A visio-spatial life cycle energy model of building materials within a bioregional context

'Mapping the embodied energy of fired clay bricks in Cuitzeo, Mexico'

Submitted by

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I hereby declare that no part of this thesis has previously been submitted for any degree of qualification at this, or any other University or Institute of learning.

"Donde haya un árbol que plantar, plántalo tú.
Donde haya un error que enmendar, enmiéndalo tú.
Donde haya un esfuerzo que todos esquivan, hazlo tú.
Se tú el que aparta la piedra del camino."

Gabriela Mistral

Abstract

A visio-spatial life cycle energy model of buildings materials within a bioregional context

Despite the general acceptance of Life Cycle Assessments (LCA) to tackle environmental problems associated with the built environment, the literature shows that this complex assessment system presents limitations as a communication tool for decision-making process given that results are difficult to interpret. By trying to reduce the complexity of following multiple variables in LCA, a simplified and more straightforward process emerged to account for only energy using, Life cycle Energy Analysis (LCEA). However, LCEA has also inherited problems associated with LCA. Thus, discrepancies in calculation procedures, the lack of geographical considerations and ecological attitude and assumptions are criticized in both approaches.

In this thesis, a Visio-Spatial Life Cycle Energy Model based on Geographical Information Systems (GIS) was developed in order to bridge the gap of LCEA as a communication tool by displaying embodied energy intensities in thematic maps taking into consideration bioregional principles in its analysis. A new dynamic Input-Output model, which efficiently simplifies the extraction process of energy paths from IO tables enabled the integration of hybrid energy coefficients to account for economic establishments dedicated to produce goods and services in the construction sector as illustrated in a bioregional case study area in Mexico. The full capability of the Visio-spatial energy model was then applied to a specific study of fired clay brick production within the bioregion. The results obtained by process analysis methods (PA) had a variation of 33.6% with respect to IO procedures, which can be considered acceptable in hybrid methods. Embodied energy figures expressed in thematic maps helped to reduce geographical assumptions and expand the sense of place in LCEA by visualizing patterns in manufacturing processes within the case study area.

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In memory of my father.

Intended audience

Given the main purpose of this thesis is to develop a bridge for science communication between experts and a primary audience for the understanding of complex data in decision making and participatory process, the multidisciplinary nature of the thesis is addressed, but not restricted, to:

Researchers in life cycle theory studies

The thesis will be mostly interesting and useful for researchers who are investigating life cycle approaches to environmental issues.

Researchers in energy and policy

Given the holistic perspective and the multidisciplinary nature of this thesis, which includes socio-economic values on energy concepts, this study provides a more general insight for researchers and policy makers.

Researchers in energy awareness

The thesis offers researchers in energy awareness an alternative approach to the inter-relationship between energy, the economy and the environment under geographic considerations.

Aside from the expert audience, this thesis will be of interest to everyone with a genuine enthusiasm to deepen understanding about environmental issues as a result of human activities.

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Glossary of abbreviations and terms

Bioregion	Geographic region with malleable natural limits, where physical elements such as flora, fauna topography and climate are the framework of socio-economic and cultural activities. Generally, watersheds delineate these areas.
Black Box	In systems theory, a black box is an unknown system that is identified through a system technique. However, in practice the black box is an abstraction that makes it difficult to see how this system works. In Input-Output energy analysis, the extraction of energy paths is considered a black box given this process is still unclear to the analyst.
Climate Change	Climate change refers to a change in the state of current climate conditions, generally associated to anthropogenic activities.
DENUE	The National Directory of Economic Units (by its name in Spanish) is a socio economic geodatabase launched in Mexico in 2010 based on economic census to account and codify economic units.
Economic Units	An economic unit is one that, produce or sells good and services within a geographical area, which includes the name of the establishment, the code economic classification system, postcode, address, description of the activity, and the number of staff.
Embodied Energy	Is an accounting system of direct and indirect energy associated with the production process of goods and services. In buildings it represents the energy consumed in its entire life cycle, from the extraction of raw material to its final breakdown or recycling.
LCA	Life Cycle Assessment refers to a standardized system to evaluate the environmental impact associated with goods and services during their lifespan.

LCEA	Life Cycle Energy Analysis accounts for only energy inputs to produce a product based on embodied and operational energy.
LCI	Life Cycle Inventory is the data collection process for both LCA and LCEA based on systematic flow model of inputs and outputs, which represents the supply chain of the production process.
Geodatabase	An organized system to store multiple files of geographical data into a single database in order to improve efficiency in GIS spatial analysis.
GIS	Geographical Information System, is a holistic computer system able to gather, store, manipulate and analyse geographical data to understand spatial relationships of real life events.
IO	Input-Output analysis is an economic modelling procedure to understand relationships between economic sectors, IO is applied to several fields of science.
IOT	Input-Output tables display statistical sales and purchase relationships between producers and consumers within an economy, generally based on its gross domestic product (GDP).
INEGI	The National Institute of Statistics and Geography (by its name in Spanish) is the coordinator of statistical and geographical information related to those activities that take place in Mexico.
NAICS	North American Industry Classification System (SCIAN by its name in Spanish) classifies economic activities for the purpose of collecting, analysing, and publishing statistical data related to Mexico, the U.S. and Canada economies. The NAICS industry codes identifies economic units based on the activities in which they are mainly engaged.

Chapter 1 The challenge facing life cycle energy assessment

1.1 Introduction

This chapter presents the general context for this research. Because of the high levels of energy consumption in the built environment, the increasing pressure to speed up the assessment of their associated side effects in the environment is subject to large-scale attention by researchers and policy makers. Life Cycle Assessment (LCA) is a prevalent environmental management tool, which is currently a key means to assess and communicate the performance of construction-related activities during their lifespan. However, recent studies show that much remains to improve LCA in order to evaluate buildings and construction materials more appropriately and to enhance its usefulness as a communication tool for policy decision-making processes, which is one of the aims of this research.

Thus, this chapter critically evaluates and outlines current gaps existing in the literature of LCA in order to point out its incompleteness. After this the identification of the research problem, the aim and objectives for this thesis are established. Secondly, within the LCA framework, embodied energy analysis is considered in terms of its appropriateness to be used in this research. The development of a new simplified system to find energy paths for input-output based hybrid methodologies is identified. Then, a systematic mapping process is proposed, which spatially represents the embodied energy of construction related activities to provide a more holistic approach in the interpretation of LCA results. Finally, a multi-method system approach is presented to integrate LCA and Bioregional principles in a case study in Mexico to underpin the theoretical findings of this study.

Although, the research is based on a Mexican case study by using local data, the expanded principles underlying it can initially be directly applied to Canada and United States, and they well could be adapted to other countries, which use Input-Output tables in their national accounts.

1.2 Background

One of the main concerns within the built environment, as one of the biggest contributors in greenhouse gas emissions (GHG), is to minimize the total amount of energy required for construction activities (Menzies et al., 2007). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), Greenhouse gas figures associated with the building sector are now more than double than a half a century ago. In 2010, this sector alone consumed 117 Exajoules (EJ) representing 32% of the world energy consumption and 30% of the total CO2 emissions. In general, is it estimated that currently the construction industry requires 60% of the total raw materials used worldwide (Zabalza Bribián, 2011). According to Salomón et al. (2013), in the Mexican built environment, along with the construction industry, the production of cement and steel are the industrial sectors with the highest GHG, where 77.4% of the total emissions were released from cement products, 20.1 % from steel and the rest from other construction activities.

Furthermore, with the current trend of the global growing population and the increasing need for more housing, specifically in developing countries with high construction rates, a challenging scenario is presented with an expected increase of 300% in the demand for energy and building materials over the next half century (Saghafi, 2011). Therefore, if the current consumption patterns of this sector do not change soon, its expansion could devastate a large portion of the earth land surface (McDonough and Braungart, 2003). Thus, to avoid exceeding earth's carrying capacity, materials and energy requirements ought to be diminished by as much as 90% in the following four decades (Birkeland, 2012a).

Although, the built environment plays a key role in energy consumption, the recommendation to enhance the energy performance of buildings in the European Union was included only in 2002 (Poel et al., 2007), and finally adopted by the European Parliament and Council on the energy performance of buildings (EBDP) on May 2010 (EPBD, 2010). In the EU, this agency is the major legislative instrument to reduce the energy consumption of buildings; however, it only addresses operational energy, which is only a single phase of the building life cycle.

Within the built environment, the energy used in buildings for lighting, appliances, heating, cooling etc. is known as the delivery or operational energy and represents direct energy consumption which is the main target identified by researchers and government policies as a focal subject for investigations to establish building regulations. However, the energy used in the production of goods and services for the built environment is also important as indirect sources of GHG and direct cause of land depletion, given the action to turn raw materials into building materials needs high amounts of energy in industrialized manufacturing process (Zabalza Bribián, 2011).

The energy involved in these production processes is called the embodied energy and over the years different assessment approaches have been addressed to measure the environmental impact associated with them (Broun and Menzies, 2011). However, LCA is clearly the most popular tool used by the environmental management and researchers to fulfil this function (Crawford, 2008). This environmental tool for decision makers is based on international standard ISO 14000 and has established a set of indicators that attempts to measure the whole impact of the built environment in order to mitigate its harmful effects in the natural environment.

LCA methodologies came historically from industry, some of the first studies using this method date from the late 1960s, being a research by The Coca Cola Company a pioneer in the environmental analysis of different beverage containers (Buyle et al., 2013), however LCA in the built environment has only been used since 1990 (Cabeza et al., 2014). The first version of these standards was published in 1997 and several updates have been made since then (Karimpour et al., 2014). Given LCA is a scientific and systemic approach, there is an increasing interest for its major incorporation in the built environment as a supporting tool for the decision-making selection of sustainable construction products and for evaluation, comparison, and optimization of construction processes (Cabeza et al., 2014).

The scientific principles of life cycle assessments are underpinned by the general system theory developed by Ludwig Von Bertalanffy in the early 20th. This theory is an interdisciplinary and rational system of thinking to understand a complex phenomenon through the relationship of different elements that are linked together in a non-linear manner (Boulding, 1956). The development of computer systems allowed System theory greater control of linking of different elements through analytical models, which can be first composed as a black box and then refined as far as necessary to achieve the desired quality of outcomes (König et al., 2010).

The intrinsic systemic characteristics of LCA have been used to support the concept of sustainable development launched by The Brundtland Commission back in 1987, which calls for an economic, social and environmental considerations *"that meets the needs of current generations without compromising the ability of future generations to meet their own needs"*. In this way, within the built environment, LCA, through its ISO standards and well-defined mandatory protocols, is used as a communication tool to promote "the three pillars of sustainability" in products according to the Brundtland commission idea (ISO, 2006).

1.3 Problem identification

1.3.1 Life Cycle Assessment

Having introduced LCA as an environmental tool for sustainable decision, it is necessary to understand the theoretical issues that LCA faces to assess sustainability in the built environment. According to Stevenson and Ball (1998, p.196) "*LCA is seductive as a sustainable indicator because it apparently provides a global perspective of the analysed goods and services which include physical and cultural aspects"*. However, LCA approaches would perform better if socio-economic factors are included in the assessment of manufacturing processes (Andrews et al., 2009).

Furthermore, LCA is mainly carried out by industry which can be influenced by political policies and informed consumers (Kloepffer, 2008). For this reason alone, LCA presents a limitation as a tool for sustainability evaluation. This limitation is clearly shown in several Eco-labelling schemes for construction materials and under this framework of sustainability, these labelling systems have been used without great success given that cultural, materiality, environment restoration and regionality are factors that are still excluded (Ball, 2002a). According to Kloepffer (ibid) and Andrews et al. (2009) , the social and economic aspects neglected in the past are now beginning to be more considered in order to complement the strengths of LCA. This tendency in the analysis of products is more remarked in recent studies (Jørgensen et al., 2012, Musaazi et al., 2015).

In spite of the good intentions and the apparent strengths of this LCA approach based on scientific methods, a diversity of technical and comprehensive limitations associated with this “powerful tool” have been also pointed out by different authors over the time (Andrews et al., 2009, Houghton, 2001, Jensen et al., 1997, Pacheco-Torgal et al., 2014). According to ISO standards principles, LCA provides objectivity, accuracy, and comparison to be used as a communication tool of complex data for decision making and environmental policies of a range of industries (ISO, 2006). However, the fact is that only specific experts understand the complex data. This leads towards complex interpretations of results, and this issue is a regular criticism of LCA (Curran, 2013). The complexity is not only restricted to results interpretation, commercially ISO standards are also expensive and time-consuming becoming unaffordable for small industries (Houghton, 2001).

The apparent objectivity of LCA relies on guidelines during the standardization process and in the scientific peer review of these studies by the same experts according to self-imposed rules such as ISO 14044 clause 6 (ISO, 2006). However, as Jensen et al. (1997) pointed out two decades ago, LCA seems to be very subjective when the review is only a checklist of these procedures. For example, Geography is included in LCA’s guidelines, but is generally considered only as a physical barrier and not in the whole context, whereas, besides variations in local resources, energy used and production, local values should also be considered. Moreover, in spite of LCA claims for objectivity during the accounting process, it is clear that its evaluation system is subject of social sciences or decisions theory (Werner, 2005), this implies that LCA utilizes subjective judgment widely, and the lack of a technical and scientific base is often notorious in the process of decision making (Jensen et al., 1997). For example, although the evaluation system in decision making in LCA could be either retrospective (causes) or prospective (effects), some LCA practitioners are not always clear which approach should be selected (Tillman, 2000). This subjectivity approach selection does not lead to a reliable interpretation of the results.

Although standardization provides a good argument for comparison, the data and modelling can only be regarded as an initial and very rough estimation of real-world problems. Several reviews show that within the built environment, particular case studies are quite difficult to compare (Cabeza et al., 2014, Buyle et al., 2013, Verbeeck and Hens, 2010). The reason is that while industrialized products follow well-defined production processes, non-industrialized and larger systems such as buildings present additional factors such as renovation or modifications, which represent a more complex analysis. A building's unique characteristics such as typology, comfort requirements, climate and even local regulations are considerations that LCA cannot easily approach.

Hence, results from LCA are merely a conceptual interpretation of reality, and do not represent absolute values and consequently they cannot guarantee their use as a system of product certification (Buyle et al., 2013). Thus, environmental policies and decisions based only on LCA are not enough and need to be linked with site-specific ecological approaches able to incorporate temporal-spatial and socio-economic considerations in order to improve reliability (Reap et al., 2003, Eufrasio-Espinosa and Stevenson, 2013, Stevenson and Ball, 1998, Ball, 2002b). This socio-economic context would provide a real-world understanding to reduce the internal subjectivity of impact analysis, and at the same time provide valuable information for those who seek to produce or purchase responsibly (Andrews et al., 2009).

