penetration for the first derivative, and the lowest market penetration is to the population in the base model. After manipulating technology for the non-Kuwaiti population, the manipulation for the Kuwaiti population has been applied where the technology penetration rates are the same for population segments (lower than non-Kuwaiti population) as no incentives have been applied. The manipulation process in the technology intervention in P.2.2 has followed the same process of P.1.1, P.1.2, P.2.1, and P.3.1. After technology manipulation, price intervention manipulation has been introduced. A variation of price elasticity between -0.12 and -0.42 (adopted from Rizaiza (1991) and Srouji (2017); with aim to be close to average figures, see Table 6.2) through duration and frequency elements has been applied by using equations in section 6.5.1.2. Here, we manipulate the price elasticity (from 2050) with the relevant variation range (= price increase 100%; the variation because of socioeconomic differences, see section 7.2.1.2) until reach the backcast target. If the price elasticity range is not applicable to reach the target, then, returning to the technology intervention and manipulate parameters; then, back to price intervention, manipulate the price elasticity with range to reach the target. To package P.3.2, the process has followed the same of P.2.2 but adding the education intervention (section 7.2.1.3).

Table 7.9: Matrix of measures and potential actions needed to reach the backcast targets in 2050

Scenario	Scenario package	Measures needed	Potential actions needed	Potential feasibility
Light	P.1.1	(i) 95% market penetration of efficient showerhead for all household population segments; (ii) Efficient showerhead adoption starts from 2019 to 2050; 32 years of innovation diffusion.	(i) A decision made by the commerce minister to ban traditional showerhead from the market and replace it with efficient ones, and/or appliances rebate programs; (ii) Workforce (plumbers) to install such a rate of showerhead market adoption (see section 8.2 for details).	Easy to implement as water saving devices are considered a non-essential commodity; hence, no need to issue a law that needs Kuwait's National Assembly (parliament) agreement.
	P.1.2	(i) 82% market penetration of efficient showerhead; and 67% of washing floor tap; (ii) Technology adoption starts from 2019 to 2050; 32 years of innovation diffusion.	(i) A decision made by the commerce minister to ban traditional showerhead from the market and replace it with efficient ones and/or appliances rebate programs; (ii) Workforce to install such rates of market adoption.	Technology adoption is easy to implement as in P.1.1.
Intermediate	P.2.1	(i) 88% market penetration of high-efficient showerhead; 84.5% of efficient toilet; and 75% of efficient washing floor tap for all household segments; (ii) Technology adoption starts from 2019 to 2050; 32 years of innovation diffusion.	(i) A decision made by the commerce minister to ban traditional showerhead from the market and replace it with efficient ones, and/or appliances rebate programs; (ii) Provide sufficient number of workforce to install such a high rate of showerhead market adoption; (iii) considerable workforce to install such relatively high technology adoption.	Technology adoption is easy to implement as in P.1.1.

Scenario	Scenario package	Measures needed	Potential actions needed	Potential feasibility
Intermediate	P.2.2	(i) 92% market penetration of efficient showerhead; 89% toilet; and 87% washing floor tap for Kuwaiti households; (ii) 95% market penetration of efficient showerhead; 94% toilet; and 94% washing floor tap for non-Kuwaiti households in the base model; (iii) 97% market penetration of efficient showerhead; 96% toilet; and 96% washing floor tap for non-Kuwaiti households in 1st derivative; (iv) 99% market penetration of efficient showerhead; 98% toilet; and 96% washing floor tap for non-Kuwaiti households in 2nd derivative; (v) Technology adoption starts from 2019 to 2050; 32 years of innovation diffusion; (vi) A water tariff increases of 100%; starts at 6.3% increase in 2035 and ends up by 100% increase in 2050.	(i) A decision made by the commerce minister to ban traditional showerhead from the market and replace it with efficient ones, and/or appliances rebate programs; (ii) Provide a considerable number of workforce to install such relatively high technology adoption; (iii) Kuwait's National Assembly should pass new legislation to amend/replace the current water tariff law.	(i) Technology adoption is easy to implement as in P.1.1; (ii) Increasing the price of water tariff is a very difficult measure to achieve as water is an essential commodity; thus, it needs new legislation that should pass by the National Assembly members (see section 8.2 for details).
Optimistic	P.3.1	(i) 96.3% market penetration of high-efficient showerhead; 94% toilet; 92% washing machine; 90% washing floor tap; 88% hosepipe nozzle; 42% kitchen tap; and 40% dishwasher for all household population segments; (ii) Technology adoption starts from 2019 to 2050; 32 years of innovation diffusion.	(i) A decision made by the commerce minister to ban traditional showerhead from the market and replace it with efficient ones and/or appliances rebate programs; (ii) Very high number of workforce to install such very high market adoption.	Technology adoption is easy to implement as in P.1.1.

Scenario	Scenario package	Measures needed	Potential actions needed	Potential feasibility
Optimistic	P.3.2	(i) 69% market penetration of efficient showerhead; 69% toilet; 69% washing machine; 68% washing floor tap; 63% hosepipe nozzle; 31% kitchen tap; and 28% dishwasher for Kuwaiti households; (ii) 75% market penetration of efficient showerhead; 75% toilet; 73% washing machine; 72% washing floor tap; 72% hosepipe nozzle; 35% kitchen tap; and 30% dishwasher for non-Kuwaiti – base model; (iii) 80% market penetration of efficient showerhead; 78% toilet; 77% washing machine; 76% washing floor tap; 76% hosepipe nozzle; 37% kitchen tap; and 35% dishwasher for non-Kuwaiti – 1st derivative; (iv) 85% market penetration of efficient showerhead; 83% toilet; 81% washing machine; 80% washing floor tap; 38% kitchen tap; and 35% dishwasher for non-Kuwaiti – 2nd derivative; (v) A water price increases of 100%; starts at 4.8% increase in 2030, and ends up by 100% increase in 2050; (vi) A national awareness campaigns start from 2030 and ends up by 2050; targeting a reduction of 13% - 15% for Kuwaitis and non-Kuwaitis (base model and 1st derivative); and 10% non-Kuwaitis (2nd derivative).	(i) A decision made by the commerce minister to ban traditional showerhead from the market and replace it with efficient ones, and/or appliances rebate programs; (ii) High number of workforce to install such high market adoption; (iii) New legislation should pass by Kuwait's National Assembly to amend/replace the current water tariff law; (iv) A governmental plan (2030 to 2050) to raise public awareness towards the importance of water demand reduction through media and other educational channels.	(i) Technology adoption is easy to implement as in P.1.1; (ii) Increasing the price of water tariff is a very difficult measure to achieve as water is an essential commodity; thus, it needs new legislation that should pass by the National Assembly members.

Previous backcast modelling was focusing on the technology intervention in which it is presented in all backcast packages. This is because that technology intervention is a non-pricing measure preferable to the case of Kuwait where pricing measure is very difficult to implement. However, there is a need to model economic intervention to reach backcast targets to diversify the backcast transition pathway options.

7.2.2.2 Economic intervention scenarios: Economic measures needed

Water pricing has been tested in the backcast MC-WEC model to reach the backcast targets. In previous backcast modelling, the economic intervention was introduced with other interventions to avoid high increase in water price (e.g., above 100%). The previous applications of the economic intervention in the model were to introduce the price intervention in a certain year (e.g., 2030). Then, the price increases every year gradually to reach the backcast endpoint where the price met a 100% increase (i.e., 1.16 US$/m^3). The price elasticity values are informed from Rizaiza (1991) and Srouji (2017) where a speculative application of elasticity values have been applied, but with values nearer to the averages of mentioned studies assuming that is a 100% increase of water prices.

Here, the economic intervention has been tested solely, and applied differently compared with the previous applications. First, the price elasticity is adopted from Srouji (2017), where the elasticity values are fixed (= -0.23 for Kuwaiti household segments and the base model of non-Kuwaiti household population; -0.33 for the first and second derivatives of non-Kuwaiti household segments). Elasticities from Srouji (2017), were selected as these are the most recent observations for the GCC and differentiate citizens and expatiates. Second, the intervention does not start part way through the backcast period but is introduced at its start. Third, water pricing increases gradually with a fixed increase rate, but applied in a compound increase manner. Historically, annual average inflation (1986 – 2020) was 2.4% (O'Neill, 2021); if the water price (unchanged from the 0.58 US$/m^3 set in 1962) had simply kept pace with inflation, it would be 2.14 US$/m^3 today. In this context the price rises modelled are not radical, so politically may be feasible. Five backcast packages have been modelled (Table 7.10). The elasticity of non-Kuwaitis is higher than Kuwaitis, but the effect of non-Kuwaitis in reducing demand is weak as they have a lower share of demand. Table 7.10 and Figures 7.23, 7.24, and 7.25 show the output of the economic intervention modelling.

Table 7.10: Backcast economic intervention scenarios 2050

Water demand reduction target, 2019-2050 (%)		**Scenario / package**	**Price increase needed to meet 2050 target** (US$/m^3)*		**Price increase, 2019-2050** (%)		**Average annual increase, 2019-2050** (%)		**Revenue from water sales** (million US$)**		
			Kuwaiti	*Non-Kuwaiti*	*Kuwaiti*	*Non-Kuwaiti*	*Kuwaiti*	*Non-Kuwaiti*	*Kuwaiti*	*Non-Kuwaiti*	*Total*
1st	32	P.A1	1.1	1.73	90	198	2.8	6.2	439.2	96.3	535.5
		P.A2	1.6	(N/A)***	177	(N/A)	5.5	(N/A)	479.0	92.9	571.9
2nd	48	P.B1	1.65	1.74	184	200	5.8	6.2	479.5	94.8	574.3
		P.B2	2.16	(N/A)	273	(N/A)	8.5	(N/A)	406.5	92.9	499.4
3rd	64	P.C	2.18	1.74	276	200	8.6	6.2	401.7	94.8	469.5

* Water prices at the backcast 2050 endpoint year; ** Demand revenue equation is presented in section 7.2.3.1; Figure 7.26 shows demand revenue of BAU scenario where comparison can be made; *** Not Applied (N/A) - water price is unchanged from the current 0.58 US$/m^3, set in 1962 and never changed, for political reasons (nb. this represents a substantial real terms fall in water price 1962 – today).