Accuracy is the aim of LCA, which depends on extensive databases where estimation procedures are performed thorough established routines in generally expensive computer programs. According to ISO guidelines, this aim is addressed to obtain objective, reliable and comparable results through different indicators for decisions making (ISO, 2009). However, many researchers dispute that precision is ever accomplished due to the inaccessibility or low quality of information. Furthermore, the lack of agreements in current methodologies, frequent mistakes in system boundary assumptions and too many indicators lead to diverse and confused results, which are hard to interpret even for the experts themselves (Crawford, 2011, Menzies et al., 2007, Dixit et al., 2012a).

1.3.2 Life Cycle Energy Assessment

In order to reduce the intricacy of LCA in the analysis of a wide range of impact categories[1], the use of energy as a single indicator is an approach widely considered to assess the impact in GHG and climate change by processes related to construction activities. This approach is named Life Cycle Energy Assessment or Analysis (LCEA) in which both direct and indirect energy inputs to produce goods and services are accounted. According to Cabeza et al. (2014) this methodology is growing in interest and is applied to several studies related to the built environment. The need for a Life cycle energy approach for construction related activities was suggested by Bekker (1982), and then: introduced and explained with more detail by different authors (Treloar, 1995, Adalberth, 1997).

LCEA is considered a simplified version of LCA to quantify the environmental impact of buildings, given that it follows the same systematic process to perform its analysis and to interpret results. Thus, faster, complete and detailed assessments are possible (Fay et al., 2000). Besides the initial embodied and operational energy, maintenance, refurbishment, demolition, reuse, recycling, and final disposition are also included in LCEA. Therefore, this process identifies the various stages with more energy demand in order to take actions to reduce them (Ramesh et al., 2010). Although energy is only a single indicator, this approach is suitable for the identification of opportunities and helps in the process

[1] *Potential common Life Cycle Assessment impact categories are: Climate change, Global warming, Ozone depletion, Land depletion, Acidification, Human air toxicity, Terrestrial ecotoxicity, Acid rain, Eutrophication.*

of decision-making to improve manufacturing processes (Mpakati-Gama et al., 2011). However, it is recognised that this indicator alone will never describe the complex reality of environmental problems (Svensson et al., 2006).

The complexity of following multiple variables to identify the path of physical energy use and consequential emissions is becoming progressively more important to decision makers at all levels to establish policies and regulations with regard to its mitigation. Within LCEA studies, there are different scales of analysis, from building materials, individual buildings to urban scales. However, according to Anderson et al. (2015) focusing only in a specific scale produces isolated analysis. For example, by concentrating only on individual buildings, any relationship to the rest of the built environment is excluded, while at an urban scale only entire systems are addressed. The reality is that buildings interrelate with other sectors of the built environment and buildings are embedded within the urban context.

Since LCEA follows the principles of LCA, it inherits the same theoretical and methodology problems already mentioned. Actual energy evaluations of buildings ignore or only consider a partial analysis of the total life cycle energy consumption (Stephan et al., 2011). Calculation methods are not agreed and suffer for inconsistency in definitions of life cycle stages and system boundaries for each construction material (Dixit et al., 2012a). Another drawback of current LCEA studies is the lack of socio-economic and ecological approaches to include a complete perspective in their analysis, given they are necessaries to address regulation frameworks in order to consider all aspects of sustainability in different scales of analysis (Buyle et al., 2013). Hence, an approach that systematically integrates all these factors is lacking.

In terms of calculation methods in LCEA there is also a great debate about which one is the most appropriate to use, given the variety and nature of them (Dixit et al., 2010). On the one hand, the traditional method is called Process analysis (LCA), which has its roots in the field of thermodynamics and accounts physical units (MJ/Kg), and is considered very accurate for simple systems, but limited for complex systems such as buildings. On the other hand, Input-Output methods (IO) come from the field of economy and are considered more comprehensive given the use of national accounts (MJ/$). Depending on the aggregated level of commodities, the accuracy of IO could vary (Wiedmann, 2010). In order to take advantage and compensate the disadvantages of both methods, hybrid methods are the most recently used, with IO based hybrid analysis being the most complete of them. However, the extraction of energy paths from IO models based on Treloar's work (1998), which is one of the most used systems to merge, IO and LCA is complex and is still considered as a black box that has to be improved in order validate this procedure (Crawford, 2008).

Currently, most of the LCEA research within the built environment is carried out in developed/cold countries, with several case studies in Europe and North America, follow by Asian countries and null participation from African and Latin American countries (Ramesh et al., 2010, Cabeza et al., 2014). Notwithstanding this fact, potential applications to extend LCA approaches have been identified in different study fields and are currently under development. Klade et al. (2015) suggests the use of LCEA as an 'oriented origin' identification tool, given that a process for calculating and communicating origin in the lifespan of products is clearly lacking. In the same context Caputo et al. (2014) carried out a study in North Italy and they state that understanding supply chains through LCA can optimize the local production, processing and consumption to evaluate the self-sufficiency of product suppliers in a given geographic region.

In LCA studies, regional and geographical frameworks have been requested (Zhang et al., 2010) in order to include ecological approaches, increase awareness in environmental impact and to address sustainability in construction related activities. An example of these approaches was proposed by Stevenson and Ball (1998) with the inclusion of bioregional philosophies to incorporate socio, economic and cultural values to better evaluate sustainability in building materials, merging in this way systems and ecological approaches. This concept was later expanded by Ball (2002b) with a bioregion mapping process to support decision making and participatory process, and a later work of Stevenson et al. (2002) addressed mapping the supply chain of building materials. However, although both studies performed well individually, the complete application of this proposal is still pending.

Building on this, the work on geographic frameworks is also supported by Fabbri et al. (2012) through the use of geographical information systems (GIS) as a tool to link different scales of energy analysis in sustainable assessments and by depicting complex information in a more synthetic way. In this context, Pullen (2007b) also supports and developed his own idea of LCEA through the spatial visualization of energy to provide an opportunity for a more comprehensive understanding of consumption patterns at urban scales to minimize energy consumption. In LCEA, the visualization of energy flows for ecological awareness is a new concept to effectively display its impacts on the natural environment, thereby gaining attention within built environment research.

1.3.3 The Spatial Energy Visual Approach

Although traditionally visualization in GIS has been concentrated in the Geography field, now it is focused on energy use, climate change, global resource flows where advanced visualization is recognized as a tool for energy understanding and conduct changes (EC, 2008). According to Glad (2009, p.19), this new approach has the potential to analysis links between energy production and consumption patterns, thus, *"visualization can function as a tool for science communication, the analysis of large data sets as well as a platform for decision making and participatory processes"*, which can be underpinned by the experienced application of bioregion through the community mapping process (Ball, 2002b).

Based on his Ph.D. thesis, Pullen (2007a, pag.224) published an article related to a GIS tool where embodied energy figures were displayed in urban spatial format in order to present a *"comprehensive approach of the whole life cycle of buildings"*. The methodology followed in this study was developed through a Spreadsheet format for the Embodied Energy of Dwellings (SEED), which was able to accept embodied energy data from several sources. Pullen's study was based on Process-based hybrid method using Input-Output data for calculation procedures. The estimated energy intensities were displayed on urban maps where each dwelling land parcels showed a colourful representation. The results obtained in Pullen's research showed that EE visualisation had the potential to display complex scientific information in a very simplified way. However, the purpose of that tool was limited as it was without representation of the different stages of the LCEA.

Previously, research carried out by Jones (2001) in Wales UK developed an environmental and decision-making tool called The Energy and Environmental Prediction (EEP). Using several sub-models through GIS, the purpose of the EEP aimed to identify the energy use in buildings, transport and industry to help decision makers to improve energy efficiency. This model was tested and then applied in a new study (Jones et al., 2007) to forecast the effects caused by energy consumption at urban scale in the existing building stock. The proposed model used accepted procedures sub-models, such as the UK Standard Assessment Procedure (SAP) developed by BRE in 1994. The spatial scale in this study was the city of Cardiff taking into consideration postcode areas. Some of the data collected for this study was gathered through a drive-by survey and household questionnaire. The energy results along with an SAP ranking were successfully displayed in thematic maps, but according to the author, it was not possible to survey every single house in that urban area.

A more recently study for mapping embodied energy optimization in transport was presented by Pearce et al. (2007) proposing to take advantage of Google Earth for storing, modelling, and displaying data. This tool was able to search and find the best option for raw material availability according to location, and modes of transportation in order to minimize the transportation embodied energy and CO_2 emissions. The Google Earth application allowed EE analysis from a neighbourhood to a global scale, and one of its aims was address to help the construction industry to select building materials within a regional context (500 mile standard) based on LEED standards. This approach is a clear example of how a spatial analysis can minimize energy. However, only transportation was considered in its analysis, omitting other stages of the material's lifespan. The regional context adopted in that study represents an artificial boundary that does not reflect the locality of the materials that a new bioregional approach could include (Scheuer and Keoleian, 2002).

The difficulty of providing a complete picture in all the life cycle stages involved in the built environment led to a study carried out by Tornberg and Thuvander (2005), where one of the objectives using GIS was to identify hotspots of resources within a regional scale addressing the local context for the development of the city building stock. The study suggested the potential use of codified energy data from different sources to be integrated into a spatial energy model. However, a limitation found in this study was related to the lack of data, where a lot of manual work was necessary to generate suitable input data in its analysis. The author suggested the use of geostatistics in order to compensate this issue.

Studies to visualize energy at urban scale were presented in the University of Cardiff university by Bassett et al. (2013) and Iorweth et al. (2013): the former study focused on estimating embodied energy impacts during design stages by chosen a process based hybrid analysis. The proposed tool in that work used an application (plugin) adapted to SketchUp software. The results included both operational and embodied energy. This work highlights the importance of choosing the embodied energy calculation method at urban scales. However, according to the author only few construction typologies were analysed and more should be considered to clarify discrepancies in EE figures. The second work is a GIS-based sensitivity tool applied to predict operational energy in 140000 dwellings at an urban scale. Statistical data in the calculation model was used for comparison with actual energy consumption. The combination of real and simulation data proved to be useful for the validation of results. Missing data in fuel types, heating systems, occupancy patterns and problems in the identification of buildings' age were identified as limitations in this work.

Finally, the initial steps to conduct this research thesis was presented by Eufrasio-Espinosa and Stevenson (2013) where the need for an integration between LCA and bioregional approaches in a case study in Mexico through a spatial life cycle energy model was identified in order to address some of the gaps here presented.

Therefore, this last work presented the initial steps for the development of this thesis proposal.

1.4 The Knowledge Gap

Although LCA and LCEA are broadly considered as useful tools to assess a broad range of environmental impacts of the built environment, much remains to complement and accelerate its usefulness and credibility as a communication tool for decision-making. Assumptions in the calculation method and assumptions in the interpretation of complex data by general users is still an issue, which needs to be addressed in order to bridge the gap of effective communication with LCA.

The extraction system to identify energy paths from IO tables is still considered as a black box, thus the need to find a more simplified method to perform this function is a key factor to perform a hybrid analysis.

The incorporation of socio-economic geographical frameworks in LCA is demanded in order to truly address sustainability in system approaches, while isolated scales of energy analysis in the built environment are also confused and need to be interconnected to achieve a more holistic approach. The need to know the origin of building materials and to visualize their embodied energy is also required to select the best option in low impact energy materials.

The pressure to tackle climate change problems and environmental impacts of the built environment require energy awareness approaches to treating them more effectively, thus the development of a Visio-spatial life cycle energy model represents an emerging opportunity for this research purpose. The need to carry out this type of studies in developing countries is also identified given the absence of them. Thus, based on the success and limitations of previous studies, a proposal is elaborated next.

1.5 Hypothesis

From conceptual to pragmatic considerations, a Visio-Spatial Life Cycle Energy Model (SLCEM) aims to simplify the understanding of LCA results (embodied energy) through its visualization in thematic maps. However, this systematic model would be first need to simplify the complex extraction system of energy paths in IO models in order to situate high energy-intensities construction materials in Mexico. Then, this approach would be able to introduce energy data within a geographic bioregion to perform a life cycle inventory for the spatial LCEA of a representative local building material. Finally, the visualization of results could help to identify energy intensities during its manufacturing process to extend the interpretation of the embodied energy results.

In order to pursue the above hypothesis, three main questions arise:

(1) How can Treloar's extraction method for energy paths be simplified for more practical use in the Mexican IO model?
(2) How can embodied energy data be integrated within a bioregion framework to perform a more sensitive energy analysis of a local product?
(3) How can visualising EE results in thematic maps extend the interpretation in LCEA?

1.6 Aims and Objectives of this Research

In order to fill the existing gap in LCA as a communication tool for decision-making, the overall aim of the research is to develop a systematic mapping process to display embodied energy intensities at bioregional scales of construction related activities. This process could be used to complement environmental impact assessments and decision making related to the built environment.

In order to achieve this aim, this research will complete the follow objectives:

(A) To improve the current extraction system of energy paths from Input-Output models (Treloar's contribution). This process is one the most used methods in hybrid life cycle energy analysis of the built environment and it is still considered as a black box.

(B) To develop an expanded spatial life cycle energy model for the analysis of construction related activities (Building/Materials), which integrates both general systems (LCA) and ecological approaches (Bioregion) in order to extend data results interpretation for decision makers.

(C) To test the capabilities of the Spatial Life Cycle Energy Model applied in a case study area in construction related activities and the analysis of a single building material.

1.7 Research Approach

In order to complement the quantitative energy analysis, a case study research provides a broader understanding of complex conditions of the analysed subject in the relationship with its environment (Yin, 2012, Flyvbjerg, 2011). Therefore, to complete the previous objectives, a spatial life cycle energy analysis within a bioregion case study in Mexico is proposed for this research.

The consideration for a case study in a Mexican bioregion comes out from the scarcity of research studies in that country, where the demand of new houses reaches one million per year (CONAVI, 2010), thus, more building materials and energy are constantly required.

Given the complexity of a Life Cycle Energy Analysis and taking construction materials as entire and independent systems, this study will adopt a multi-method system approach that in turn requires a varied set of data sources and software tools to perform its function.

Based on the availability of Input-Output tables, the lack of data in terms of building materials in Mexico (CONAVI, 2010) and the complexity and time consuming process of LCEA, the Input-Output based hybrid approach is identified as the best option to perform the initial embodied energy analysis of construction materials within the system boundaries selected. (See section 2.3 for further discussion of these methods options). Thus, IO will provide energy flows of construction materials from the national economy while Process analysis (LCA) will provide accurate and reliable data to avoid uncertainty in results.

Knowing that in Mexico, Input-Output tables and the National Database of Economic Units (DENUE) share the same coding system (NAICS), once the IO model is incorporated within the bioregion study area through GIS. ArcGIS software is selected because the author is familiar with this software and because it allows the analysis and the representation of quantitative data within a spatial geographical framework where the obtained spatial energy model can be used later for two purposes:

- Firstly, to test its capabilities to incorporate energy coefficients into all the construction related economy units located within the case study. Thus, a generic bioregional life cycle energy inventory could be the framework for a deeper analysis of building materials.

- Secondly, to estimate the initial embodied energy of a single construction material locally produced in a bioregion area, complementing in this way the calculation procedure with first-hand data to finally display results in thematic maps.

For further steps to achieve individual objectives in this research, the entire process is illustrated below (Table 1.1):

Table 1.1 General Research Methodology Flow Chart

	Steps/Objectives	Methodology
↓	1 Develop a LCEA model National Level	(IO)
↓	2 Select a Bioregion case study area	(GIS)
↓	3 Bioregional Characterization	(GIS)

↓	4 Develop a bioregional database	(GIS-DENUE)
↓	5 Select target sector to analyse	(IO)
↓	6 Evaluate the supply chain of the target sector	(IO)
↓	7 If available use LCA data, If not, connect with local producers.	(DENUE)
↓	8 Data collection or Life cycle inventory	(LCI)
↓	9 Perform hybrid energy analysis	(IO Based Hybrid Analysis)
↓	10 Spatial analysis and results depict	(GIS)
↓	11 Interpretation of results	(GIS)

Step (1). Given the absence of data in Mexico related to life cycle inventories to analyse the built environment, the initial step of this research will be focused on the development of Mexican embodied energy coefficients through Input-Output methodologies. This process uses the North America industrial classification system and will provide both direct and indirect energy factors through excel spreadsheets using input-output tables of the national economy.

Step (2). After the systematic approach (IO) developed in step (1), the second step in this research will be the selection of an appropriate bioregion case study area in Mexico. The selection of a suitable and in some degree already categorized bioregion will be considered an asset to provide the geographical framework needed for the integration of a bioregional approach. This process will be performed with different sources and GIS Software.

Step (3). The third step will be the integration of the bioregional approach. Hence, a more tailored characterization of natural local resources will provide the so far undefined bioregional capacity as a supplier of natural resources to the local built environment. This step will anticipate what type of construction materials used in the bioregion are actually produced outside of this area. This process will be also be carried out with different sources and GIS Software for resources identification.

Step (4). This step will provide a Bioregional characterization of construction related activities based on current economic units identified within this area. Given that the national statistics directory of economic units (DENUE) has an extensive database codified according to the same system used in the Input-Output model, a tailored life cycle inventory will be created in order to incorporate energy coefficients developed in step 1. Hence, excel spreadsheets will be used to export data to GIS software.

Step (5). This step will be applied into a case study in chapter six, according to the expected capabilities of the dynamic input-output model to analyse different targets sectors. Within this step, the selection of a building material produced in the bioregion will be made based on its energy intensity and numeric representativeness.

Step (6). This step will assess the supply chain of the selected building material, through the economic energy paths of the Input-Output Model developed in step 1. Therefore, results will be useful to determine the level of downstream stages needed to collect data according to LCI/process needs.

Step (7). According to step 6 results, within step 7 a Life cycle inventory is necessary to analyse a specific target sector (building material). Given Mexico lacks of LCI in building materials, it is assumed that data collection will be needed. Therefore, taking into account potential results of the energy paths of the analysed construction material the most important data collection could be identified. Although, within this research this step will be addressed only to the analysis of a single building material, there is no limitation to target more industrial sectors in the analysis of the production of other building materials.

Step (8). This step will request data collection from building materials producers to obtain first-hand data to estimate direct energy intensities based on process analysis method. Results will be used later in step 9 for a hybrid analysis.

Step (9). According to IO based hybrid methodologies, this step will carry out the life cycle energy of the selected building material merging IO data and results from step 8. Thus, a top-bottom analysis will be performed through excel spreadsheets.

Step (10). Once the life cycle energy analysis is completed, the results will be export to GIS software for mapping embodied energy results to support this study. Following this process, a spatial analysis using geographic Interpolation techniques will be carried out to display visual thematic LCEA Maps for the chosen bioregion.

Step (11). The final step will be the interpretation of results using the set of maps developed in step 10.

1.8 Structure of the study:

The research is structured as follows; Chapter 1 addressing the research background, Chapters 2 and 3 present the systems approach, Chapters 4 presents the theoretical bioregional approach and its potential to complement LCA. Chapter 5 and Chapter 6 demonstrate the application of the Visio-spatial energy model. Finally, Chapter 7 presents the general summary and conclusions of this study. The outline of the chapters is presented below.

Chapter 1 – The challenge facing life cycle energy assessment
The aim of this chapter is to present the general context for this research, literature review and current gaps to establish the general methodology to perform the spatial life cycle energy analysis proposed in this study.

Chapter 2 – Situating life cycle energy analysis.
The purpose of this chapter is to present the current structure of Input-Output models, the state of calculation procedures in hybrid approaches and their gaps to

identify energy paths to estimate the embodied energy related to the Mexican construction sector.

Chapter 3 – Revised Mexican Input-Output model.
This chapter presents the process to build the revised Mexican Input-Output model and the new dynamic and simplified extraction technique of energy paths for hybrid analysis in embodied energy procedures.

Chapter 4 - Bioregion framework for embodied energy mapping.
This chapter presents the bioregional theory as a contextual framework for making sense of place in life cycle inventories of the built environment.

Chapter 5 – Bioregion case study.
This chapter introduces the process for a descriptive and systematic characterization of the Cuitzeo bioregion case study in Mexico, where finally a bioregional life cycle inventory of the local construction related activities is identified for energy coefficients insertion.

Chapter 6 – Fired Clay Brick production: demonstration of spatial LCEA model.
This chapter completes the process for demonstrating a new spatial embodied energy mapping through a case study of a bioregional fired clay brick production, where embodied energy is depicted to explore the sense of place in LCEA results and its interpretation.

Chapter 7- Conclusions.
This chapter presents the general summary, the discussion of findings, and the main arguments presented within during the development of this research in relation to the general aim and objectives.

1.9 Scope and limitations

Given the explorative nature and the characteristic of the visualization approach of this research, the scope of the life cycle stages and system boundaries considered for this study will be cradle to gate for the building material case study. The geographical scope is limited only to the case study of one bioregion in México, because of time limitation during this research and the complexity to gather data from local building material manufacturers.

1.10 Summary

In this chapter, the introduction to this research was presented. First, a review of the current level of knowledge in life cycle approaches was discussed in terms of life cycle assessments (LCA) and its simplified version (LCEA). Energy visualization applied to the built environment was identified as an emerging approach to simplify the comprehension of complex data. The existence of current gaps in the literature was identified in order to establish the research questions which justify the development of this research thesis. Thus, a new Visio-spatial life cycle energy model represents an emerging opportunity for this research purpose, which in turns requires a multi-method systematic approach to support the completion of this study. The first step to achieving this aim is presented in the next chapter.

Chapter 2 Situating Life Cycle Energy Analysis

2.1 Introduction

For this research, the first step is to develop embodied energy coefficients to perform a life cycle energy model for the Mexican built environment. However, before this objective is performed, this chapter presents the concept and levels of energy analysis, the meaning of embodied energy and the current state of its calculation procedures in different target sectors within the built environment, the structure of Input-Output (IO) models, and the gaps in knowledge that exist within this context.

In addition, the significance of, and differences between, embodied energy methods will be explained, followed by the acknowledgment of the variation of results and their interpretations. The consideration of a new simplified technique to extract energy paths from the IO energy model that allows a better integration with Input-Output based hybrid analysis will be defined. This will establish the basis from which to develop the revised Mexican economic Input-Output model in chapter 3.

2.2 Energy analysis

The modern concept of energy analysis was established by the International Federation of institutes for Advanced Studies (IFIAS, 1974) in a series of workshops that took place in Sweden and The Netherland during the decade of the 70's, given the importance of these events, were later known as the convention of conventions (Roberts, 1975). In those workshops, a group of scientists and economists defined the term of energy analysis and debated about the basic rules for calculation procedures. While scientists suggested the use of physical units to measure energy requirements of manufacturing processes, the economists argued that these processes are the result of productive and consumption human activities, in which energy should be incorporated based on monetary terms (IFIAS, 1978).

As cited by Giampietro et al. (2013, p.32), as a result of the agreements in these workshops, the process of energy analysis in goods and services was defined as "*the amount of energy source which is sequestered by the process of making a good or service*". Within this concept, IFIAS proposed a basic model of system boundaries and levels in which goods and services should be investigated to perform a reliable energy analyses (Dixit et al., 2013). The proposed criteria to carry out that process required the definition of the system boundary to be established, which in turn determines the required level of energy analysis as seen in Figure 2.1.

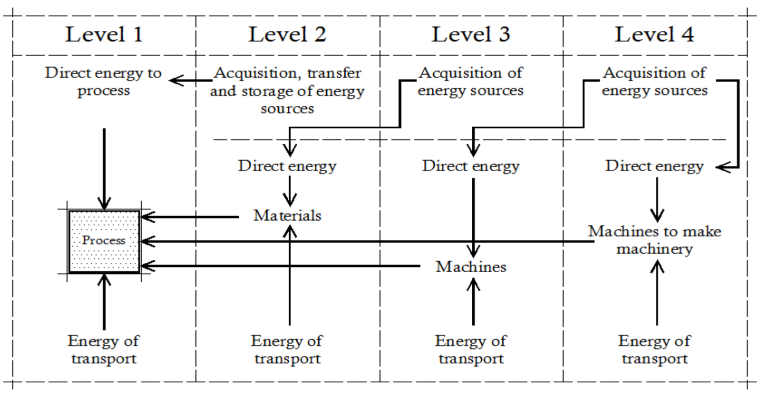

Figure 2.1 Levels of energy analysis proposed by (IFIAS, 1975)

2.2.1 Levels of energy analysis

Level 1 accounts only the direct energy inputs of the main process (fig 2.1). These inputs are fossil fuels and electricity representing primary energy, and the energy accounted in this level is approximately 50% of the theoretical total energy. Level 2 involves the energy required to extract, process and distribute materials. The energy in this level is around 40% of the total energy. Level 3 incorporates the energy to make capital equipment, such as machines. The energy accounted in this level is generally less than 10% of the total energy. Level 4 concerns the energy to make machines, which are also used to make machines as capital equipment. This energy level accounts for a very low proportion of less than 3% of the total energy to make a product. Finally, the energy used in transportation is accounted at all levels (Alcorn, 1997).

2.2.2 Life cycle energy analysis in the built environment

As mentioned in Chapter 1, within the built environment, the calculation procedure to consider all energy inputs during all stages of the building lifespan is known as Life cycle energy analysis (LCEA) (Treloar, 1995). Thus, both in the analysis of entire buildings or the analysis of a basic building material, the LCEA accounts both for the direct energy, better known as the operational energy, and the indirect energy, which is also known as the embodied energy. As seen previously, LCEA is considered the simplified version of LCA used to quantify the environmental impact of buildings. As same as LCA, LCEA consists of four phases in their analysis; Goal and scope, Life Cycle Inventory, Impact assessment and results interpretation (Ramesh et al., 2010).

In LCA, the selection of system boundaries depends on the object to be analysed and can be applied to basic building materials or complex systems such as a dwellings (Dixit et al., 2013). For example, the four common system boundaries for the energy analysis of building are represented in Figure 2.2; The Cradle to Gate system boundary involves the stages from raw materials extraction until the production of the building material, not including the successive phases of construction. The Gate to Grave system compromises the stages from the transportation of the building material until its final disposal in the landfill. Finally, the cradle to cradle contains the entire lifespan of the material, including its recycling or reuse, this last system boundary proposed by McDonough (2002).

System Boundaries			Phases	Life Cycle Stages	
Cradle to Cradle	Cradle to Grave	Cradle to Gate	Production Phase	Raw Material	Upstream of Building
				Extraction	
				Transport	
				Main production process	
				Transport	
				Packing and Storage	
		Gate to Grave		Transport	
			Construction Phase	Construction & Assembly onsite	Building
				Prefabrication off site	
				Transportation on site and off site	
				Administration	
			Occupancy Phase	Water heating	Downstream of Building
				Lighting	
				Air Conditioning	
				Heating	
				Operational Building appliances	
				Transport	
				Renovation	
				Maintenance	
			Years	Lifetime	
			End of life Phase	Demolition	
				Transport	
				Disposal	
				Reuse	
				Recycle	

Figure 2.2 System boundaries for a building LCEA

Although, in the analysis of buildings, system boundaries could be relatively easy to identify, in the analysis of building materials the criteria depend on the number of manufacturing processes in which the material is produced. Thus, in construction materials, system boundaries have been readily adopted according to different scopes, functional units, data availability or researchers preferences (Lotteau et al., 2015). Hence, the complexity of identifying the different system boundaries of each element or construction material in a building complicates the analysis needed for accurate calculations (Jones, 2010). In general, just a few studies have taken into account all the system boundaries involved in buildings (Ramesh et al., 2010).

Despite the importance in the selection of system boundaries for embodied energy procedures, there is still no agreement in how to consider them, provoking results that cannot be entirely used for comparison purposes (Dixit et al., 2013). Additionally, discrepancies and imprecisions of current methods to perform embodied energy inventories lead to potentially unreliable results (Dixit et al., 2012a, Wan Omar et al., 2014).

Based on previous facts and for the purposes of this research, in the analysis of a single building material in Chapter 6, a cradle to gate system boundary should be considered taking into account embodied and direct energy.

2.2.3 Operational Energy

Although operational energy usually applies to buildings, in order to establish its relationship with building materials, the concept is described next. Operational energy, also known as the recurrent, end-use or delivered energy, represents the higher demand of energy that is used by occupants and building services during the building lifetime. Basically, this energy supplies power to cover basic human needs of lighting, cooking, and water heat. It also supplies cooling and heating energy to adjust the performance of the building envelope according to climate conditions (Pullen, 2000).

In theory, the lower the embodied energy of materials used in buildings, the more energy efficient the building would be, however, some studies showed that in solar and low-energy buildings the proportion of the embodied energy in construction materials is actually higher than the operational energy during their life cycle (Sartori and Hestnes, 2007, Thormark, 2006).