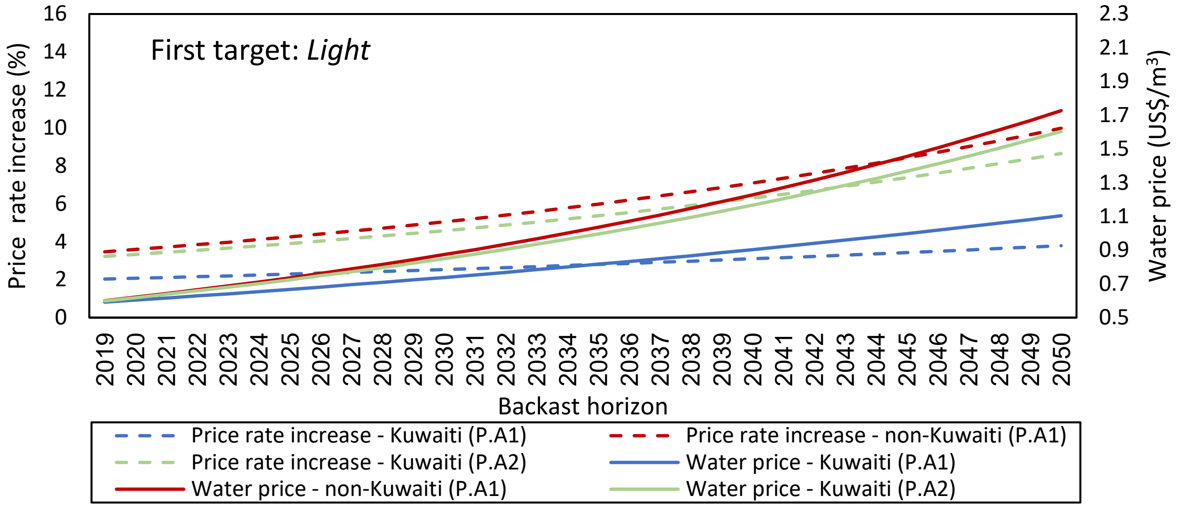

Figure 7.23: Water price increase in P.A1 and P.A2

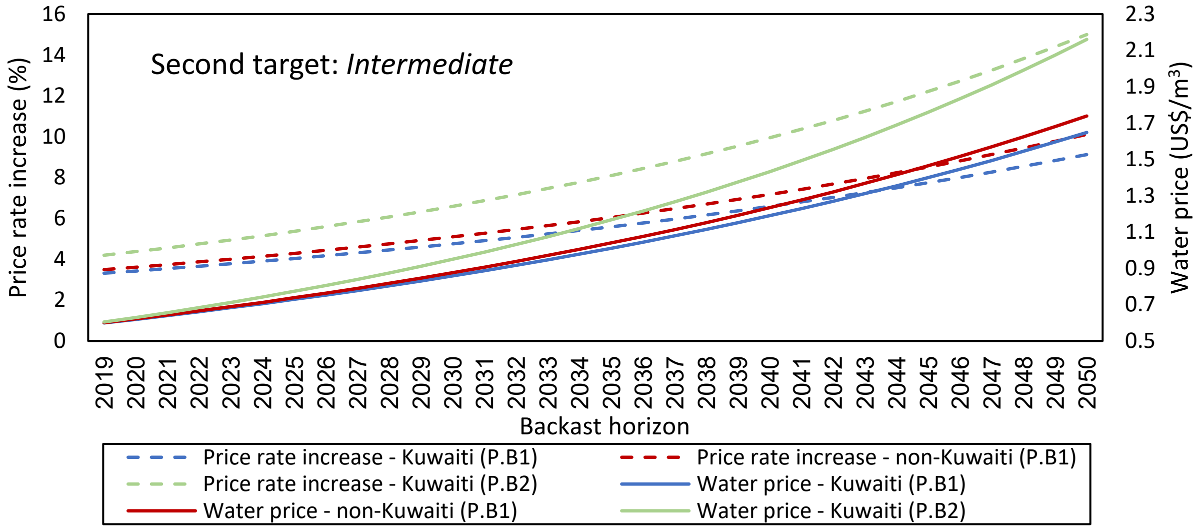

Figure 7.24: Water price increase in P.B1 and P.B2

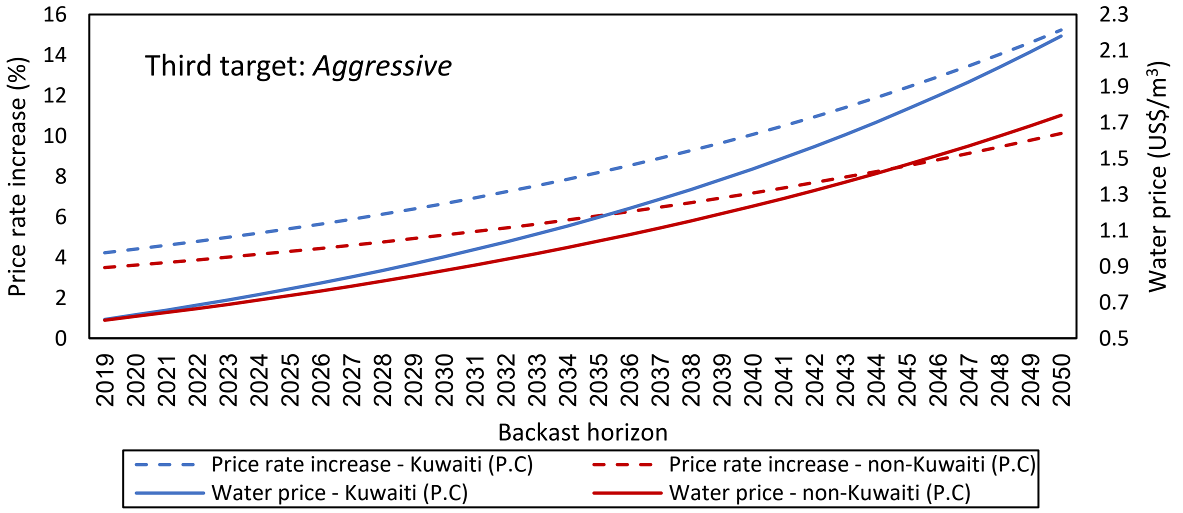

Figure 7.25: Water price increase in P.C

7.2.3 Backcast scenario appraisal: Impact assessment

This section is the wider appraisal of the impact of the developed backcast scenarios. The appraisal encompasses economic, environmental, and feasibility/acceptability assessment. In economic assessment, aggregate and disaggregate assessment has been applied (i.e., total cost production and PHC cost production of backcast scenarios compared against BAU scenario). In the environmental assessment, the carbon dioxide emission of desalination plants has been assessed (i.e., a comparison between backcast and BAU scenarios). Finally, there is a feasibility and acceptability appraisal which has been discussed in section 7.2.3.3.

7.2.3.1 Economic impact assessment

In terms of demand implications, production cost is calculated as the cost of production of per m^3 (2 US$), plus the cost of delivery to end-user (1 US$) giving 3 US$ per m^3 of demand (Al-Humoud and Jasem, 2008; Fadlelmawla, 2009; Al-Damkhi *et al.*, 2009; Aliewi *et al.*, 2017). These costs are in common use in the Kuwait desalination industry and no more recent data is currently available. The aggregate production cost can be calculated through the following equation;

$$APC_t = p_t * q_t \tag{30}$$

Where APC is the aggregate production cost at time t ; p the price per unit[28] (m^3); q the quantity of water billed and collected at time t. Concerning the production revenue (benefits), a change in q parameter to present the cost costumers pay per unit (0.58 US$)[29] has been applied. Then, the economic efficiency has been calculated through the following equation;

$$NB_t = b_t - c_t \tag{31}$$

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[28] The price per unit comprises the production and delivery costs.

[29] The cost customer pay per unit has been assumed to double (1.16 US$ in 2050) to non-Kuwaiti households in P.2.2 and the entire population in P.3.2.

Where NB is the net benefits at time t; b is the total benefits; and c is the total production cost at time t. To calculate the PHC cost production/revenue per unit, the following equation has been used;

$$PCRPHC_t = h_t/p_t \tag{32}$$

Where $PCRPHC$ is the production cost/revenue per PHC at time t; h is the total household population (or it can Kuwaiti/non-Kuwaiti households); p is the total production cost/revenue at time t. To calculate the economic efficiency of PHCs, equation (31) has been used to PHC's level.

BAU scenario

Figure 7.26 illustrates the total production cost increases from 1.39 billion US$ in 2019 to 1.99 billion US$ by 2050 (nominal prices unadjusted for inflation). This is an increase of 601.80 million US$, and an average annual increase of 19.4 million US$. Costs increase most in 2020 (1.82% per year) and least in 2050 (0.57% per year) with an aggregate cost increase is 43.28% over the period. The total revenue from water sales is 276.55 million US$ in 2019, rising to 389.15 million US$ in 2050, an average annual increase of 3.5 million US$. Water supply to an average Kuwaiti household costs 3,314 US$ yr^{-1} against revenue of 647 US$ yr^{-1}, whilst for a non-Kuwaiti household cost is 748 US$ yr^{-1} against a revenue of 146 US$ yr^{-1}. Overall, the average household cost is 1,814 US$ yr^{-1} against a revenue of 350 US$ yr^{-1}, far below full cost recovery. In terms of economic efficiency performance, the difference between total revenue and production cost is -1.12 billion US$ in 2019, the gap increased to -1.61 by 2050. The difference in Kuwaiti households is -835 million US$ in 2019, increased to -1.22 billion US$ by 2050; whilst non-Kuwaiti households, the difference is -286.61 million US$ 2019 increased to -387.43 US$ by 2050. The economic efficiency in PHC level, the difference in the aggregate PHC is -1,425 US$ in 2019, rising to -1,463 US$ in 2050, while the difference in Kuwaiti household is -2,672 US$ in 2019 increased to -2,674 in 2050. To non-Kuwaiti households, the difference is -604 US$ 2019, decreased[30] to -603 US$.

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[30] The decline is as a result of decreasing non-Kuwaiti households by 2050.

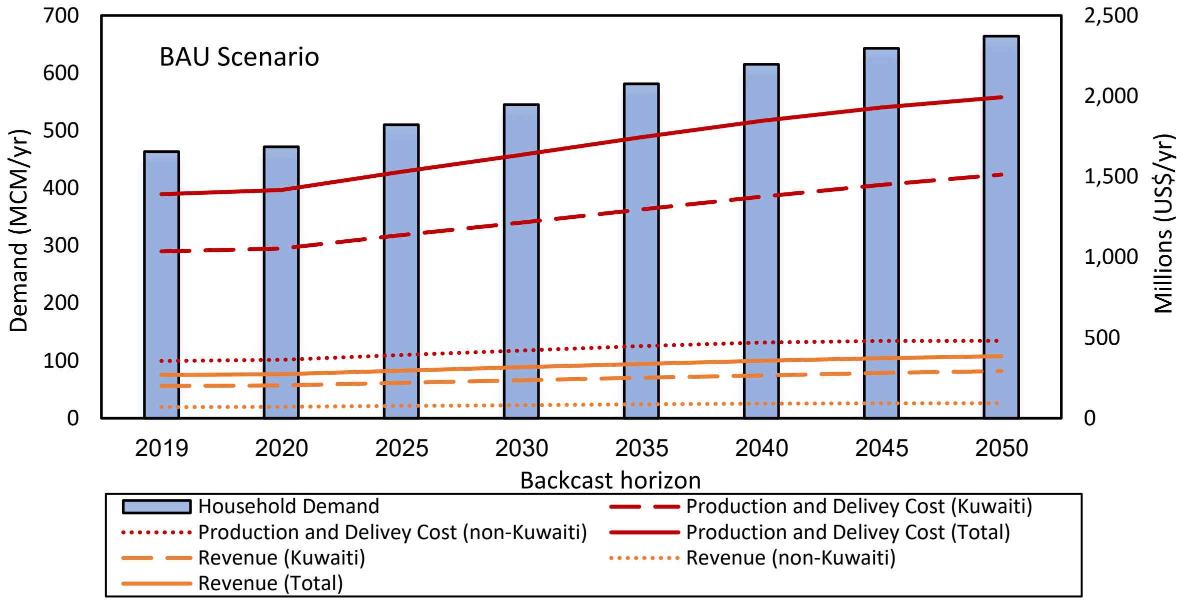

Figure 7.26: Production cost and revenue under BAU scenario

Light scenario

Figure 7.27 illustrates the total production cost decreases from 1.38 billion US$ in 2019 to 1.33 billion US$ by 2050; this is a decrease of 60.31 million US$. Costs increase most in 2025 (1.48 billion US$) and least in 2045 (1.31 billion US$). The total revenue from water sales is 268.62 million US$ in 2019, rising to 256.96 million US$ in 2050. Water supply to Kuwaiti household costs 2,214 US$ yr^{-1} against revenue of 428 US$ yr^{-1} in 2050, whilst for a non-Kuwaiti household cost is 497 US$ yr^{-1} against a revenue of 96 US$ yr^{-1}. Overall, the average household cost is 1,210 US$ yr^{-1} against a revenue of 234 US$ yr^{-1}. For economic efficiency performance, the difference between total revenue and production cost is -1.12 billion US$ in 2019, decreased to -1.07 US$ by 2050. The difference in Kuwaiti households is -834.69 million US$ in 2019, decreased to -814.58 million US$ by 2050; whilst non-Kuwaiti households, the difference is -286.11 million US$ 2019 decreased to -257.57 US$ by 2050. The economic efficiency in PHC level, the difference in the aggregate PHC is -1,424 US$ in 2019, declining to -975 US$ in 2050, while the difference in Kuwaiti household is -2,672 US$ in 2019 decreased to -1,780 in 2050. To non-Kuwaiti households, the difference is -603 US$ 2019, decreased to -401 US$.