Furthermore, (Dixit et al., 2010, Miller, 2001) point out that strict regulations in insulation materials, improvements in the thermal performance of building envelopes, and appliances energy efficiency are reducing operational energy figures. The proportion of embodied energy in relation to operational energy use is therefore, becoming higher, as the embodied energy figure has remained similar.

Hence, embodied energy is becoming increasingly significant in the LCEA of buildings.

2.2.4 Embodied energy

Initially known as capital energy, the Embodied Energy (EE) concept was developed under the premise "*when you consume anything, you are consuming energy*" (Bullard III and Herendeen, 1975, p.268). Hence, this approach was developed to quantify how much energy is used in the production of goods and services. As mentioned before, (IFIAS) went on to define this concept more technically under the field of thermodynamics as the Process Energy Requirement (PER) where both direct and indirect energy are considered in the manufacturing process of a product. However, it was not until 1978 that the first appearance of the term *"embodied energy"* is mentioned in page 153 of the IFIAS's workshop report.

A later definition of embodied energy, more related to the analysis of construction activities, was introduced by Treloar (1998, p.2) as "*the energy consumed in all activities necessary to support a process*" taking into account direct and indirect energy consumption during downstream and upstream stages [2] associated with construction processes. However, the general consensus in this research field is that after many years, the overall term of embodied energy has not been completed understood and agreed yet, and is still open to different interpretations (Miller, 2001, Dixit et al., 2012a).

For a single construction material, EE is the total consumption of primary energy over the life cycle of a building material, where the different stages for its production are broken down for specific analysis (Hammond and Jones, 2008). As explained before, extraction of raw materials, manufacture, and transportation are the most common stages of this process, also known as a Cradle to Gate system boundary. For buildings, on-site construction, maintenance, demolition,

[2] In the production process of goods and services, upstream stages involve any part of the processes before the material/service itself, for example the extraction of raw materials. Downstream stages involve the material's industrial process itself and further stages, such as the sale and distribution of the material. The example of upstream and downstream stages are well represented in Figure 2.2 where the upstream stages of a building represent a cradle to gate system boundary, while the downstream stages of the building represent a gate to grave system boundary, however, these stages might vary depending on the finished product.

reuse, potential recycling and final disposal of materials also represents embodied energy figures, but with different system boundaries that frequently are not considered in EE calculations (Thormark, 2006).

Summarizing, embodied energy is a single indicator in LCEA to account the energy requirements of simple building materials, composite products or entire projects. According to Thompson and Sorving (2007, p.279) "*this account system plays an important role to understand, achieve and assess sustainability in the built environment*." However, embodied energy monitoring systems by policy-makers cannot be agreed until calculation methods by experts have been developed and agreed.

2.3 Energy Analysis Methods

Methods in energy analysis have been developed in different approaches according to scopes and investigation's purposes. Statistical analysis, Process-based analysis (LCA or PA for this research identification), Input-Output-based analysis (IOA) and Hybrid analysis (HA) with its variants, and more recently stochastic analysis are the most common methods used to perform embodied energy calculations with a certain level of acceptability according to the common available data (Anderson et al., 2015).

However, these methods need to be compared and validated given that the particular nature of each of these procedures present a different perspective from which to analyse the same problem, and that this is one of the factors responsible for variations and inconsistencies in embodied energy results (Crawford and Treloar, 2003, Dixit et al., 2010). Basically, Input-Output and Process analysis are the most representative methods in energy analysis, IOA comes from the field of economics following a top-down approach, while PA comes from the field of physics (thermodynamics) and uses a bottom-up analysis process (Wiedmann, 2010). Description and characteristics of these methods are presented below beginning with a summary of the methods they use.

2.3.1 Statistical analysis

This method considers available national, regional or industrial statistics in order to estimate energy intensity factors that later are multiplied by the price of the product in order to obtain the energy intensity in physical units of that product in relation to its mass. Even though national statistical data and methods are considered to be relatively speedy and useful for initial embodied energy calculations, if statistic data shows incompleteness and lack of detailed to carry out a proper analysis, this method alone will be not able to provide reliable outcomes (Baird et al., 1997).

According to Treloar (1995, p.29) some of the most common anomalies found in statistical analysis suggest that figures on the average of national production processes do not represent local production methods very well and this difference could be very significant when attempting to adequately estimate the embodied energy of a product. In addition, the percentage of data coverage in national statistics and the time of data collection are also considered as important anomalies affecting the reliability of this method. In this way, available statistics are confused and difficult to compare, representing an important constraint for this method (Thompson and Sorving, 2007). However, in the absence of data for more sophisticated methods, this simplistic approach it is commonly used for industrial use to accelerate the decision-making process (Menzies, 2011)

2.3.2 Stochastic Methods

In mathematics, stochastic methods obtain values from a resultant sequence of combined unsystematic or random variables (BRITTANICA, 2015). This statistical method is rarely mentioned in the embodied energy literature and has been developed in response to the deterministic categorization applied to the IOA process. According to Pullen (2007a) this alternative method effectively covers uncertainties in embodied energy calculations associated with the manufacturing process of same products by different plants. The method uses hybrid analysis and Monte Carlo simulation. Thus, this approach has the potential to identify environmental problems in specific industries which could take advantage of government target policies to reduce greenhouse gas emissions. Current work on this method is carried out in Ireland by (Acquaye et al., 2011b, Acquaye et al., 2011a) in the analysis of any type of structures and could be applied in other countries. However, it needs to be further expanded giving that stochastic methods are still depending on IO and process data.

2.3.3 Process analysis

Process analysis (PA) is a method, which collects selected data for product analysis in order to estimate both direct and indirect energy requirements and the system boundaries involved in its manufacturing process. The systematic procedure and the requirements to perform this analysis follows the rules described at the beginning of this chapter (IFIAS, 1974). These procedures were also adopted and applied to Life Cycle Assessments for standardization purposes (ISO, 2006).

PA has therefore been given the status of a consistent and widely used method for embodied energy calculations supported by laws of thermodynamics, where physical units are represented in energy quantities per unit mass of the product. However, despite its capabilities, several studies (Menzies et al., 2007, Lenzen, 2000, Dixit et al., 2012a, Crawford, 2008) have suggested that even extensive analysis and the accuracy of results based on this methodology are not enough to achieve the necessary completeness to consider it reliable.

The main disadvantages associated with PA are also well identified, where the lack of boundaries definition, the exclusion of inputs and truncation error in upstream processes among others, could lead up to 50% of incompleteness in its results (Dixit et al., 2010). An additional issue with this method is related to its applicability, where under the premise of standardization, the use of generic databases and simulation tools is applied to analyse case studies in countries with different manufacturing process and energy sources, thus jeopardizing their results (Mpakati-Gama et al., 2011).

Therefore, in countries with a lack of data and life cycle inventories, a more systematic and clear way to use foreign data is necessary. Moreover, although this method works well to assess individual products, its applicability to evaluate more complex systems such as residential buildings needs to be revised as explained in section 3.4

2.3.4 Input-Output analysis

Input-Output analysis (IOA), which is a division of econometrics, is a conventional and widely known modelling system or top-down technique developed by Wassily Leontief in the 1930s to trace and analyse interrelationships in national economic sectors. Sometime later, the usefulness of this approach based on national accounts for planning and decision making was adopted and standardized in 1993 by the statistics division of the United Nations (Wiedmann, 2010).

However, the true potential of IOA for the quantification of environmental impacts and energy analysis of products was introduced by different authors during the period of the 70's & 80's (Bullard III and Herendeen, 1975, Bullard et al., 1978, Hill, 1978, Miller and Blair, 2009, Constanza, 1980) and then applied to the built environment in the calculation of the embodied energy of construction materials and buildings.

In embodied energy procedures, this economic approach relies on input-output tables that turn economic data into energy flows through the incorporation of primary energy factors and energy tariffs. The obtained outcome in this calculations represents embodied energy factors of industrial sectors generally displayed in GJ that then are multiplied by the cost of individual products resulting in the energy intensity of this product commonly expressed in MJ per unit of national currencies £,$, etc. (Crawford, 2011).

Despite the comprehensiveness associated with this method, IOA has several limitations: the periodicity to release input-output tables vary from country to country between one and five years and this delay could lead to inconsistent energy factors (Crawford, 2004). The aggregation level and the commodity of sector groups in input-output tables also represent uncertainty factors with considerable variations in the analysed sectors such as 42 commodities in (Liu et al., 2012), 113 in (Treloar, 2001) or 480 in (Hendrickson et al., 2006). Given that IOA tends to homogenize the products of a specific industry, this method is suitable to display holistically their system boundaries but is not precise enough to estimate their energy intensities (Lenzen, 2000).

Finally, as summarized by Alcorn (1997) the disadvantages of IOA are associated with changes in price levels, changes in technologies, IO tables aggregation levels, differences between producer vs purchaser's prices, energy cost capital, physical flows, assumed proportional currency values and the lack of certainty in base year data.

2.3.5 Hybrid Analysis methods

The purpose of Hybrid Analysis (HA) methods, widely explained in the literature, are to compensate the weaknesses and shortcomings associated with PA and IOA, covering in this way all the system boundaries and the detailed level of analysis that a product requires for its assessment. Basically, HA can be well-defined as an amalgamation of physical and monetary units (Wan Omar et al., 2014). According to Wiedmann (2010) although there are several options to combine these former approaches, which represent two different commitments, two separate main HA methods have been developed, which are described next.

2.3.5.1 Process based hybrid analysis

The framework for this HA method begins with the quantification of materials and direct energy inputs of an individual product following by the incorporation of indirect energy factors of the Input-Output model, and sometimes complemented with statistical data to achieve faster and accurate results (Alcorn and Baird, 1996, Pullen, 2007b). However, as cited by Dixit et al. (2010) complex materials present problems for this method, given that this is a typical characteristic inherent from process analysis along with the subjectivity to include or exclude processes based on researchers' assumptions (Suh et al., 2003).

2.3.5.2 Input-Output based hybrid analysis

Although no EE method currently available is accurate, according to Crawford and Treloar (2003), an Input-Output based HA approach could be considered almost flawless in the study of buildings life-cycles. This method is also known as an Economic Input Output Life Cycle Assessment (EIO-LCA) (Hendrickson et al., 2006). Firstly, this method derives energy intensities from industrial sectors and then these intensities are broken down into energy paths. This step allows the researcher to emulate, compare and modify input-output factors with data from PA. In spite of the several methodological procedures to carry out this combination (Wiedmann, 2010), one of the most cited processes is based on a systematic technique developed by Treloar (1997), and perfected through the years by himself and several other researchers (Treloar, 1998, Fay et al., 2000, Treloar et al., 2001b, Crawford and Treloar, 2004).

Despite that (IO) analysis and its HA variations are the most accepted and used procedures to carry out mathematical calculations in EE, there are some examples of studies in this area that are limited to the use of numerical data or graphs from the literature, rather than creating new data i.e. (Thormark, 2006). This kind of assumption might lead to some level of analysis inaccuracy (Sartori and Hestnes, 2007). More recently, these HA methods have incorporated some variations of LCA as a more accurate approach. An HA life cycle inventory (LCI) is proposed by (Crawford, 2008), a life cycle energy assessment (LCEA) is suggested by (Kofoworola and Gheewala, 2009), and a new protocol is requested by (Dixit et al., 2012b), where a consensus for overall EE analysis in the built environment is needed to unify results.

2.3.6 Variation of results

As shown in section 2.2.1 levels of energy analysis, deeper considerations of these levels return more accurate and reliable results and reduce uncertainty in the life cycle energy analysis of construction related activities, for which the inconsistencies and variations of these results are well known by the research community. However, according to Wan Omar et al. (2014) there are few studies that empirically are addressing the quantification of uncertainties of these variations as is the case of Dixit et al. (2013). Additionally, the lack of data, assumptions and additional factors also have an impact in the uncertainty of the mathematical models used to perform embodied energy calculations (Cabeza et al., 2014).

According to studies carried out by Crawford (2011, p.95), the variation in embodied energy results through different calculation methods is quite significant. Figure 2.3 shows a comparison of a residential building case study analysed through the main LCE methods, with an existing gap of 75% between the Input-Output based HA method and the traditional PA, which is the most popular method with which to carry out analysis in the study of buildings. Taking Crawford's data, a matrix table (Table 2.1) of potential variations between methods is expressed in percentage as a benchmark for this research, which illustrates the problem of variability between method results.

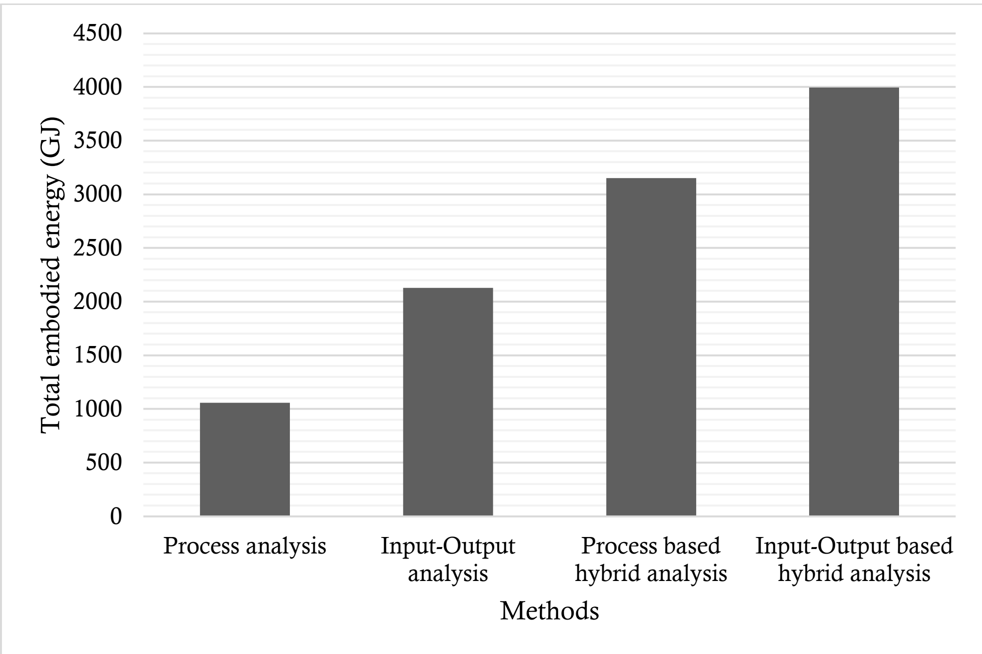

Figure 2.3 Variation of results according to analysis methods (Crawford, 2011)

Table 2.1 Matrix of potential variations of results between analysis methods

Analysis methods	**Process analysis (LCA)**	**IO analysis**	**Process based hybrid analysis**	**IO based hybrid analysis**
Process analysis (LCA)	0%			
IO analysis	50.31%	0%		
Process based hybrid analysis	66.74%	32.52%	0%	
IO based hybrid analysis	73.54%	46.75%	21.08%	0%

2.4 Elements of Input Output models

As explained before, IOT has been adapted to estimate the EE of products or dwellings through the identification of system boundaries and direct and indirect energy flows. Back in 1965 (Miernyk) pointed out that the make-up of large IOTs which involve complex systems could be managed with high-speed computers in abstract languages by skilled mathematicians or with simplified non-mathematical system techniques to expedite these proceedings.

On the other hand, Constanza (1980) has claimed that the flow of energy also known as energy paths is the most important aspect of energy analysis to define direct and indirect energy required for the manufacturing of those goods and services. Given that energy paths are the basis for HA they represent the potential to find *"the finest level of disaggregation in upstream processes of input-output models"* (Treloar et al., 2001a, pag.306).

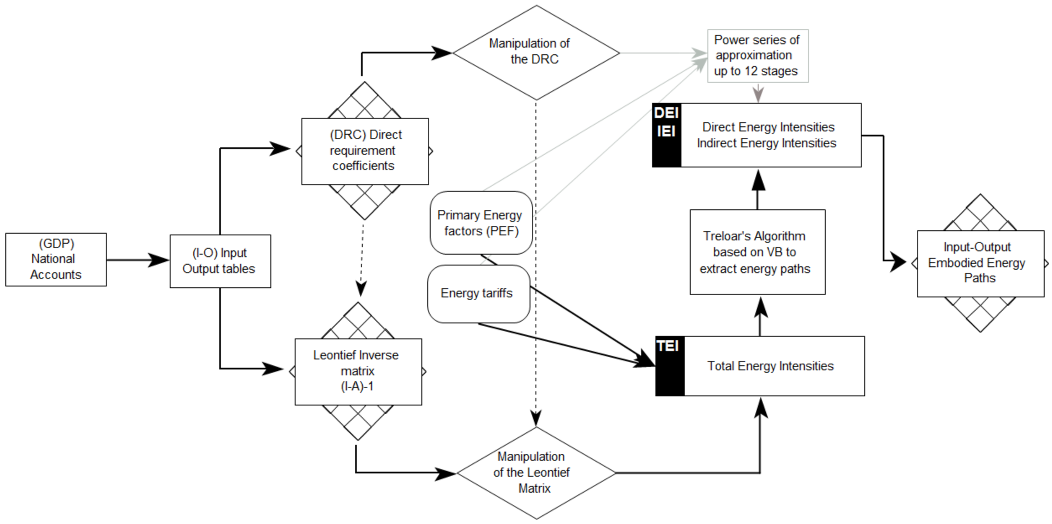

Figure 2.4 Elements of IO models

Although this research thesis takes Treloar's theoretical model as its basis as seen in (Figure 2.4), the practical technique developed by Pullen (2007a) to carry out the same step will be useful to additionally develop a simplified process to identify energy paths. Given that the elements and the make-up of IOTs are well documented in the literature (Wiedmann, 2010), they are mentioned, but not covered in depth in this thesis: the calculation process requires the following elements;

2.4.1 Direct Requirement Coefficients (DRC)

Within IO analysis the derivation of total energy intensities (TEI) is the first step to find energy paths of construction materials according to Treloar (1998) IO model. Technical coefficients "A" also known as Direct requirement coefficients (DRC) derived from the Direct IO matrices will be also used in this research in order to obtain direct and indirect energy intensities of the twelve upstream stages of manufacturing process identified by (IFIAS, 1974).

2.4.2 Leontief inverse matrix

The Leontief Inverse IO matrix $(I - A)^{-1}$ is generally complementary information provided along with the matrix of direct requirement coefficients in IO tables. If not available, the Leontief inverse matrix could be easily generated in basic matrix operations in software programs such as excel (Pullen, 2007b). This matrix expresses both direct and indirect coefficients providing in this way the total technical requirement coefficients of the industrial sectors. According to Treloar's thesis (1998), the resulting coefficients of this matrix should be in theory equivalent to results of infinite series also known as power series. However, he could not match his results in his IO mathematical proceedings (Treloar, 1998, pag.64), instead of that he simply used a Gaussian algorithm for comparison, which weakens his model because small discrepancies between the inverse matrix and the power series were found by the author. Although minimal, these inconsistences will be addressed in Chapter 3.

2.4.3 Power series of approximation

Using the DRC table, the power series approximation is a common and useful technique to separate direct and indirect energy within the total energy intensities of the national economy, $[I + A + A^2 + \ldots + A^n]$. This approach, which traditionally is an alternate tool from IO calculations, covers and identifies twelfth theoretical upstream stages S (Treloar, 1998), which are involved during the manufacturing process of each construction material. The potential results of the twelve upstream stages in the power series of approximation should lead towards zero. Hence, according to Miller and Blair (2009) results of twelfth upstream stages of the power series should approach results of the inverse matrix near the limit as expressed in (Equation 1). In simple words the power series goes beyond the four levels of energy analysis established by IFIAS (1974) mentioned in section 2.2 of this thesis.

Equation 1 (Miller and Blair, 2009)

$$(I - A)(I + A + A^2 + A^3 + \ldots A^S) = (I - A^{S+1})$$

Where;

$(I - A)(I + A + A^2 + A^3 + \ldots A^S)$ represents the power series of approximation

$(I - A^{S+1})$ represents the Leontief matrix

2.4.4 DRC Manipulation and PEF and tariffs incorporation

The manipulation of IO matrices is a key step to remove problems associated with the double counting of energy in IO tables and incorporate systematically primary energy factors and tariffs within the matrix. Several methods to remove the unwanted energy have has been developed (Shane Bush et al., 1993, Peet and Baines, 1986). However, the improved version presented by Treloar in 1998 proved to be more precise (Lenzen and Crawford, 2009). This step is illustrated below with the DRC matrix of the Mexican economy. Thus, in the original IO table (Table 2.2), identified energy supply sectors of the direct requirement coefficients are removed in their columns by setting 0.0000 values, resulting in a modify matrix (Table 2.3), only after this step is performed, primary energy factors and tariffs can be introduced.

DRC		**Mexican Economic Sectors 1-262**						
Sectors	**NAICS code**	1111	→	2121	2211	3241	→	9321
Oilseed, legume and cereal growing	1111	0.01874210	→	0.00000000	0.00000000	0.00000000	→	0.00000000
↓	↓	↓	→	↓	↓	↓	→	↓
Coal mining	2121	0.00000000	→	0.09536209	0.01517581	0.00012950	→	0.00000000
Electricity	2211	0.00849943	→	0.04112175	0.00616582	0.00028653	→	0.08576270
Products from petroleum and coal	3241	0.02791188	→	0.05054034	0.18134311	0.00937955	→	0.09283961
↓	↓	↓	→	↓	↓	↓	→	↓
Extraterritorial and international organizations	9321	0.00000000	→	0.00000000	0.00000000	0.00000000	→	0.00000000

Table 2.2 A condensed representation of the original DRC Matrix provides by INEGI (2012)

Modified DRC		Mexican Economic Sectors 1-262						
Sectors	NAICS code	1111	→	2121	2211	3241	→	9321
Oilseed, legume and cereal growing	1111	0.01874210	→	0.00000000	0.00000000	0.00000000	→	0.00000000
↓	↓	↓	→	↓	↓	↓	→	↓
Coal mining	2121	0.00000000	→	0.00000000	0.00000000	0.00000000	→	0.00000000
Electricity	2211	0.00849943	→	0.00000000	0.00000000	0.00000000	→	0.08576270
Products from petroleum and coal	3241	0.02791188	→	0.00000000	0.00000000	0.00000000	→	0.09283961
↓	↓	↓	→	↓	↓	↓	→	↓
Extraterritorial and international organizations	9321	0.00000000	→	0.00000000	0.00000000	0.00000000	→	0.00000000

Table 2.3A condensed represenation of the modified DRC matrix

2.4.5 Primary Energy Factors (PEF)

Primary energy involves both renewable and nonrenewable energy sources while secondary energy consists of the energy available for final use. In IO analysis one of the aims to estimate the embodied energy of construction materials or buildings is to know how much energy belonging to fossil fuels sources is used in their production, hence, this energy must be expressed in primary form (Hammond and Jones, 2008, Ramesh et al., 2010). PEF are indicators of the total of primary energy used from the manufacturing process of products to the consumer (cradle to site).

Although PEF are key to perform energy analysis in the built environment, acccording to (Molenbroek et al., 2011) their inclusion has been always unclear and controversial, where changes overtime and the lack of scientific methods can easily *"jeopardize results"* (Vosbeek, 2012). Hence, in order that PEF can be properly integrated into input output models they must show economic national representativeness based on the same general framwork used to built the IO Tables (Pullen, 2007a). However, according to Pullen, some IO analysis does not follow this rule and takes PEF from previous studies without clarifying this step.

2.4.6 Energy tariffs

In IO models, the inclusion of energy tariffs have been object of several studies by recognizing the difficulty in dealing with non-uniform energy prices among economic sectors (Bullard III and Herendeen, 1975). The solution was the modification of IO tables where energy supplier sectors can include energy in physical units and the other economic sectors to keep monetary values (Pachauri, 2007). Over the time, several forms of energy tariffs were developed to be included in IO tables; fixed, variable and average tariffs. The technical explanation of each of them is well explained in the literature, (Treloar, 1998, Pullen, 2007a, Vosbeek, 2012) and is not explained deeper in this section.

Basically, the use of energy tariffs depends on their availability, for example despite Treloar (1998) suggesting that variable tariffs are better than fixed energy tariffs because energy units can be easily introduced in IO models, he could not use them given that during his research these data were incomplete for Australia. On the other hand, Pullen (2007a) used average energy costs to combine data from the original IO tables expressed in money transactions and data in energy quantities for a local national body. Hence, the best available option to introduce energy tariffs in the Mexican IO model should be considered in Chapter 3 of this research.

2.4.7 Energy flows

In national accounts, energy is usually considered in Petajoules (PJ) and once that IO model has been carried out, the results obtained are called energy coefficients. Given that these coefficients combine primary energy in physical units and tariffs in currencies, they are normally expressed in Gigajoules (GJ/$) applied to industrial sectors or Megajoules (MJ/$) applied to components or individual products (Pullen, 2007a).

In IO tables, the sum of all the energy coefficients in a specific sector represents its total energy and this figure must be disaggregated to the highest level in order to be used in HA. Treloar (1997, p.376) defined energy paths *"as a series of transactions that lead to a direct energy requirement, where theoretically, energy is* *consumed directly to each node, and each upstream node requires goods and services from any sector of the economy".* Constanza (1980) pointed out that the flow of energy was the most important aspect of energy analysis to define direct and indirect energy required for the manufacturing of those goods and services.

As mentioned in section Input-Output based hybrid analysis, this systematic technique, developed by Treloar (1997), is one of the most cited processes to extract energy paths found in the literature (Crawford et al., 2011). However, in spite of the considerable advantages of this extraction method, in practice the complex algorithm to find energy paths based on computer language (visual basic) limits its applicability and reproduction. A more recent proposal (Skelton et al., 2011) to map embodied energy flows is based on a concept called Structural Path Analysis (SPA), where large IO models display massive figures of transactions between economic sectors, in this way the analyst has to choose which paths should be aggregated or omitted.

Hence, a clearer and simplified process to find energy paths is needed and will be investigated in chapter three of this research.

2.5 Input-Output models

In EE calculations, it is quite common to find studies using values calculated by others where new reports, journal articles and conference proceedings are constantly being published providing figures, case studies, and calculation procedures (Abanda et al., 2012). However, the exact mathematical models supporting these methodologies are hardly ever taken into consideration and are simply replicated. With all the elements of the IO tables, the ability to use large matrices to estimate energy coefficients depends on having these models, if not, this process would be time-consuming and difficult to achieve as a manual exercise (Hawkins et al., 2006). As mentioned before, it is well known that models have the capability to track and display efficiently detailed energy flows in the entire supply chain and can be used to anticipate results.

The use of mathematical models in IO to carry out environmental analysis was first suggested by Leontief in 1970, its application to embodied energy and carbon footprint calculations is still very much in development, however, the understanding of this type of tools is usually managed by experts. Currently, there are few examples available such as the Economic Input-Output Life Cycle Assessment tool (http://www.eiolca.net/) of the Carnegie Mellon University where students, researchers and practitioners can use them to take decisions for construction activities.

Although Treloar developed a very important model to combine IO data with PA to perform hybrid analysis, it appears that its applicability has been mainly limited to Australia and New Zealand case studies or a few other developed countries as shown in studies of (Crawford and Treloar, 2004, Stephan et al., 2013). However, in spite of the shortcomings mentioned before, the development of an adapted and revised IO model based on Treloar's work will be an asset and will be applied in Mexico to calculate energy coefficients of construction related activities in this research.

2.6 Summary

This chapter presented a review of the concept of LCEA applied to the built environment. This approach is relatively new and its apparent simplicity is gaining interest by the scientific community. However, energy analysis is still in development and calculation procedures need to be agreed. Although, in theory, the general recommendations by the IFIAS are a basis from which to assess the built environment, in practice all the phases of the building lifespan represent a more complex system where more work is required in energy analysis.

The availability of data, the nature of available EE methods, the inclusion of primary energy factors, the current state of mathematical procedures to carry out EE calculations and the significance of variation in results were issues identified in this chapter. Therefore, for the purpose of this study, an adapted and revised IO based hybrid analysis will be developed taking into account the main characteristics and shortcomings of Treloar's method. This model will be the basis to identify energy paths in the analysis of building materials of the Mexican construction sector based on the available IO tables of that economy, which are required to be processed in this study. However, a clearer and simplified process to identify the most important paths of the Mexican construction sector must be developed.

Chapter 3 Revised Mexican Input-Output Model

3.1 Introduction

After situating life cycle energy analysis and the identification of gaps in calculation procedures applied to the built environment, the purpose of this chapter is to complete the first step of the overall research approach proposed in section 1.7. Therefore, the most recent version of the Mexican Input-Output tables (INEGI, 2012) will be used to calculate total energy intensities (TEI) of industrial sectors through the derivation of direct and indirect energy intensities (DEI). The estimation process will be carried out through excel spreadsheets based on the IO model developed by Treloar (1998).