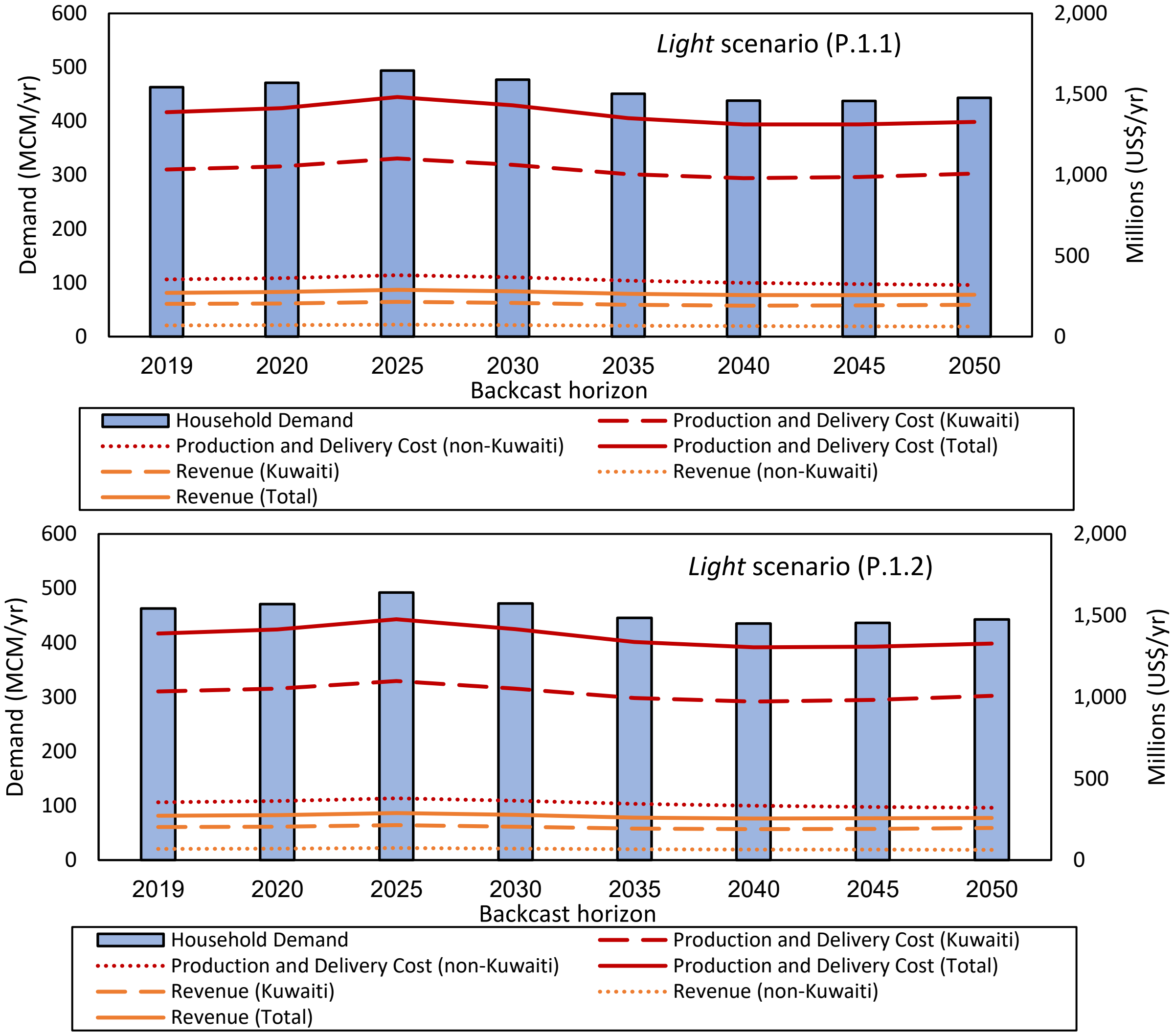

Figure 7.27: Production cost and revenue under the Light scenario

Intermediate scenario

Figure 7.28 shows the total production cost decreases from 1.38 billion US$ in 2019 to 1.03 billion US$ by 2050 in both packages (P.2.1 and P.2.2); this is a decrease of 353.30 million US$. Costs increase most in 2025 for both packages (1.45 billion US$) and least in 2050 (1.03 billion US$) in P.2.1; whereas P.2.2 is 963.98 million in 2045. The total revenue from water sales is 268.56 (P.2.1), and 267.35 (P.2.2) million US$ in 2019, falling to 200.26 million US$ (P.2.1), and 234.19 (P.2.2) in 2050. Water supply of household cost in 2050 is 943 US$ and 943 yr^{-1} against a revenue of 182 and 213 US$ yr^{-1} to P.2.1 and P.2.2, respectively. To Kuwaiti household, the cost is 1,722 and 1,885 US$ yr^{-1} against revenue of 333, and 365 US$ yr^{-1} in 2050 to P.2.1 and P.2.2, respectively. Whilst for a non-Kuwaiti household cost is 390 and 273 US$ yr^{-1} against a revenue of 75 and 106 US$ yr^{-1} in 2050, to P.2.1 and P.2.2, respectively. For economic efficiency performance, the difference between total revenue and production cost is -1.12 billion US$ for the two packages in 2019, decreased to -835.57 (P.2.1) and -801.56 (P.2.2) million US$ by 2050. The difference in Kuwaiti households is -834.52 million US$ in 2019 to both packages, decreased to -633.63 (P.2.1) and -693.85 (P.2.2) million US$ by 2050; whilst non-Kuwaiti households, the difference is -286.04 (P.2.1) and -280.91 (P.2.2) million US$ 2019 decreased to -201.94 (P.2.1) and -234.19 (P.2.2) US$ by 2050. The economic efficiency in PHC level, the difference in the aggregate PHC is -1,423 (P.2.1) and -1,417 (P.2.2) US$ in 2019, falling to -761 (P.2.1) and -730 (P.2.2) US$ in 2050. While the difference in Kuwaiti household is -2,671 US$ in 2019 (two packages) decreased to -1,389 (P.2.1) and -1,521 (P.2.2) US$ in 2050. To non-Kuwaiti households, the difference is -602 (P.2.1) and -592 (P.2.2) US$ 2019, decreased to -314 (P.2.1) and -168 (P.2.2) US$ in 2050.

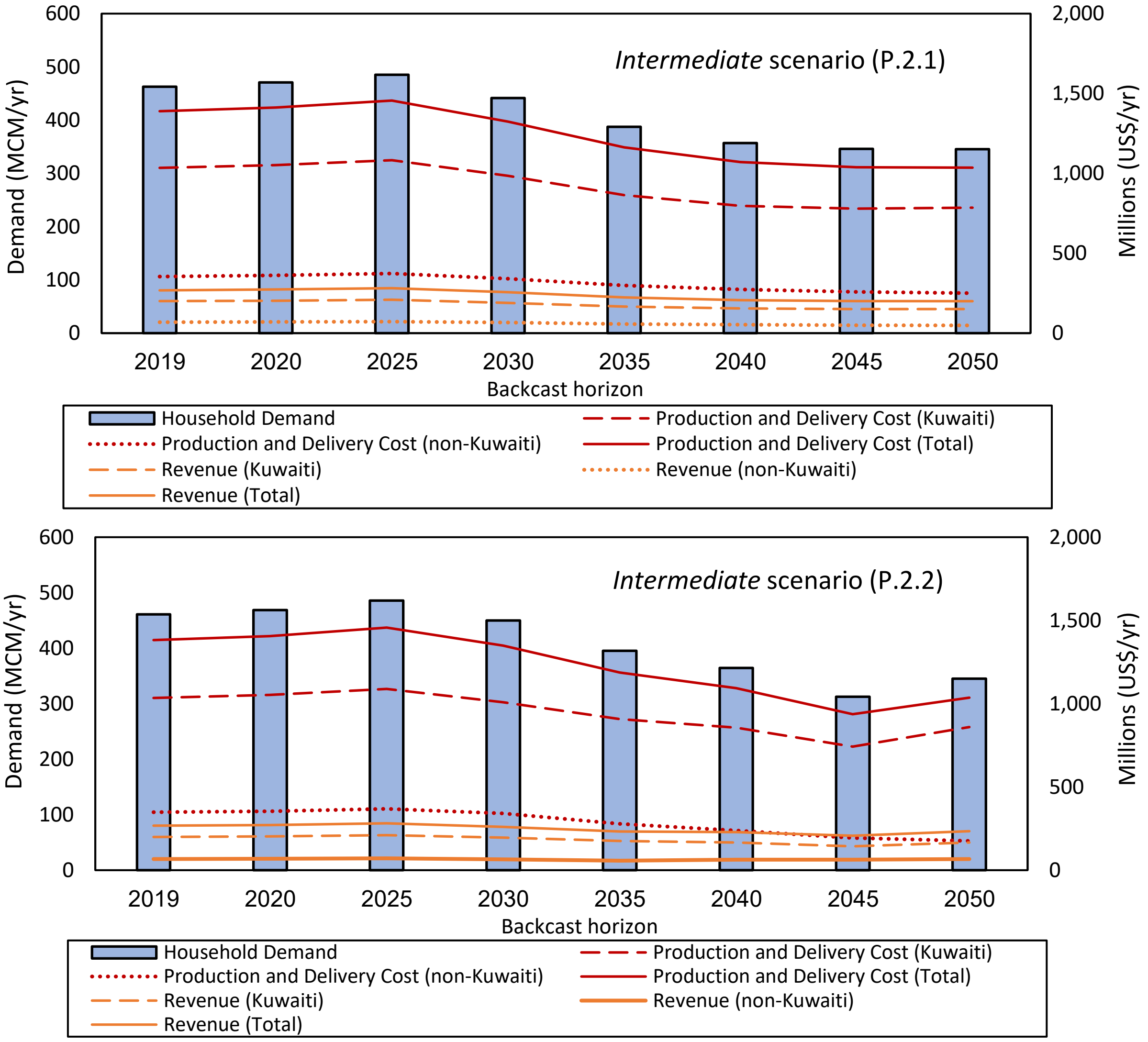

Figure 7.28: Production cost and revenue under the Intermediate scenario

Optimistic scenario

Figure 7.29 shows the total production cost decreases from 1.388 (P.3.1) and 1.389 (P.3.2) billion US$ in 2019 to 716.40 million US$ by 2050 (two packages). Costs increase most in 2025 for both packages to reach 1.42 (P.3.1) and 1.45 billion US$, and least in 2050 for the two packages. The total revenue from water sales is 268.53 million US$ in 2019 (P.3.1), and 268.56 (P.3.2), dropped to 138.51 million US$ (P.3.1), and escalated to 276.88 (P.3.2) in 2050. Water supply to household cost in 2050 is 1,764 US$ and 1,764 yr^{-1} against a revenue of 126 and 252 US$ yr^{-1} to P.3.1 and P.3.2, respectively. Water supply to Kuwaiti household costs 1,196 and 1,247 US$ yr^{-1} against revenue of 231, and 482 US$ yr^{-1} in 2050 to P.3.1 and P.3.2, respectively. Whilst for a non-Kuwaiti household cost is 266 and 229 US$ yr^{-1} against a revenue of 51 and 89 US$ yr^{-1} in 2050, to P.3.1 and P.3.2, respectively. For economic efficiency performance, the difference between total revenue and production cost is -1.12 billion US$ in 2019 (for two packages), decreased to -557.95 (P.3.1) and -439.18 (P.3.2) million US$ by 2050. The difference in Kuwaiti households is -834.42 (P.3.1) and -834.52 (P.3.2) million US$ in 2019, decreased to -440.05 (P.3.1) and -348.88 (P.3.2) million US$ by 2050; whilst non-Kuwaiti households, the difference is 286.01 (P.3.1) and 286.56 (P.3.2) million US$ 2019 decreased to -137.90 (P.3.1) and -90.30 (P.3.2) US$ by 2050. The economic efficiency in PHC level, the difference in the aggregate PHC is -1,423 US$ in 2019 (two packages), falling to -526 (P.3.1) and -400 (P.3.2) US$ in 2050. While the difference in Kuwaiti household is -2,671 US$ in 2019 (two packages), decreased to -965 (P.3.1) and -765 (P.3.2) US$ in 2050. To non-Kuwaiti households, the difference is -602 US$ 2019 (two packages), dropped to -215 (P.3.1) and -141 (P.3.2) US$ in 2050.

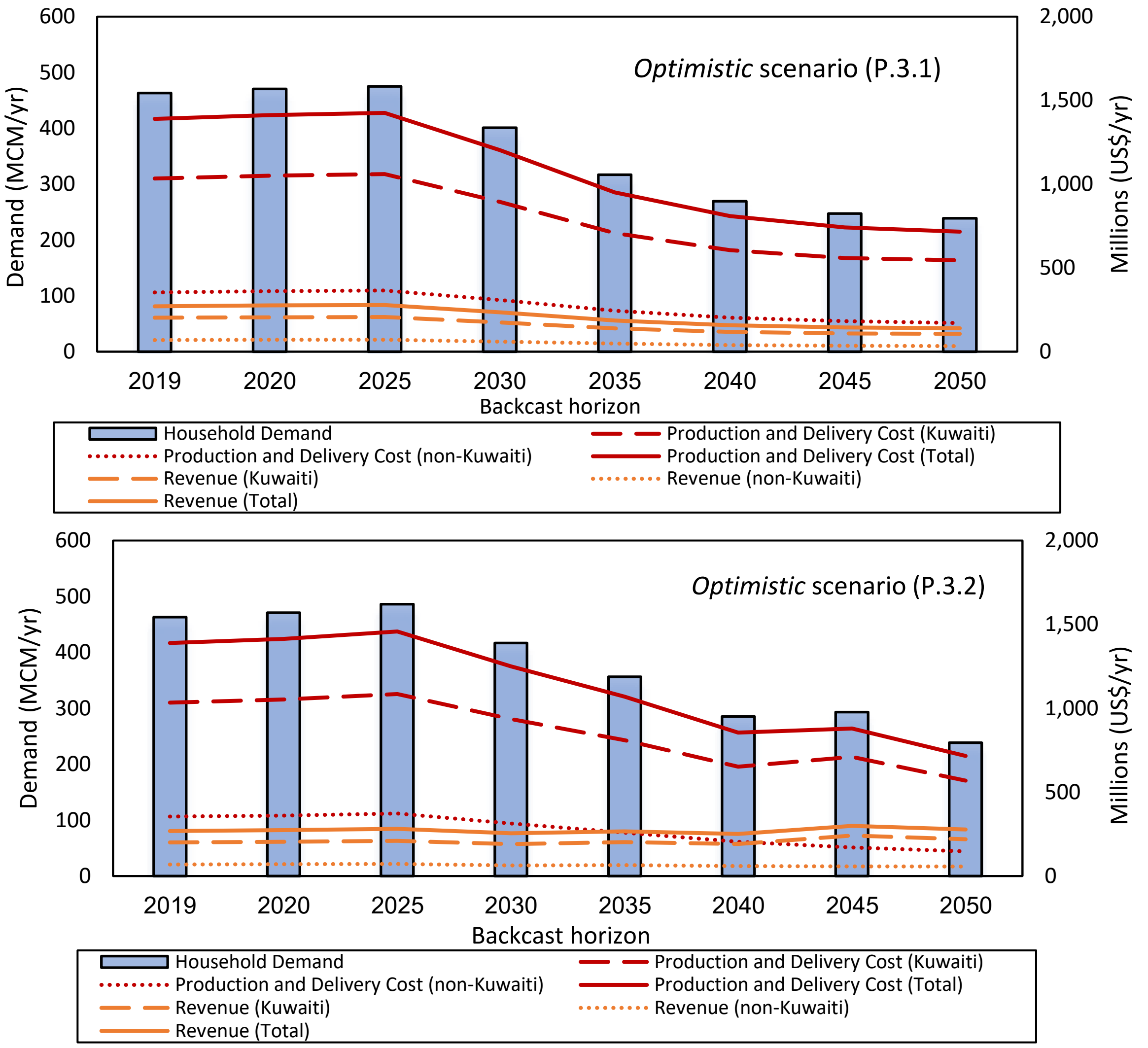

Figure 7.29: Production cost and revenue under the Optimistic scenario

7.2.3.2 Environmental impact assessment: Carbon dioxide emission

Kuwait operates thermal seawater desalination plants (membrane plants are used for wastewater treatment). From prior studies (Raluy *et al.*, 2004; Darwish *et al.*, 2009; Dawoud, 2012; Fath *et al.*, 2013), the CO_2 emission estimate[31] has been selected as 23.4 (kg/m^3) of water produced in the thermal plants. To assume the CO_2 emissions from desalination plants into atmosphere, this equation has been applied;

$$CE_t = d_t / e_t \tag{33}$$

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[31] Kuwait operates dual plants that desalinate water and generate electricity; thus, the coefficient used is an estimate from previous studies.

Where CE_t is the carbon dioxide emission into atmosphere at time t; d_t refers to water produced (this is applied for grand aggregate, and aggregate Kuwaiti, and non-Kuwaiti demand); and e_t is carbon dioxide emission per unit produced (23.4 kg/m^3) at time t. To calculate PHC's CO_2 footprint, the following equation has been applied;

$$HCF_t = p_t/e_t \tag{34}$$

Where HCF_t is the household carbon dioxide footprint at time t; p is the household population (grand aggregate, and aggregate Kuwaiti and non-Kuwaiti); and e is the CO_2 emission to equivalent household population (e.g., Kuwaiti) at time t.

BAU scenario

Figure 7.30 shows that total households CO_2 emission increases substantially with the rising demand, from 10.85 million tonnes in 2019, to 15.54 million tonnes in 2050, an annual average increase of 1.02%, equivalent to 151,434 thousand tonnes. For Kuwaiti households, CO_2 emission increases from 8.1 million tonnes in 2019, to 11.8 million tonnes in 2050; whilst non-Kuwaiti households emission increases from 2.8 million tonnes in 2019, to 3.6 million tonnes in 2050. Regarding PHC carbon footprint, the total household emits 13.8 tonnes in 2019, increased to 14.1 tonnes in 2050. Whilst Kuwaiti household emits 25.8 tonnes 2019, increased slightly to 25.9 tonnes in 2050; a non-Kuwaiti household emitting 5.8 tonnes throughout BAU horizon.

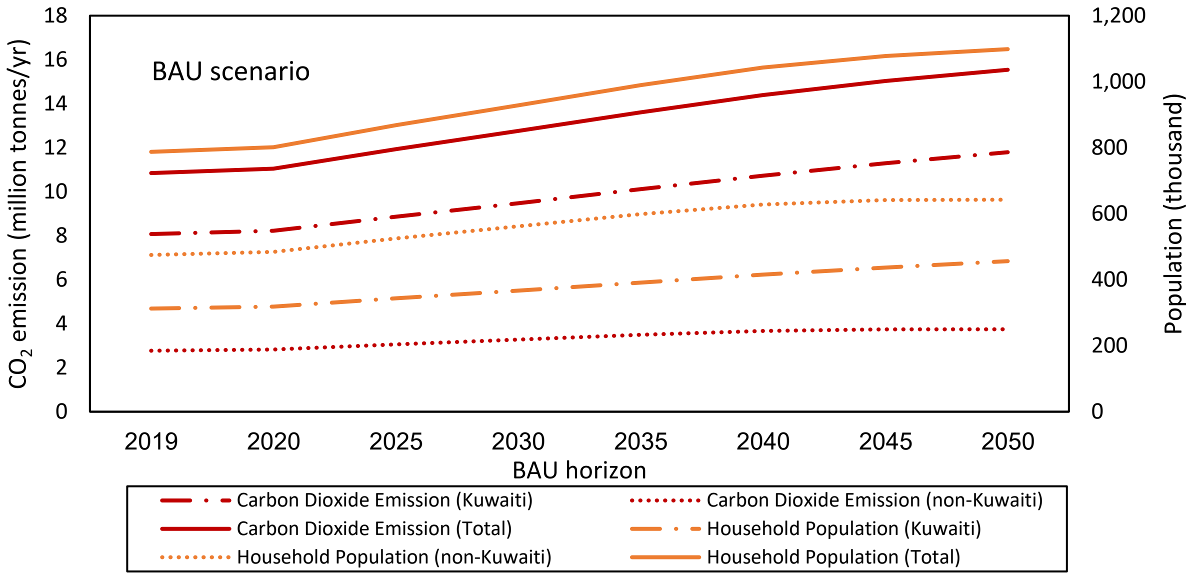

Figure 7.30: Carbon dioxide emission under BAU scenario

Light scenario

Figure 7.31 shows that total households CO_2 emission decreases from 10.83 million tonnes in 2019, to 10.35 million tonnes in 2050, an annual average decrease of 0.14%, equivalent to 15.07 thousand tonnes. For Kuwaiti households, CO_2 emission decreases from 8.07 million tonnes in 2019, to 7.85 million tonnes in 2050; whilst non-Kuwaiti households emission decreases from 2.76 million tonnes in 2019, to 2.50 million tonnes in 2050. Regarding PHC carbon footprint, the total household emits 13.8 tonnes in 2019, decreased to 9.4 tonnes in 2050. Whilst Kuwaiti household emits 25.8 tonnes 2019, decreased to 17.2 tonnes in 2050; a non-Kuwaiti household emits 5.8 tonnes 2019, decreased to 3.9 tonnes in 2050.