The development of a simplified process to find energy paths through a dynamic IO model will also allow the estimation of the embodied energy of multiple industrial sectors, identifying the breakdown of their energy intensities in all the upstream stages. Finally, for the purpose of this study, the total energy intensities of the residential and non-residential construction sectors will be completed to identify the most important embodied energy building materials used by those sectors. Thus, the energy coefficients and energy flows developed in this chapter will become the base that later could be combined with more detailed local data for a proper hybrid analysis of the case study of a single building material in Chapter 6.

3.2 Developing the Input-Output model

3.2.1 Structure

The basic data for the assembly of the IO model in this research required of the symmetric Input-Output tables (IOT) of the Mexican economy concerning to the national accounts. In Mexico, IOT are released every five years and during this investigation three different versions corresponding to 2003, 2008 and 2012 financial years were used. This is because of The National Institute of Statistics and Geography (INEGI), which is in charge for the publication of national accounts, delayed to release the last editions. Thus, for the purpose of the study, the last updated version of 2012, which was published in November of 2014 is used (INEGI, 2014c).

Unlike the first available version of IOT (2003) used in this study, with only 79 economic sectors included (four digits code), the 2012 version uses 262 different sectors built into deeper aggregation levels (six digits code) (see Table AP.A1 Example of NAICS code designation in Appendix A-1). These tables are codified according to the North American Industrial Classification System (NAICS) which was adopted by USA, Canada, and Mexico in 1994 to allow statistical comparison as a part of the North American Free Trade Agreement (NAFTA) (INEGI, 2013b). Given the importance of this code system for this research, its structure is described in more detail in Appendix A-1.

For the development of the IO model, the direct input-output matrix, and the Leontief Inverse input-output matrix were considered. The direct input-output table consisted of a matrix of 262 x 262 cells provides direct requirement coefficients (DRC) of the Mexican industrial sectors. As usual and illustrated in Table 3.1, in IOT, the rows represent inputs (sales) and the columns represent outputs (purchases) of each sector. As pointed out in section 2.4.4, the DRC table was modified according to Treloar's methodology (1998, p.47). From the 262 sectors, four energy supply sectors were identified and processed to avoid double counting and allowing the incorporation of primary energy factors and energy tariffs.

20012			Mexican Economic Sectors 1-262						
Sectors NAICS code			OUTPUTS (Purchase)						
			Oilseed, legume and cereal growing	→	Residential building construction	Manufacturing of products based on clays and refractory minerals	General freight trucking	→	Extraterritorial and international organizations
			1111	→	2361	3271	4841	→	9321
INPUTS (Sales)	Oilseed, legume and cereal growing	1111	0.01874210	→	0.00000000	0.00000000	0.00000000	→	0.00000000
	↓	↓	↓	→	↓	↓	↓	→	↓
	Residential building construction	2361	0.00000000	→	0.00597140	0.00000000	0.00000000	→	0.00000000
	Manufacturing of products based on clays and refractory minerals	3271	0.00000000	→	0.01005046	0.00058715	0.00000000	→	0.00000000
	General freight trucking	4841	0.00425300	→	0.00587808	0.00730515	0.00622915	→	0.00573465
	↓	↓	↓	→	↓	↓	↓	→	↓
	Extraterritorial and international organizations	9321	0.00000000	→	0.00000000	0.00000000	0.00000000	→	0.00000000

Table 3.1 Schematic representation and example of Input-Output process

3.2.2 Primary Energy Factors and Average Energy Tariffs:

As cited in section 2.4.5, traditional IO procedures in embodied energy calculations only include those sectors based on fossil fuels. In the inclusion process of Primary Energy Factors (PEF) into IO tables, the non-representation of national economies using the same framework in which Input-Output model is built was also identified. As suggested by (Pullen, 2007a) the incorporation of physical data should correspond to the same financial year of the IOT in order to properly introduce primary energy factors.

The inclusion of PEF into the Mexican IOT was also subject to the above technical problems. The recognised Mexican energy supply sectors in the IOT are; Coal mining (NAICS code 2121), Electric power generation, transmission and distribution (NAICS 2211), Gas supply through pipes to final consumers (NAICS 2222) and manufacturing of products derived from petroleum and coal (NAICS 3241). However, from these four sectors initially identified, the gas supply was discarded, given that technical coefficients are not included in the IOT.

Furthermore, the electricity sector in Mexican IO tables included all type energy sources without distinction between renewable and non-renewable sources.

Therefore, in order for the author to properly include primary energy factors in the electricity supply sector, an additional procedure had to be performed by adding data in physical units from the Mexican energy balance (SIE, 2012). Thus, from the power plants (electricity supply sector), 53.12% of the total energy was removed, this energy comes from, Nuclear, Hydro, Geothermal, Solar, Wind power, Bagasse, firewood and Biogas sources. In the same way in order to include the absence of energy data in the Gas supply sector, energy was added in physical units into sector 3241 of IOT with data from (SIE).

Physical units of nationally delivered energy expressed in petajoules (PJ) were obtained according to estimations shown in Table AP.A3-1 and Table AP.A3-2 of Appendix A-3 (SIE, 2012). The Sankey diagram below (Figure 3.1)[3] elaborated with these data illustrates well this process. Thus, according to Pullen's recommendations, in this study, both primary energy factors and energy tariffs are estimated keeping their proportionality and representativeness of the Mexican economy within the IOT (See Equation 2 and Equation 3).

Equation 2 Average energy tariff

$$\boldsymbol{T_e = \frac{TD_d}{n_\$}}$$

Where;

T_e= the national average energy tariff, in Gj units per peso, e;

TD_d= the total domestic demand of energy, in million of pesos,d;

$n_\$$= the sells of the energy supply sector, in million of pesos, e;

[3] *Given that a trial version of e!Sankey software was used to create the diagram, there are some visible grey watermarks. Please, ignore them.*

Equation 3 Primary energy factor

$$P_e = \frac{TD_e}{n_e}$$

Where;

P_e= the primary energy factor of the sector, e;

TD_e= the total delivery energy, in PJ;

n_e= the delivery energy of the energy supply sector, in PJ;

As illustrated below in Table 3.2, economic units representing sales in millions from the total domestic demand of the total symmetric matrix of the national accounts were considered in tables (INEGI, 2012). In addition, as cited in sections 2.3.4 and 2.4.7, energy is included according to its scale and national currency. Therefore, given that IOT are built at an industrial sector level, for the purpose of this research, energy tariffs are expressed in gigajoules per Mexican pesos (GJ/$ MXN).

Table 3.2 Average energy tariff & Primary energy factors

		Total Domestic demand	**Delivered Energy**	**Average energy tariff**	**Primary energy factor**
Energy Supply Sectors	**Code**	**Sells ($ Million)**	**PJ**	**(GJ/$MXN)**	**PEF**
Coal mining	2121	$ 22,885.03	97.37	**0.002**	**0.023**
Electric power generation, transmission and distribution	2211	$ 262,236.40	364.12	**0.026**	**0.084**
Manufacturing of products derived from petroleum and coal	3241	$ 711,329.04	3856.95	**0.072**	**0.893**
Total		$ 993,779.71	4318.44		

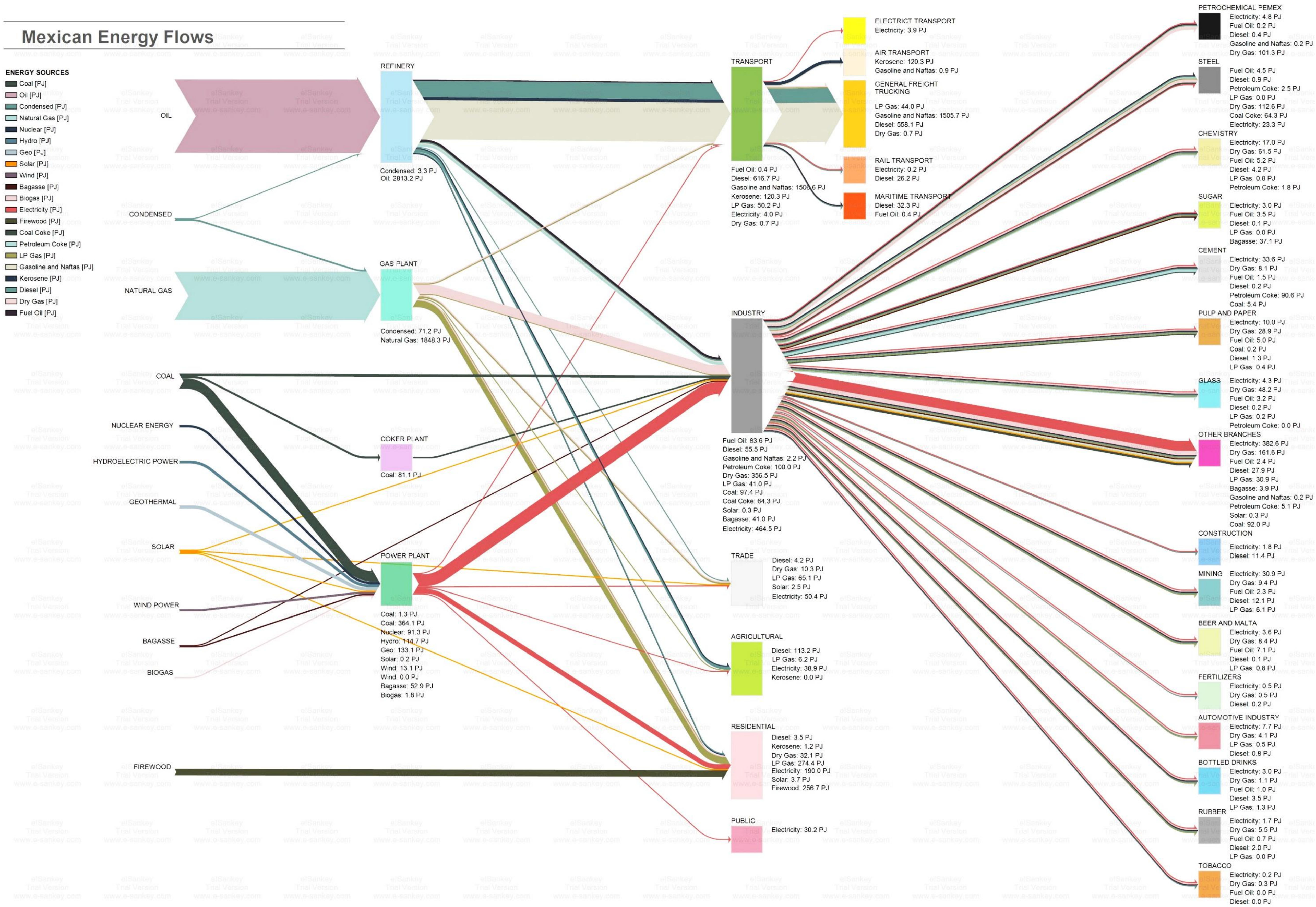

Figure 3.1 Mexican Energy Flows

3.2.3 Energy intensities of Mexican sectors

Using IO approaches to understand sectorial relationships, energy intensities of the Mexican economic sectors were then estimated in order to obtain the mapping framework for potential Mexican energy paths, which in chapters 5 and 6 will be used to estimate the embodied energy of general sectors and individual products used by construction sectors at bioregion area of that country.

As proposed in section 2.5, the total energy intensities (TEI) of the Mexican input-output model are estimated based on Treloar's analytical framework (1998), but considering its shortcomings and order to reinforce the calculation procedure this step is enhanced by using Pullen's practical approach (2007a). Hence, this model uses both matrices extraction techniques; the Leontief inverse matrix with the sum of direct and indirect requirement coefficients and the power series of approximation. In this enhanced analytical process, the missing validation of results requested in sections 2.4.2 and 2.4.3 will be accomplished.

The Treloar's mathematical procedure to obtain TEI and DEI is shown in Equation 4 and in Equation 5 respectively. However, as suggested by Pullen, the Direct energy intensities (DEI) are practically calculated in excel spreadsheets, first through the manipulation of the energy supply sectors as seen in Table 3.3 below, and then the indirect energy intensities were derived by the expanded version of the power series of approximation as seen in Table 3.4 below. For representation purposes and as an example, this last table only shows one of the twelve interactive rounds carried out in this procedure. The equations for summarising these energy intensities after working them out are shown immediately below.

Equation 4 Total Energy Intensities (TEI)

$$\boldsymbol{X_n = \sum_{e=1}^{E} T_{en}\ x\ tariff_e\ x\ PEF_e}$$

Where if n is an energy supply sector, then $\varepsilon_n = 0$, and;

$X_n =$	the total energy intensity of the target sector, n;
$E =$	is the number of energy supply sectors, n;
$T_{en} =$	the total requirement coefficients for inputs from energy supply sectors;
$tariff_e$=	the national energy tariffs in units of energy per $MX peso, and;
PEF_e=	the primary energy factors

Equation 5 Direct Energy Intensities (DEI)

$$\boldsymbol{\varepsilon_n = \sum_{e=1}^{E} D_{en}\ \text{x}\ tariff_e\ \text{x}\ PEF_e}$$

Where if n is an energy supply sector, then $\boldsymbol{\mathcal{E}}n$=0, and:

$\varepsilon_n =$	the direct energy of the target sector, n;
$E =$	is the number of energy supply sectors, e;
D_{en}=	the direct input of each energy supply sector into the target sector, n;
$tariff_e =$	the national average energy tariffs, in units of energy per (In this case, Mexican peso);
PEF_e=	the updated primary energy factors

Table 3.3 Direct Energy Intensities calculation procedure

			Mexican Economic Sectors 1-262				
Energy sector	**NAICS code**	**row/ column**	**1**	**2**	**3**	→	**262**
Coal mining	2121	21	$DRC_{21\ 1} x T_{2121} x P_{2121}$	$DRC_{21\ 2} x T_{2121} x P_{2121}$	$DRC_{21\ 3} x T_{2121} x P_{2121}$	→	$DRC_{21\ 262} x T_{2121} x P_{2121}$
Electricity	2211	25	$DRC_{25\ 1} x T_{2211} x P_{2211}$	$DRC_{25\ 2} x T_{2211} x P_{2211}$	$DRC_{25\ 3} x T_{2211} x P_{2211}$	→	$DRC_{25\ 262} x T_{2211} x P_{2211}$
Products from petroleum and coal	3241	66	$DRC_{66\ 1} x T_{3241} x P_{3241}$	$DRC_{66\ 2} x T_{3241} x P_{3241}$	$DRC_{66\ 3} x T_{3241} x P_{3241}$	→	$DRC_{66\ 262} x T_{3241} x P_{3241}$
Direct Energy Intensities			$\mathbf{DEI_1}$	$\mathbf{DEI_2}$	$\mathbf{DEI_3}$	→	$\mathbf{DEI_{262}}$

Where;

DRC_e= the direct requirement coeffcient of the energy supply sector, e;

T_e= the national average energy tariff, in units per mexican peso, e;

P_e= the primary energy factor of the sector, e;

DEI_e= the Direct Energy Intensity of the sector, n;

Table 3.4 TEI Calculation procedure

		Mexican Economic Sectors 1-262				
Column	Row/Column	**1**	**2**	**3**	→	**262**
$\mathbf{DEI_1}$	1	$DEI_1\ x\ DRC_{1\ 1}$	$DEI_1\ x\ DRC_{1\ 2}$	$DEI_1\ x\ DRC_{1\ 3}$	→	$DEI_1\ x\ DRC_{1\ 262}$
$\mathbf{DEI_2}$	2	$DEI_2\ x\ DRC_{2\ 1}$	$DEI_2\ x\ DRC_{2\ 2}$	$DEI_2\ x\ DRC_{2\ 3}$	→	$DEI_2\ x\ DRC_{2\ 262}$
$\mathbf{DEI_3}$	3	$DEI_3\ x\ DRC_{3\ 1}$	$DEI_3\ x\ DRC_{3\ 2}$	$DEI_3\ x\ DRC_{3\ 3}$	→	$DEI_3\ x\ DRC_{3\ 262}$
↓	↓	↓	↓	↓		↓
$\mathbf{DEI_{262}}$	262	$DEI_{262}\ x\ DRC_{262\ 1}$	$DEI_{262}\ x\ DRC_{262\ 2}$	$DEI_{262}\ x\ DRC_{262\ 3}$	→	$DEI_{262}\ x\ DRC_{262\ 262}$
Indirect Energy Intensities (first round)		$\mathbf{IEI_{(1)1}}$	$\mathbf{IEI_{(2)2}}$	$\mathbf{IEI_{(3)3}}$	→	$\mathbf{IEI_{(262)262}}$

3.2.4 New dynamic model for energy paths

As a hybrid analysis is required to identify energy paths to match economic and physical energy coefficients, during this research the process to extract energy paths developed by Treloar was initially considered given the considerable advantages shown in the literature. However, after some attempts to carry out this process it was found that in the practice, the complex algorithm to find energy paths based on computer language (visual basic) limits its applicability and reproduction, at least from the point of view of someone not expert in this language. Therefore, a more practical way to achieve this process and to be independently reproduced in further studies was necessary as carried out in this thesis. This is now explained below.

As explained in section 2.4.7, Treloar (1998, p.42) suggested that *"summing all the direct energy paths in the model at the limit would be equal to the total energy intensity of the target sector"* and that his hypothesis should be investigated in practical terms. In Treloar's model, the computational algorithm based on visual basic was initially articulated in a mathematical expression to calculate 12 upstream stages, however, given the complexity of this procedure it was later simplified by the same author as shown in Equation 6 below.

Equation 6 Energy paths

$$\boldsymbol{X_n} = \boldsymbol{\mathcal{E}_n} + \sum_{i=1}^{N} \boldsymbol{D_{in}} \left[\boldsymbol{\mathcal{E}_i} + \sum_{j=1}^{N} \boldsymbol{D_{ji}} \left[\boldsymbol{\mathcal{E}_j} + \sum_{k=1}^{N} \boldsymbol{D_{kj}} \; [\boldsymbol{\mathcal{E}_k} + \boldsymbol{I}] \right] \right]$$

Where n, i, j and k are any stage 0, 1, 2, and 3 sectors respectively, and;

X_n= the total energy intensity of the target sector, n;

ε_n= the direct energy intensity of the target sector, n, and so forth (for i,j and k);

N= the number of sectors (equal for n,i,j, and k); and

D_{in}= the primary energy factors.

According to Treloar (2001a, p.305) the main argument for using this computational algorithm was because of the "vertical results from the power series of approximation were still considered as a 'black box' without sufficient data, and they needed to be disaggregated within each upstream stage into energy paths". Thus, in order to calculate how many paths were involved in each upstream stage, Treloar used a known mathematical procedure in IO developed where the number of energy paths are an increasing exponential in each round of the power series given millions of possibilities according to the number of sectors involved (See Equation 7). Then, a number of energy paths was systematically reduced based on the number of non-zero coefficients in each sector's column. However, even after this step the number of energy paths still needed to be identified, hence Treloar proposed a systematic algorithm "pruning system" based on an *arbitrary threshold value* to reduce the time and to facilitate the final calculation procedure.

Equation 7

$$\boldsymbol{n^s} = \left(\boldsymbol{S^0} + \boldsymbol{S^1} + \boldsymbol{S^2} + \boldsymbol{S^{12}}\right)$$

Where n, is the number of economic sectors and s is the upstream stage number.

In this research, the method used for the identification of energy paths from Mexican IO model follows the same rules as described as above. However, the process was different, turning into a new dynamic model by using the expanded version of the power series of approximation. Additionally, some of the previous assumptions were investigated and avoided given that an additional transposition step in the expanded power series of approximation is taken, which in turn gives form to a dynamic energy model which is described next.

In the development of the revised Mexican IO model, the calculation of energy paths was carried out in excel spreadsheets and covered twelve upstream stages following the mathematical criteria expressed in Equation 6, but practically developed in detail through the expanded version of the power series of approximation suggested by (Pullen, 2007a) as shown in Table 3.3 and Table 3.4 above. However, once the power series was carried out, the expanded vertical results (Input-Output columns) are rearranged with an additional transposition step. This simple procedure allows the management of energy coefficients in a more efficient way, given the new rearrangement of the IO table organize with precision upstream stages.

In fact, this systematic process was explained in detail by Miernyk (1965), but not considered in Treloar, Pullen or other authors works. As suggested by Miernyk (1965, Chap. 2) "In practice, if the A matrix is expanded to the twelfth power (upstream stage) using the power series of approximation a workable results will be obtained". The author (1965, Chapter 4.) also pointed out that with this step "the static input output model turns into a dynamic model" allowing the analysis of different economic target sectors within the IOT. Although, the use of the extended power series is described in Pullen's PhD thesis for energy intensities estimation, this technique was not used it for energy paths identification.

Thus, the capability to reorganise a set of successive matrices and the convenience of selecting target sectors permits the Mexican Input-Output model to extract instant energy paths from the theoretical twelfth upstream stages described in section 2.4.3 of this thesis. Then, a set of filters in excel sorts and organizes the data from largest to smallest reorganized the energy coefficients. This last step helped to identify the most important Mexican economic sectors, which are providing the higher energy intensities for any sector to be analysed (target sector), and at the same time discarded insignificant sectors, which do not have any relationship with the target sector. The impact of this simple new step will be discussed further in section 3.4 for a more complete analysis.

3.3 Results of the Mexican Input-Output model

3.3.1 Energy Intensities of non-energy economic sectors

The data defined in section 3.2.1 were used to build the Mexican input-ouput model for the estimation of total energy intensities (TEI), Figure 3.2 below displays the distribution of energy requirements within the Mexican economic sectors (see Appendix A-4 for the full list). Thus, the TEI national average was 0.00244846 GJ/$ and excluded energy supply sectors avoiding in this way double counting.

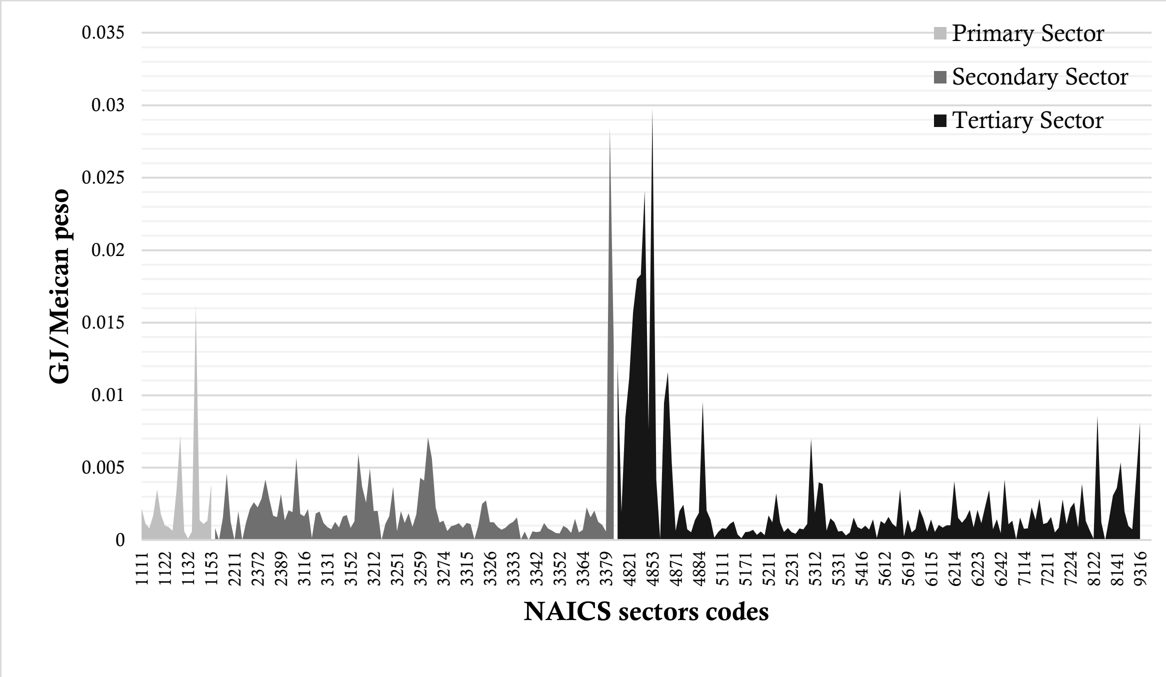

Figure 3.2 Distribution of Energy Intensities

Although, all the economic activities in the above graph are categorized by the NAICS code system (see Appendix A-1) and they will be explained in detail in Chapter 5, in general, in national economies within the primary economic sector, are located those activities dedicated to the use natural resources. The secondary economic sector involves the manufacturing of goods and the tertiary economic sector implicates goods and services.

Some of the sectors with higher-energy intensities of the Mexican economy are located in the middle of the above graph corresponding to secondary and tertiary activities. According to IO principles, all the economic activities are interrelated, however, for the purpose of this study and in order to better visualize those economic activities that in some way are related to construction activities the graph in next page (Figure 3.3) depicts their direct and indirect energy intensities.

Thus, the graph below shows that in Mexico, transportation services by air, rail, and general freight trucking play an important role in terms of higher energy requirements. It is also noticed that the manufacturing of 3362-Cement and concrete products, 3261-Glass and glass products, 3271-Lime, gypsum and gypsum products, and 3272-Other non-metallic mineral products are also high-energy consumers within the Mexican economy, all of them with a strong link as building materials suppliers to the construction sector. However, at this point no energy paths have been identified to determine which building material will be used to demonstrate the applicability of the IO model into the Visio-spatial analysis.

Figure 3.3 Direct (DEI) and Indirect (IEI) energy intensities of construction related activities

3.3.2 The residential building construction sector

Within the arrangement of the IO tables, seven economic sectors (commodities) in Mexico are dedicated to construction activities, from these sectors; two are devoted to the construction of residential buildings (2361) and non-residential buildings (2362), which are major consumers of building materials and raw materials. For the purpose of this study, both sectors are examined to identify their energy flows and to determine the building material to be analysed in depth in a case study (Chapter 6) according to the general research methodology requirements set out in section 1.7.

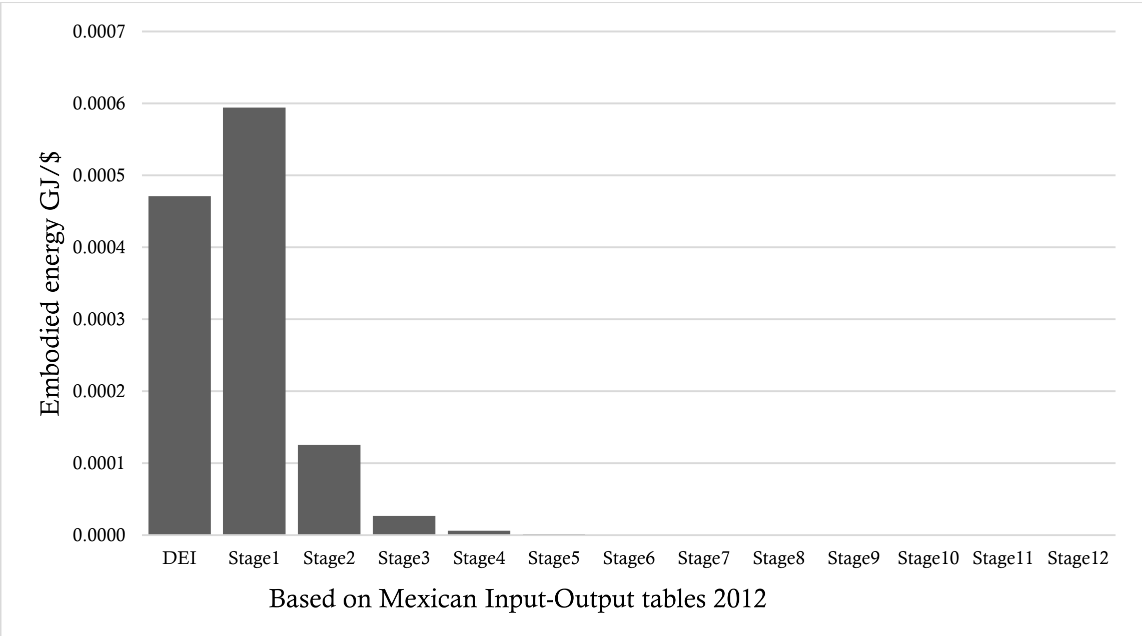

Figure 3.4 Residential building construction (Upstream Stages)

The residential building construction sector (2361) involves construction and assembly onsite and prefabrication off site of both single and multifamily dwellings. Renovations, maintenance or repairs of those dwellings are also included in this sector. The 2361 sector has a total energy intensity (TEI) of (0.001237883 GJ/$) and the breakdown of upstream stages shown in Figure 3.4 indicated that 38.52% (0.000470962 GJ/$) of the energy is used in a direct way (Labour included) during the phase of construction. Stage 1 represents the energy requirements of building materials with 48.50% (0.0005938478 GJ/$). The rest

12.98% (0.00001590144 GJ/$) corresponded to lower levels of energy requirements involved in manufacturing processes and services from which a house is built.