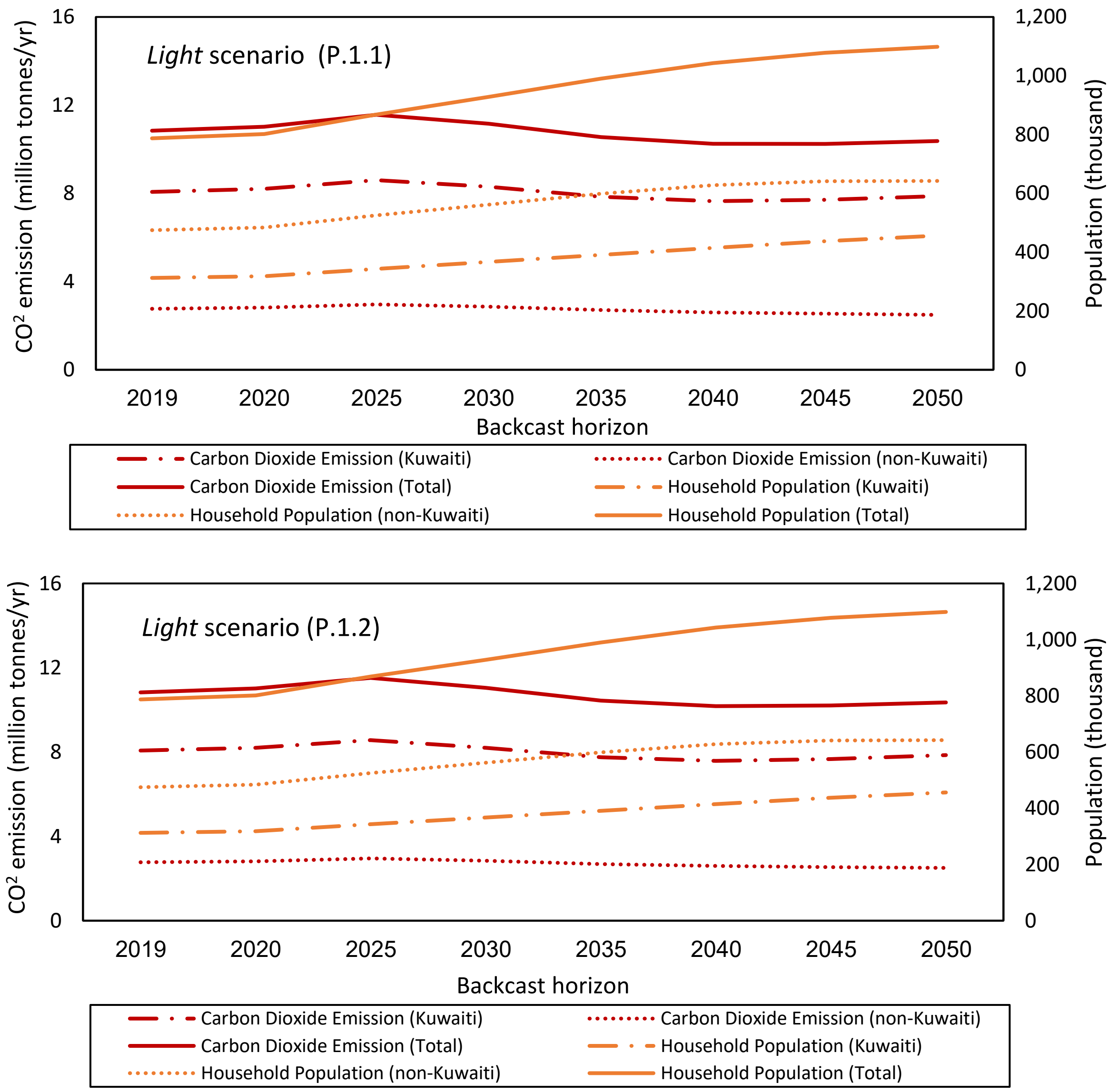

Figure 7.31: Carbon dioxide emission under the Light scenario

Intermediate scenario

Figure 7.32 shows that total households CO_2 emission decreases from 10.83 (P.2.1) and 10.79 (P.2.2) million tonnes in 2019, to 8.07 million tonnes in 2050 (two packages), an annual average decrease of 0.78%, equivalent to 84.60 thousand tonnes. For Kuwaiti households, CO_2 emission decreases from 8.06 (P.2.1) and 8.07 (P.2.2) million tonnes in 2019, to 6.12 (P.2.1) and 6.70 (P.2.2) million tonnes in 2050. Whilst non-Kuwaiti households' emission decreases from 2.76 (P.2.1) and 2.71 (P.2.2) million tonnes in 2019, to 1.95 (P.2.1) and 1.36 (P.2.2) million tonnes in 2050. Regarding PHC carbon footprint, the total household emits 13.8 (P.2.1) and 13.7 (P.2.2) tonnes in 2019, decreased to 7.4 tonnes in 2050 (two packages). Whilst Kuwaiti household emits 25.8 tonnes 2019 (two packages), decreased to 13.4 (P.2.1) and 14.7 (P.2.2) tonnes in 2050. Non-Kuwaiti household emits 5.8 (P.2.1) and 5.7 (P.2.2) tonnes 2019, decreased to 3 (P.2.1) and 2.1 (P.2.2) tonnes in 2050.

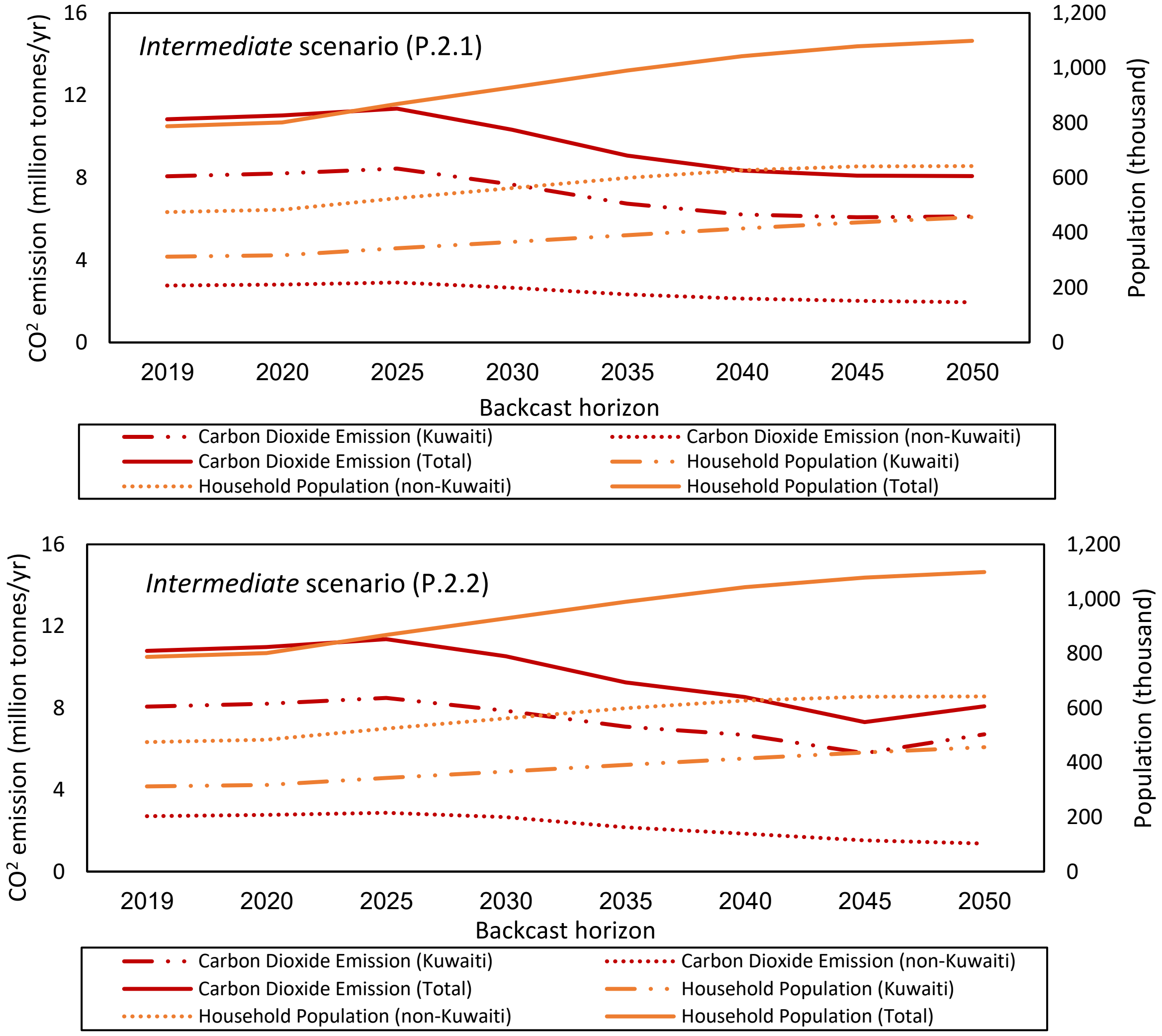

Figure 7.32: Carbon dioxide emission under the Intermediate scenario

Optimistic scenario

Figure 7.33 shows that total households CO_2 emission decreases from 10.83 million tonnes in 2019 to 5.58 million tonnes in 2050 (two packages), an annual average decrease of 2.1%, equivalent to 5.25 thousand tonnes. For Kuwaiti households, CO_2 emission decreases from 8.06 million tonnes in 2019 (two Packages), to 4.25 (P.3.1) and 4.43 (P.3.2) million tonnes in 2050. Whilst non-Kuwaiti households' emission decreases from 2.76 million tonnes in 2019 (two packages), to 1.33 (P.3.1) and 1.14 (P.3.2) million tonnes in 2050. Regarding PHC carbon footprint, the total household emits 13.8 tonnes in 2019, decreased to 5.1 tonnes in 2050 (two packages). Whilst Kuwaiti household emits 25.8 tonnes 2019 (two packages), decreased to 9.3 (P.3.1) and 9.7 (P.3.2) tonnes in 2050. Non-Kuwaiti household emits 5.8 tonnes 2019 (two packages), decreased to 2.1 (P.3.1) and 1.8 (P.3.2) tonnes in 2050.

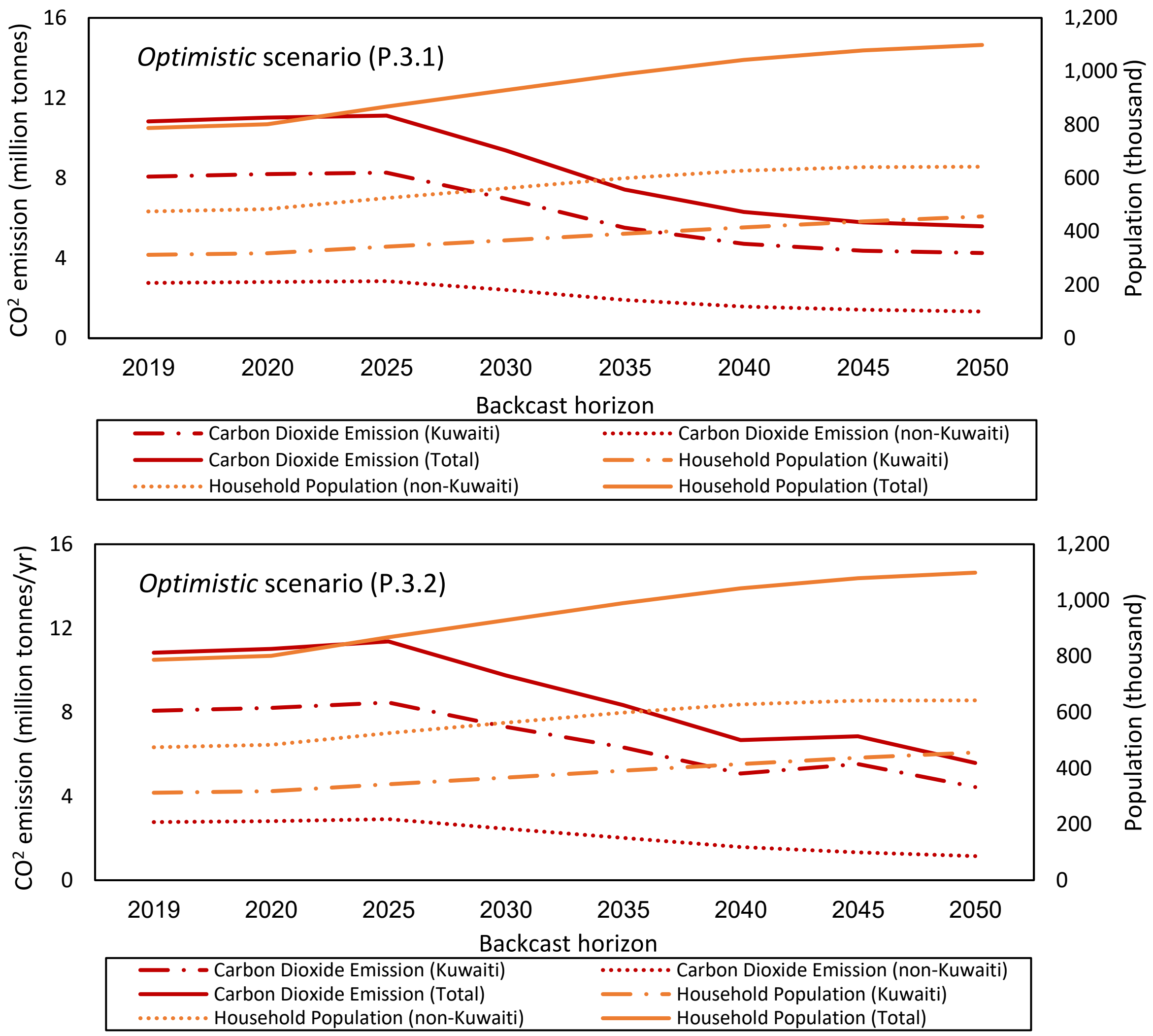

Figure 7.33: Carbon dioxide emission under the optimistic scenario

7.2.3.3 Feasibility and acceptability assessment

As a result of the Covid-19 pandemic outbreak, the appraisal of feasibility and acceptability of backcast conservation measures couldn't be in place. This is because of the measures that the state of Kuwait has implemented. The first measure is to ban expatriates (so as the researcher) from inter Kuwait for several months; (i) March to August 2020; and (ii) January to August 2021. Where the plan was to visit officials and policymakers in the government and members of the National Assembly to discuss the possible conservation measures that can be adopted. The second measure is the government's announcement of the closure of all ministries from 9th April 2020 to an uncertain period so that meets cannot be held with the government's members (e.g., Assistant secretaries and directorate managers). Another key barrier is the government resignation for several months and the National Assembly adjournment to call to elect for a new period. In the government resignation case, the Amir of Kuwait gave the caretaker (resigned) government to run the urgent businesses, where unurgent businesses (e.g., holding meetings with government members) is not allowed until the new government is formed. In the National Assembly adjournment case, a new election means new parliament's members to be elected in financial and economic affairs committee and environmental affairs committee; thus, these committees were closed for several months until new members are elected. These barriers have come together to prevent preparing and holding interviews with officials.

Holding online meetings was an unpreferable measure due to the difficulty in preparing and fixing a date to hold an online meet. Unlike the practice in the UK, officials (government and parliament members) in Kuwait are rarely using emails to contact the public (phones are the alternative); this implies the difficulty to manage an online meet. Accordingly, a physical meeting (face-to-face) was the only choice to assess the feasibility and acceptability of the backcast conservation measures. And was a suitable method where the engagement is at a higher level (a physical interview is much better than a virtual interview). Also, was suitable to conduct Delphi technique using semi-structured interview methodology to extract consistent agreement (two-round Delphi). Due to the circumstances discussed above, the appraisal of feasibility and acceptability has been recommended in future works (by supervision team or other researchers/scientists). However, a discussion over feasibility and acceptability has been presented in the conclusion and recommendations chapter.

7.3 Conclusion

Adopting a backcasting approach has shown measures needed to transition the household water demand sector to desired future's outlooks. These outlooks are represented in the backcast targets that are obtained from literature survey. The first target is *no more water* to be in service from the base year (1% per annum, 32% total backcast period); the second target is the *aggressive* target, a reduction of 2% per annum (64% total backcast period) and; the third is *moderate* target that falls between *no more water* and *aggressive* targets with a reduction of 1.5% per annum (48% total period). Three intervention conservation measures (technology, economic, and education) have been used to achieve backcast targets and to explore the transition pathways through model (backcast MC-WEC) application. A manipulation exercise to parameters in the model have been implemented and backcast scenarios (*Light*, *Intermediate*, and *Optimistic*) have been developed. Each scenario has been developed through two manipulation packages where parameters have been presented differently in terms of backcast interventions' mixing, intensity, and timing. Scenario's packages are essentially developed to create different pathways that lead to backcast destination in which professional stakeholders (e.g., policymakers and officials) can discuss the feasibility and acceptability of backcast conservation measures. So that professional stakeholders can differentiate (feasibility and acceptability) the conservation measures in each scenario and compare between scenarios.

Based on backcast MC-WEC modelling, grand aggregate household demand has been reduced to 443 MCM (221 MCM reduction compared to BAU scenario) in *Light* scenario by 2050; 345 MCM (319 MCM reduction compared to BAU scenario) in *Intermediate*; and 239 MCM (425 MCM reduction) in *Optimistic* scenario, see Figure 7.34. Conservation measures intervened in *Light* scenario are modest where high market penetration of efficient showerhead (P.1.1) and mix of efficient showerhead and toilet with moderate market penetration (P.1.2) have been implemented. To *Intermediate* scenario, the measures intervened were moderate presented in the high-efficient showerhead and efficient toilet and tap with relatively high market penetration (P.2.1), and efficient showerhead, toilet, and tap with moderate market penetration associated with an introduction of increasing water price to non-Kuwaiti households (P.2.2). In *Optimistic* scenario, measures intervened are aggressive, consisting of adoption of high-efficient appliances for all components associated with high market penetration (P.3.1). And adoption of efficient appliances for all components with relatively high market penetration as well as introduction of increasing water price to the entire household population associated with public education intervention.

In terms of backcast scenario economic and environmental implications, the total production cost has reduced to 1.33 billion US$ (663.10 million US$ reduction compared with BAU production) in *Light* scenario by 2050; 1.03 billion US$ (956.39 million US$ reduction) in *Intermediate* scenario; and 716.40 US$ (1.27 billion US$ reduction) in *Optimistic* scenario. The total revenue of water production in the backcast scenarios are lower than BAU even with scenarios that the economic measure has been introduced. This is a result of the quantity demanded of water where water production in BAU scenario is much higher than in the backcast scenarios; thus, much water is billed and collected in BAU and lower in backcast scenarios. Economic efficiency is the measure of how efficient the economy is, where the comparison between production cost and revenue is calculated. The total revenue of BAU scenario is 389.15 million US$ by 2050, compared with 256.96 million US$ in *Light* scenario, 200.26 million US$ (P.2.1), and 234.19 (P.2.2) in *Intermediate*, and 138.51 million US$ (P.3.1), and 276.88 (P.3.2) in *Optimistic* scenario[32]. Whilst economic efficiency is -1.61 billion US$ in BAU scenario in 2050 compared with -1.07 in *Light* scenario, -835.57 million US$ (P.2.1) and 801.56 (P.2.2) in *Intermediate*, and -557.95 million US$ (P.3.1) and -439.18 (P.3.2) in *Optimistic* scenario. Even though the cost recovery hasn't achieved in all backcast scenarios, the revenue reached is substantial in comparison with BAU scenario in terms of economic efficiency. The failure of achieving the cost recovery is attributed to the high subsidised water tariff in which customers pay 20% of total production cost (ratio of 1:5), even when price assumed to increase 100% in *Intermediate* (P.2.2) and *Optimistic* (P.3.2) scenarios where customers assumed to pay 40% of total production (ratio of 1:4). To the environmental implications, CO_2 has been reduced to 10.35 million tonnes in *Light* scenario, 8.07 million tonnes in *Intermediate* scenario, and 5.58 million tonnes in *Optimistic* scenario in comparison with 15.54 million tonnes in BAU scenario by 2050. This is equivalent to a reduction of 33.3% to *Light*, 48% *Intermediate*, and 64% *Optimistic* scenarios.

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[32] This is compared with high revenues resulted from the backcast economic intervention packages in Table 7.10.

The key findings of the backcast modelling are; first, investing in Shower component with efficient appliances has shown its ability to reduce demand to 32%, the reduction rate could increase if efficient appliances are replaced with high-efficient ones (can reach 40% of demand reduction). Second, is that Kuwaiti villa dwellings are responsible for over 70%[33] of household demand; therefore, investment in this segment of the population can result in a substantial demand reduction. Third, applying economic interventions to non-Kuwaiti households has delivered a weak impact on the grand aggregate demand which indicates that economic intervention must include Kuwaiti households (where water is traditionally supplied at a very low price for political reasons) in order to achieve good demand reduction rates. Fourth is that technology intervention has shown the superiority and consistency against other interventions in reducing demand even with the aggressive target. From model manipulation, demand could reduce to slightly over 70% of BAU demand if all micro-components reached full market penetration (e.g., imposing legislation to replace traditional appliances with high-efficient ones).

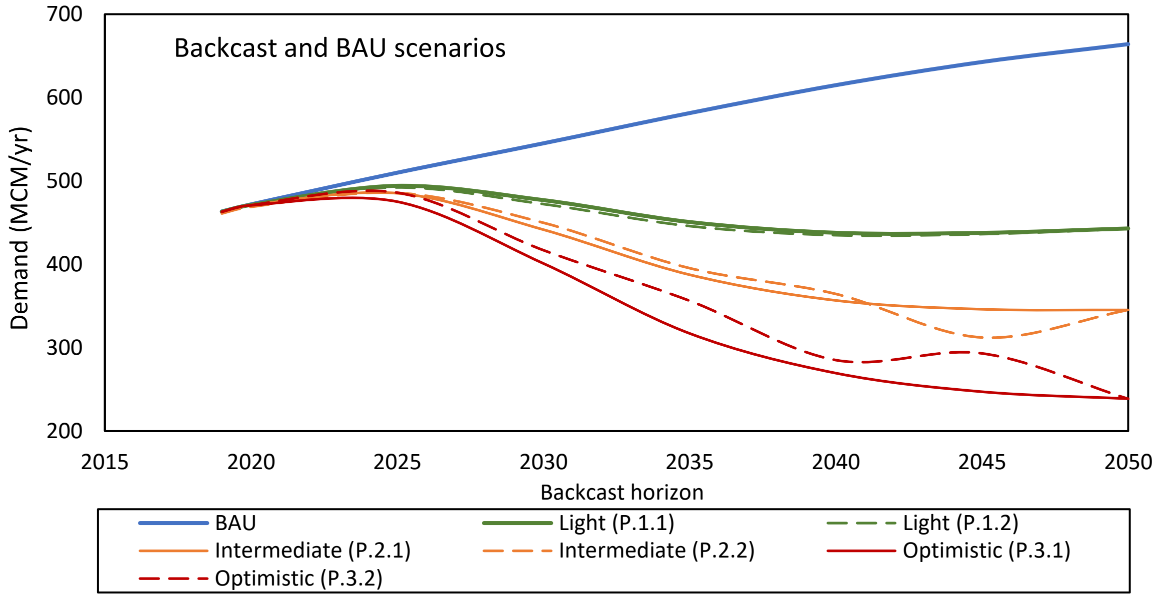

Figure 7.34: Backcast scenarios against BAU scenario

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[33] If floor or flat in a villa and annex dwelling types are added to villa, the proportion will substantially increase as it represents a part of villa dwelling type (but it has been treated individually).

Chapter 8 Conclusion and recommendations

This thesis aimed to explore initiatives and regulations that might reduce household water demand radically, and to transition Kuwait from its present unsustainable supply management towards water efficiency, security, and sustainable demand management. A wider appraisal of such demand reduction, presented in economic and environmental benefits evaluation and the feasibility and acceptability of proposed conservation measure interventions, was also conducted. The need for the study was underpinned by evidence gaps highlighted in literature, presented in section 2.5. The study employed a backcasting "*soft-path*" approach to explore potential transition pathways to a more sustainable water future for Kuwait. This backcasting approach has been combined with a micro-component behavioural model to allow in-depth exploration of possible interventions.

This chapter begins by summarising the major findings, highlighting the study's originality, proposing potential publications, and by discussing study limitations. A discussion of the feasibility and acceptability of measures follows, after which recommendations are made on how the study results can contribute to specific actions that implementing entities (governmental bodies) can take in developing policies and management plans. The chapter concludes with a statement on future research needs.

8.1 Major findings, originality, potential publications, and limitations of the study

1. Major findings:

a. Without further intervention, household water demand will substantially increase in future, driven by strong population growth.

b. Backcasting has shown realistic steps required (8.2) to reduce household demand from current extremely high demand to more sustainable lower demand, represented by three demand targets for 2050 (i.e., moderate to aggressive reduction).

c. The employment of a micro-component model has delivered a good scope of generating future demand under different intervention packages, with precise control of these interventions under several population segments and household sizes.

d. Household demand is most strongly driven by the Kuwaiti household population (rather than the expatriate population) and substantially by those households in villas.

2. Study originality:

The study contributes new knowledge to studies on water resources management in general and Kuwait and GCC in particular, in several ways. The in-depth analysis of water demand of the household sector of Kuwait is one of very few studies in the broader "MENA" region that used micro-component behavioural modelling and thus, delivers insights into a thorough and efficient method of studying water demand/consumption in the household sector. Furthermore, this is the first study in Kuwait and GCC region that comprehensively identified the micro-component consumption using the OVF approach. More importantly, the definition of Kuwait household population segments and the projection of household growth has been accomplished in this study, where no previous study has projected household population of Kuwait before. This characterisation of the household population would be useful for water demand analysis in countries with a similar socio-cultural context (i.e., large migrant worker population with different consumption habits to citizens).

This study accomplished important methodological improvements in studying household demand management. The household sector accounts for the largest share of water demand in Kuwait, as in other GCC countries, where the methods will have relevance. The backcast MC-WEC model could be useful for GCC countries to model, assess, and evaluate the impact of proposed intervention measures in exploring their own transition pathways for the household water sector. The structure developed in the backcast MC-WEC model gives the flexibility to adapt, fix, and manipulate parameters to fit the household sector of any member of the GCC countries.

The novelty and importance of the backcast MC-WEC model in reducing household water demand effectively and bringing about sector efficiency is a subject to initiate the adoption of this model in the GCC countries. This can be achieved through commercialising the model to the relevant stakeholders and officials in Kuwait and other GCC countries. In Kuwait, diffusing the model can be achieved through; for instance, a presentation for the cabinet on the benefit of adopting the backcast MC-WEC model where the cabinet can then decide and plan whether adopt the model for better future demand management. Furthermore, it can be diffused through workshops for relevant stakeholders (e.g., KISR, MEW, and KFAS) to indicate the application of the model and its advantages and characteristics as well as the key strengths of using such a model in the household sector. These workshops can also pose enquiries on how the backcast MC-WEC model could be implemented and run in-house. On the GCC scale, commercialising the model can follow different channels. For instance, presentations in conferences on the GCC scale in water industry and management (e.g., Gulf Water Conference) where professional stakeholders, academics, and GCC officials are gathered to grasp the state-of-the-art Knowledge. Furthermore, it can be done by participating in the GCC Unified Water Strategy that is carried out by the GCC supreme council. Additionally, it can be diffused for any individual member of the GCC. For example, engaging with a research group in the UAE National Water and Energy Centre where the opportunity to disseminate the backcast MC-WEC model is high. In which the underlying factors (e.g., the wider benefits) to adopt the model to the household sector can be clearly explained, thus, implementing the model at the country level.

Potential publications:

A. Water demand forecast under business-as-usual scenario in the household sector: a special microsimulation technique (chapters three and four):

This includes the data preparation to start developing the BAU demand forecast of the household sector, for example; (i) missing data assumption; and (ii) FMF spatial microsimulation modelling. This article explains how a behavioural model is used to; first, develop the baseline demand estimate model and the validity test included, then; (ii) build the BAU demand forecast which includes the sensitivity test and defines the BAU base model. If this work is successfully published, it will be then the first publication to produce a demand forecast in the household sector of Kuwait and used a model and method that have never been used before (neither Kuwait nor GCC), which are; (i) a behavioural model development; and (ii) spatial microsimulation methodology utilisation.

B. Household demand using a micro-component model: an OVF approach (chapter five):

There is some literature on micro-component use in the household sector of Kuwait (and other GCC countries), but they are not comprehensive (e.g., not including non-Kuwaiti, household sizes, etc.). What distinguishes this study is the adoption OVF approach and the inclusion of the household population segments (e.g., Kuwaiti and non-Kuwaiti; high-income "base model" medium- and low-income "first and second derivative" households). If this work is successfully published, it will be then the first publication that produces a comprehensive micro-component model in Kuwait and GCC; a micro-component model of the household sector that is ready to be used to forecast/backcast water demand.

C. Future demand scenarios of Kuwait household sector: backcast soft-path approach (chapters six and seven):

Here is the development of the backcast packages and scenarios where the conservation measures interventions are applied in shaping transition pathways under defined backcast targets. This article will include the appraisal of backcast scenarios' economic and environmental impact against BAU scenario's impact.

3. Limitations:

The study confronted limitations most notably due to constraints of data availability but also the outbreak of the Covid-19 pandemic. The insufficient and limited data on water demand and demographics of the household sector brought difficulties in developing a backcast-MC model, although the very sparse data poses difficulties for more conventional modelling approaches too. Data limitations existed on aggregate and disaggregate levels. For aggregate water demand, observed household demand is available only for very limited years (2014 – 2017), with no further specification, (e.g., aggregate Kuwaiti v. non-Kuwaiti demand). At the disaggregate level, PHCs/PCCs is not fully available, e.g., PHCs of one member household have not been included in CBS survey plus some missing PHC values and values of a single observation. Regarding micro-component data, there is a severe shortage in OVF data for Kuwaiti households and almost no data for non-Kuwaiti households; as well as a complete data absence on swimming pool and bathtub components. Thus, the study faced some challenges regarding the micro-component model development which led to; (i) applying several qualitative and quantitative analyses to compensate data limitations; (ii) excluding swimming pool and bathtub components from the model altogether; and (iii) accepting some shortcomings in the model (see, section 5.3.1). Furthermore, there is no sufficient data that explores a consumer's behavioural changes over the BAU forecast horizon (e.g., lifestyle changes that led to change in consumption patterns); thus, the PHCs/PCCs consumption behaviour has been kept static alongside the BAU forecast horizon.

On demographics, a complete absence of data concerning ethnicity prevented expanding the forecasting/backcasting demographic analysis. Kuwait has a diverse population with several ethnic groups (e.g., Arab, African, Asian, and European) where different cultural distinctions exist; thus, different consumption habits may emerge that distinguishes an ethnic group from others (Williamson *et al.*, 2002; Harlan *et al.*, 2009). The head of the Kuwait census division (in SCPD), Hasan Abd-Alghafoor stated "*the only census that included ethnicity distinction is the census of 1957, since then, ethnicity distinction has been ignored in later censuses*". Another more fundamental demographic limitation is that the absence of a comprehensive population projection. A projection that projects population on aggregate and disaggregate level, e.g., by country's sectoral distribution, by governorates, and crucially projection of household size distribution. The limitation of TED/KISR's population projection has led to indirectly using projection where several further quantitative manipulations have been applied to generate insight into the meet the study's needs.

Due to the outbreak Covid-19 pandemic, the intended appraisal of the feasibility and public acceptability of proposed intervention measures / transition paths was omitted from the study (see, section 7.2.3.3). However, we are able to make some more speculative comments, informed by personal experience of Kuwait, which appear in the following section.

8.2 Potential feasibility and acceptability of backcast strategies

Based on the prior institutional practices, current legislation, existing political regime, and socioeconomic structure, the feasibility and acceptability of proposed backcast strategies for Kuwait can be anticipated. The discussion has two sections, addressing feasibility and acceptability of the pricing measure, then the technology adoption.

1. <u>Pricing intervention of backcast scenarios</u>:

Two proposals were modelled in the backcast MC-WEC model. The first is the introduction of price change to non-Kuwaiti households (*Intermediate* scenario; package 2.2). The second is the introduction of price change to the entire household population (*Optimistic* scenario; package 3.2). In terms of feasibility of implementation, any change in water tariff in the household sector must be agreed by at least two thirds of the National Assembly, comprising government ministers (16 members) and other parliamentarians (50 members) which has historically made it very hard to change water policy (water tariff in the household sector has not changed since the establishment of the Ministry of Electricity and Water in 1962). Another aspect of feasibility is the difficulty associated with the enforcement of new legislation on water prices in the household sector; for instance, if new legislation has been issued to increase water price to non-Kuwaiti households, then, a complexity could arise in enforcing this law. This is because of the real estate registration law (section 5.2.1) that gives the right of perpetual ownership of a property to Kuwaitis and citizens of the GCC (Al-Mohami, 2017). This would make it hard to define the non-Kuwaiti households, as non-Kuwaiti households (except GCC citizens) don't have the right to possess a property; thus, they are settling in rented properties. The complexity would bring about the difficulty to enforce such law.

In terms of public acceptability, any proposed increase/change in water price in the household sector has been met with opposition and rejection by parliament members, and it would be the same in the future. Kuwait has a rent economy that depends on exporting oil (90% of the country's economy (MacDonald, 2021)) to gain capital; thus, it is considered by the public as a national treasure that the public should benefit from it, e.g., via low energy, water, and fuel prices. Consequently, it wouldn't be, probably, acceptable to even a long-term period. Thus, any pricing strategy would likely require a concerted national campaign, outlining price rise rationale and benefits, to gain both public and political support.

2. Technology intervention of backcast scenarios:

Water saving devices have been introduced alongside backcast scenarios. Adoption intensity is relatively high in the *Intermediate* scenario package 2.1, high in *Optimistic* scenario 3.2, and very high in package 3.1. The feasibility to apply this technology can be classified into two aspects; the first, is the institutional regulation; and the second is the capacity and capability that the government can achieve the high-intensity installation of efficient/high-efficient appliances in a short period. To the first aspect, there is no need to pass new legislation by the National Assembly to ban traditional appliances and substitute with efficient and high-efficient ones, as such appliances are not classed as essential commodities, unlike water and electricity, thus can be pass by a decision made by the minister of commerce.

To the second aspect, it would be very challenging to install a huge quantity of appliances within a short term. This is because Kuwait has a very weakly developed plumbing industry with few trained installers (i.e., very rare to find a Kuwaiti plumber). The plumbing industry is driven and controlled by non-Kuwaitis; thus, feasibility here highly uncertain. Furthermore, what if the government issues legislation to reduce non-Kuwaiti population (as is being considered)? What if a considerable number of non-Kuwaiti population start voluntarily departing the country? Is the number of current plumbers in the market enough to achieve such a strategy? To the first inquiry, the government has issued a decision to not renew visas for expatriates over 60-years-old; it is a part of Kuwait policy to balance Kuwaiti and non-Kuwaiti populations. To the second inquiry, because of Covid-19 pandemic, more than 400,000 non-Kuwaitis (≈ 15% of total non-Kuwaiti population) have cancelled their residency and departed Kuwait, and some have been deported, within a short period (from 2020 to 2021). This action has led to; (i) wages increase for blue collar jobs; and (ii) a longer wait period to get a service, to weeks, and in some cases, months (CNBC, 2021). However, in terms of public acceptability, technology intervention actions wouldn't be a political dilemma as with the price intervention. Technology would thus be easier to implement, so long as attention is given to developing the necessary workforce capacity in the plumbing sector.

8.3 Integrated and effective demand-side management of the household water sector

Based on literature review, developed backcast scenarios, and the appraisal of the economic and environmental impact of the developed scenarios, the study suggests adopting integrated water demand management based on IWRM principles, particularly a shift in focus from water-supply augmentation policies to efficient water-demand management policies. The study also reflects other key IWRM principles, including evaluation of the status of the water resource, outlining of both short-term and long-term goals for the system, defining objectives and actions to attain the selected goals, assessment of the benefits and costs of each action, and evaluation of the effects of such actions and progress to achieve the goals, to eventually attain water efficiency, security, and productivity in the household sector.

Within this broader context the study suggests focusing on the following demand management options as follows;

1. Reform the water tariff scheme:

The current tariff is a volumetric uniform tariff, of 0.8 Kuwaiti Dinar for 1,000 imperial gallons (equivalent to 0.58 US$ per cubic metre). The tariff structure was fixed in the early 1960s and has not changed since then. Although the tariff structure is simple and relatively cheap, it doesn't bring about social equity and transparency. High-income householders most probably have larger houses than the median-and low-income households; thus, more water consumption, which eventually leads to high-income households benefiting more from subsidies. The country uses the metric system measurements which the public have adopted yet the Ministry of Electricity and Water uses imperial system measurements in all activities, including customer billing, which has led to a considerable number of customers being ignorant of their consumption (e.g., high or low) as they are not familiar with the imperial system. This perhaps feels a minor point, but in practice is indicative of the serious lack of attention given to water pricing in Kuwait. Thus, the Ministry of Electricity and Water is recommended to first, progressively raise water prices so as to exert a downward pressure on demand, and to raise prices with clear recognition of prices needed for full cost recovery. Note that simply returning prices, in real terms, to their value set in 1962, will be able to essentially deliver on the most aggressive of the backcast targets set. Second, and associated with this, is the need to evaluate alternative tariff structures that are better able to encompass wider sustainability concerns such as social equity (e.g., an increasing block tariff, or lifeline tariffs that ensure any subsidies go to lower-income households). The MEW should also adopt the metric system.

2. Investing in innovative water technology:

Water saving devices have shown their potential to reduce water demand radically without fundamentally altering the consumer's behaviour / reducing level of service; thus, technology would be an excellent tool to transition the country to a more efficient and sustainable future. It is considered a more politically and culturally feasible tool to implement in Kuwait than tariff reform which is considered very difficult. Therefore, adopting this strategy is recommended as the state's government priority option, but with tariff / pricing reform to follow in time.

3. Investing in public education and outreach:

Public education is considered an adjunct tool for water demand management policies; however, it is a very important tool to implement in the case of Kuwait. Raising customer’s awareness of absolute scarcity of this resource in Kuwait, as well as the associated adverse environmental impacts of securing desalination water (e.g., GHGs emissions and increasing global heating). Raising awareness of the adverse economic performance (e.g., high production cost against low water tariff and the opportunity cost of such performance) might lead customers to participate in saving the environment and the economy through reducing their consumption. It also can be helpful when investing in innovative water technology through encouraging customers to adopt these technologies, and to reduce the associated rebound effect (“*Jevons Paradox*”) by, e.g., raising awareness of the main aim of manufacturing these technologies.

4. Efficiently reuse household wastewater:

The estimated annual volume of recycled wastewater produced is between 206 and 254 MCM (as of 2016); of this, 40% is discharged into the sea. Full reuse of treated wastewater (in effect elsewhere in the Middle East, for agricultural and landscape irrigation use) is highly recommended, as this would displace demand on ground- and desalination water from non-household sectors. This is consistent with the “*Middle East Green*” initiative of the first Middle East Green Initiative Summit, Riyadh, of October 2021 (Kennedy, 2021). The aim of the initiative is to plant 40 billion trees to reduce carbon emissions and tackle desertification. Kuwait has pledged to achieve its share of the target set in the summit. Thus, full reuse of household wastewater would help to displace water demand from other sectors and have co-benefits for urban greening and climate mitigation.

5. Institutional capacity building:

The Ministry of Electricity and Water is the sole authority responsible for water production and distribution in Kuwait and hosts the Water Study and Research Division

(WSRD). The WSRD is recommended to combine efforts with KISR, KFAS, and PACI to develop and strengthen their abilities and skills to study and assess water supply-demand situations at both aggregate and disaggregate levels. There is a clear need to co-ordinate and enhance capacity in data gathering and analysis, to better support the Ministry in investment appraisal, planning and drawing up of future water resources management policies for the country.

8.4 Future research needs

The current study indicates where further research on aspects of water resources management and demand management in the household sector of Kuwait is required. The study recommends research conducting;

1. A comprehensive long-term population projection:

Effective household water demand analysis and management is currently constrained by limited demographic data. In particular a more comprehensive and sophisticated population projection is needed. More regular demographic census, collating consistent micro-level data for Kuwaiti and non-Kuwaiti populations is needed, addressing as a minimum location, household size, dwelling type, gender, age, ethnicity, and socio-economic status. A demographic projection based on more sophisticated methods such as cohort component methodology and a probabilistic approach enables sensitivity and uncertainty investigation. This would be particularly helpful for water resources research but also much other social science research where population parameters are required.

2. Behavioural models in extrapolation future water demand:

Most previous studies have employed time series regression modelling to predict future Kuwait water demand. Regression models don't address behavioural change in consumer's consumption; hence a shortcoming of these models is the inability to represent new interventions not previously used (i.e., adoption of efficient appliances and consumer behavioural change coefficient). Therefore, there is a need to develop behavioural models to better understand and represent consumer behaviour.

3. Investigating PHC/PCC in the household sector in Kuwait:

There is a need to better understand what drives PHC and PCC in the household sector. A comprehensive investigation that addresses the ownership-volume-frequency variables in all population segments (Kuwaiti and non-Kuwaiti) would be a valuable information resource. A survey to accomplish this research would benefit water resources research in Kuwait and probably other GCC countries (where the socioeconomic context is similar) in exploring future demand trajectories.

4. Understanding environmental psychology theories in household water demand:

Environmental theories are widely used to understand the effect of environmental issues (e.g., global heating) in promoting pro-environmental consumption. However, no Kuwait or GCC work exists, an important omission as cultural practice here often varies widely to those of prior research. Interest in this field has grown in Kuwait / GCC countries, with respect to carbon emission, following the *Middle East Green* initiative and the *Conference of the Parties the 26th (COP26),* and there are clear benefits of extending this interest to water demand.

5. Feasibility and public acceptability of backcast measures developed in the current study:

There is a need to fully test the feasibility and acceptability of the backcast measures of the present study, as per the pre Covid-19 plan. This would inform as to what degree measures are feasible and acceptable. It would deliver a set of options to authorities to adopt a suitable scenario to reduce household water demand. No such feasibility-acceptability appraisal of water demand interventions has been conducted anywhere in the GCC.

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Appendices

Appendix A: Micro-component use of indoor activities

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Component	**Shower – Kuwaiti**				
Number of showers taken per day	At least once a day.	One time: 77%; Two and three times: 23%.	N/A[*]	At least once a day.	At least once a day.
Shower duration	< 10 Minute: 6.6%; 10 – 20 Min.: 23.4%; 20 – 30 Min.: 20.7%; 30 – 40 Min.: 32%; 40 – 60 Min.: 15.3%; > 60 Min.: 2%. Average: 30 Min.	N/A	N/A	N/A	N/A
Component	**Shower – non-Kuwaiti**				
Number of showers taken per day	At least once a day.	N/A	N/A	N/A	N/A
Shower duration	< 10 minute: 12.4%; 10 – 20 minute: 28.2%; 20 – 30 minute: 25.4%; 30 – 40 Min.: 24.8%; 40 – 60 Min.: 8.2%; > 60 Min.: 0.9% Average: 25 Min.	N/A	N/A	N/A	N/A

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Component	**Toilet – Kuwaiti**				
Use per day – Frequency	N/A	2 Times: 25%; 3 Times: 28.6%; 4 times: 32.1%; 5 – 7: 14.3%.	N/A	N/A	N/A
Volume per flush	N/A	Not mentioned. Represent 9.6% out of daily per capita consumption.	N/A	N/A	N/A
Component	**Toilet - non-Kuwaiti**				
Use per day – Frequency	N/A	N/A	N/A	N/A	N/A
Volume per flush	N/A	N/A	N/A	N/A	N/A
Component	**Washing Clothes – Kuwaiti**				
Number of washes per week	N/A	Three times: 6.7%; Four times: 13.3%; Five times: 13.3; Six times: 3.3%; seven times: 20%; > seven times: 43.3%	N/A	One time: 5%; Two time: 23%; Three time: 12%; Four time: 13%; Five time: 2%; Six time: 1%; Seven time: 44%	One time: 5%; Two time: 23%; Three time: 12%; Four time: 13% Five time: 2%; Six time: 1%; Seven time: 44%
Washing method	Washing machine/ washing by hand	Washing machine/ washing by hand	N/A	N/A	N/A
Washing Duration	N/A	N/A	N/A	N/A	N/A
Component	**Washing Clothes – non-Kuwaiti**				

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Number of washes per week	N/A	N/A	N/A	N/A	N/A
Washing method	Washing machine/ washing by hand	N/A	N/A	N/A	N/A
Washing Duration	N/A	N/A	N/A	N/A	N/A
Component	**Washing Dishes – Kuwaiti**				
Number of washes per week	N/A	Four times: 3.7%; Six times: 3.7%; Seven times: 33.3%; eight times: 3.7%; Fourteen times: 29.6%; twenty-one times: 25.9%	N/A	N/A	N/A
Washing method	N/A	Dish washer and washing by hand	N/A	N/A	N/A
Washing Duration	N/A	N/A	N/A	N/A	N/A
Volume per wash/load	N/A	N/A	N/A	N/A	N/A
Component	**Washing Dishes – non-Kuwaiti**				

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Number of washes per week	N/A	N/A	N/A	N/A	N/A
Washing method	N/A	N/A	N/A	N/A	N/A
Volume per wash/load	N/A	N/A	N/A	N/A	N/A
Washing Duration	N/A	N/A	N/A	N/A	N/A
Component	**Washing Floors (including outdoor surface) - Kuwaiti**				
Number of washes per week	N/A	Average: 17 times.	N/A	One times: 1%; Two times: 31%; Three times: 13%; Four times: 4%; Five - Seven times: 6%.	One times: 1%; Two times: 31%; Three times: 13%; Four times: 4%; Five - Seven times: 6%.
Washing method	Bucket and hose	Bucket and hose	N/A	N/A	N/A
Washing volume	N/A	10.5% out of total per capita consumption.	N/A	N/A	N/A
Washing Duration	N/A	N/A	N/A	N/A	N/A
Component	**Washing Floors (including outdoor surface) – non-Kuwaiti**				
Number of washes per week	N/A	N/A	N/A	N/A	N/A
Washing method	N/A	N/A	N/A	N/A	N/A

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Washing volume	N/A	N/A	N/A	N/A	N/A
Washing Duration	N/A	N/A	N/A	N/A	N/A

[*] Not/Available (N/A)

Appendix A: Micro-component use of outdoor activities

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Component	**Car Washing**				
Number of owned cars – Kuwaiti	Four cars are the average of owned cars for Kuwaiti households. 100% of Kuwaiti households have cars	One to four cars: 36.8%; five to Seven cars: 44.1%; More than seven: 19.1%	N/A	Every household have at least a car. 56.8% of households have five cars or more., 18.3% for four cars; 15% have three cars, 8% have two cars, and 2% have one car	Every household have at least a car. 56.8% of households have five cars or more., 18.3% for four cars; 15% have three cars, 8% have two cars, and 2% have one car
Number of owned cars – non-Kuwaiti	Two cars are the average of owned cars for non-Kuwaiti households; 90% of non-Kuwaiti households have cars	N/A	N/A	N/A	N/A
Car washing per week	72% of total households washing car daily		N/A	N/A	N/A
Washing duration	N/A	N/A	N/A	N/A	N/A
Wash volume	N/A	5.2% of daily per capita consumption	N/A	32 to 227 litres per wash	N/A

Study	**Burney *et al.* (2017)**	**Aliewi and Alayyadhi (2018)**	**Mukhopadhy *et al.* (2001)**	**Al-Humoud and Jasem (2008)**	**Al-Humoud and Al-Ghusain (2003)**
Washing method	Bucket and hose	Bucket and hose	N/A	Bucket and hose	N/A
Component	**Garden/Lawn Irrigation**				
Garden Availability	N/A	46.7% of Kuwaiti villas	45.8% of Kuwaiti Villas	N/A	N/A
Garden Size	N/A	N/A	From 10 metre squared to 600 metre squared	N/A	N/A
Irrigate per Week	N/A	Seven times: 63.2%; Five times: 15.7%; Four times: 5.3%; Three times: 5.3%; Two Times: 10.5%	Not clearly stated, mentioned to several times per week	One time: 2%; Two times: 12%; three times: 43%; four times: 32%; five times: 10%; six to seven times: 1%	One time: 2%; Two times: 12%; three times: 43%; four times: 32%; five times: 10%; six to seven times: 1%
Irrigate Volume per Week	N/A	6.4% of daily per capita consumption	From 16,629 litre to 26,130 litre per week	N/A	N/A
Irrigate Duration	N/A	N/A	N/A	N/A	N/A
Irrigation Method	N/A	Hose, sprinkler, and spraying	N/A	N/A	N/A