Based on the dynamic input model previously described, the most important energy paths were identified covering the 100 per cent of the total energy intensity of the residential building construction sector (code 2631). It was found that after the direct and indirect energy intensity of the sector itself 39.08%, Cement and concrete products from the sector (3273) showed the highest energy flows to the residential buildings construction sector with 19.63% of the total energy requirements. The second most important energy path is in the sector of other specialized construction works (2389) with 10.10% of energy flows.

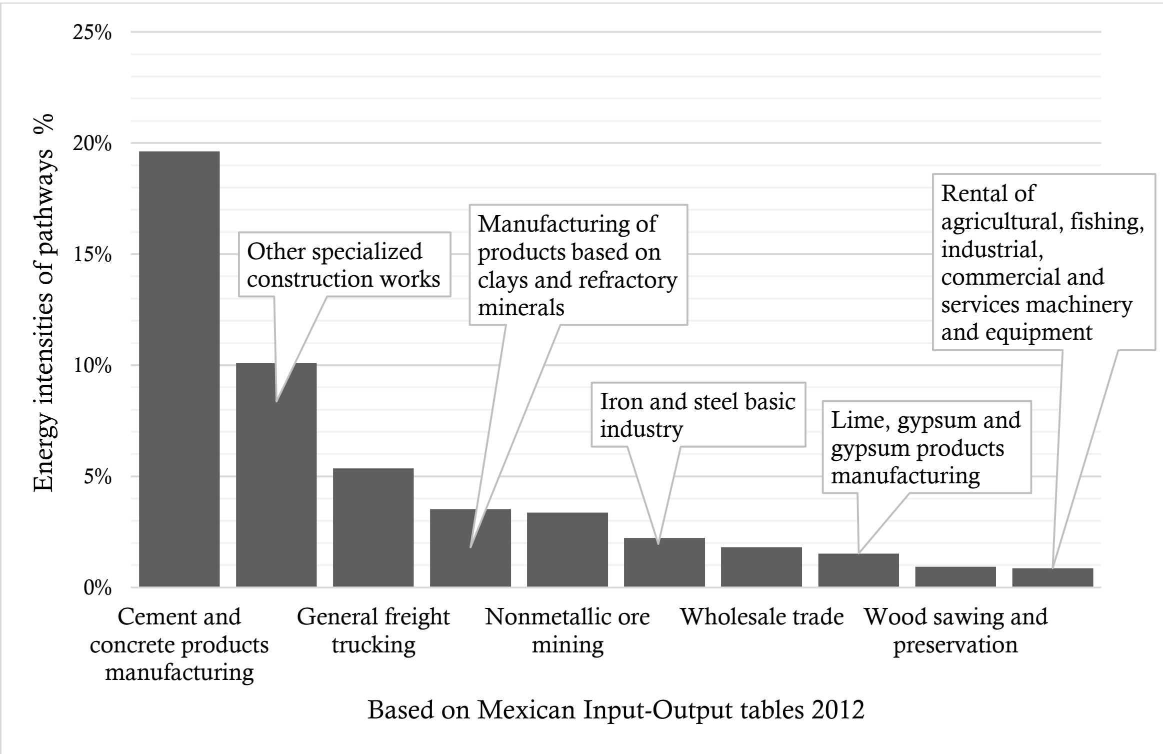

Figure 3.5 Top energy paths for the residential building construction sector

As a service, the General freight trucking sector (4841) provided 5.36% of the energy flows used in the residential sector, while the manufacturing of products based on clays and refractory (3271) delivered 3.53% of energy flows, thus being the second most important building material used in Mexico. Non-metallic ore mining (2123) and Iron steel basic industries (3311) are other sectors with significant influence in the residential sector as indirect embodied energy suppliers within a range of 3.37% to 2.23%. The top energy paths for the residential sector are shown in Figure 3.5, the full list is located in Appendix A-6 and the complexity of the interactions to calculate these energy flows are depicted in Figure 3.6.

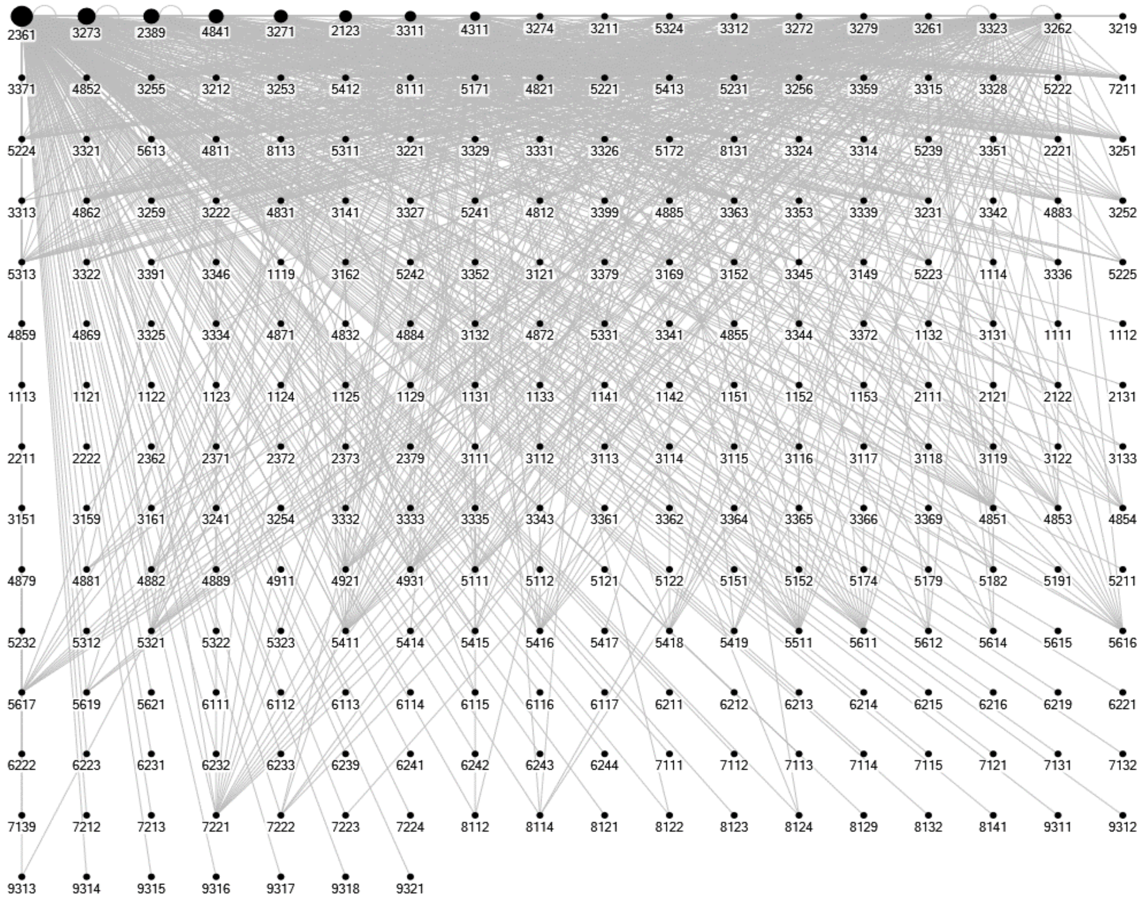

Figure 3.6 Complexity of energy paths of the residential building construction sector

3.3.3 Non-residential building construction

The Non-residential building construction sector (2362) also involves construction and assembly onsite and prefabrication off site of industrial, commercial and services buildings. Renovations, maintenance or repairs of those buildings are also included in this sector.

The Non-Residential sector showed a total energy intensity of (0.0021584104 GJ/$) and the breakdown of upstream stages shown in Figure 3.7 indicated the requirements of direct energy during the phase of construction in 52.59% (0.0011350781 GJ/$). Energy requirements of this sector in terms of building materials are estimated in 37.83% (0.0008165267 GJ/$), while the rest 9.58% (0.0002068056 GJ/$) corresponded to lower energy requirements, representing indirect construction activities involved in the manufacturing of different building materials and components from which non-residential buildings are built.

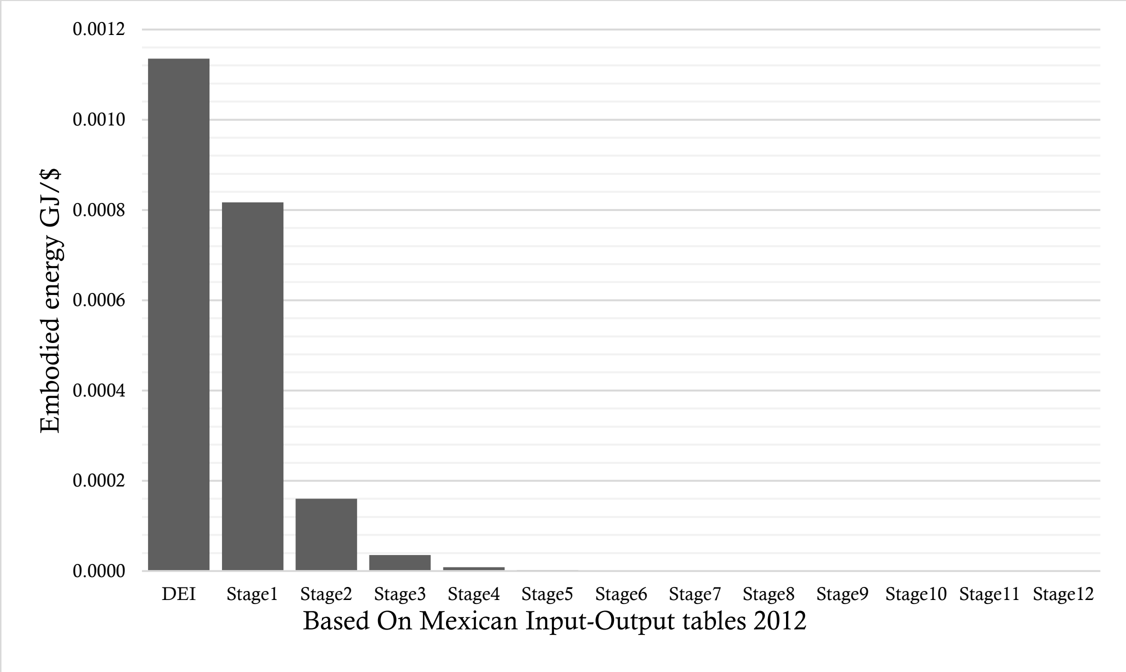

Figure 3.7 Non-residential building construction (Upstream Stages)

The most important energy paths of energy requirements identified in the Non-residential building construction sector (code 2632) showed again that after the direct and indirect energy intensity of the sector itself 53.78%, cement and concrete products from sector (3273) are the main energy suppliers to non-residential buildings with 14.80% of the total energy requirements. Similarly, the second most important energy path is the sector of other specialized construction works (2389) with 10.39% of the energy flows.

As shown in Figure 3.8, transport services located at the General freight-trucking sector (4841) provided 3.94% of the energy flows used in the non-residential sector. The Non-metallic ore-mining sector (2123) delivered 2.66% of the total energy requirements, while the manufacturing of products based on clays and refractory (3271) supplied 2.62% of energy flows to the non-residential sector, thus being the third most important building material used in Mexico within this sector. Finally, the Wholesale trade sector (3271) and Iron steel products manufacturing (3312) are other sectors with significant influence in the non-residential sector as indirect embodied energy suppliers. The full list and the complexity of the interactions are not included given that they follow the same process already presented in the residential sector.

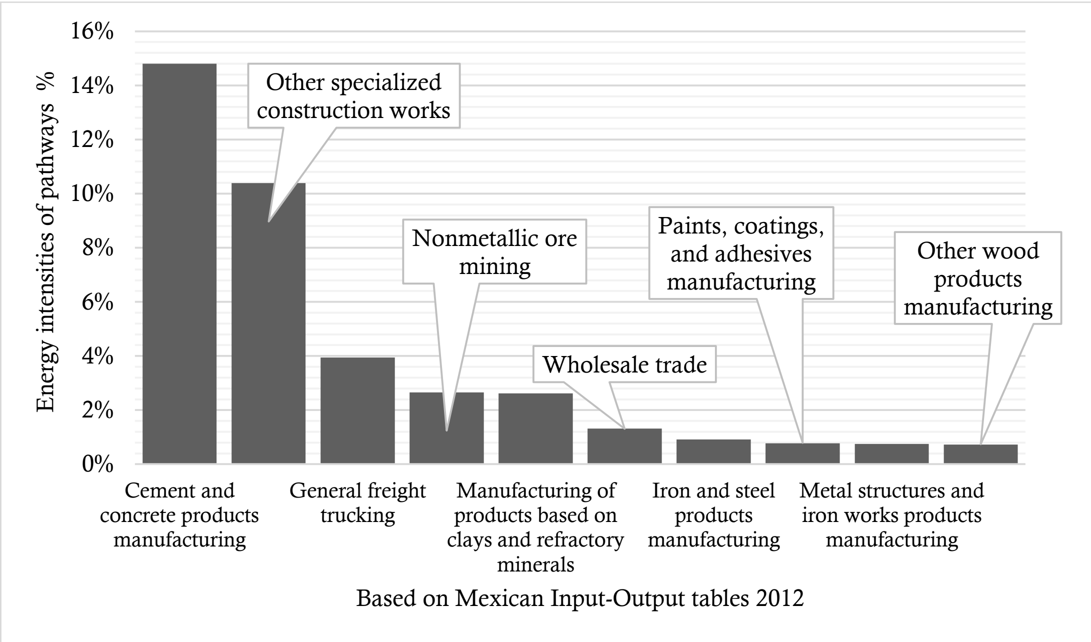

Figure 3.8 Top energy paths for the Non-residential building construction sector.

The table below (Table 3.5) shows the comparison between the residential and non-residential building construction sectors in the Mexican territory in terms of their three most important building materials requirements (expressed in energy). In this table are identified the potential building materials to analyse in Chapter 6, being Cement and Clay manufactured products, and the Non-metallic ore mining, which represents aggregates such as gravel, sand, etc. Therefore, both cement and clay products are suitable for a deeper analysis. However, only the most representative of them within the bioregional area will be considered.

Table 3.5 Building materials requirements comparison between residential and non-residential construction sectors

2361 Residential building construction			2362 Non-residential building construction		
3273	Cement and concrete products manufacturing	19.63%	3273	Cement and concrete products manufacturing	14.80%
3271	Manufacturing of products based on clays and refractory minerals	3.53%	2123	Non-metallic ore mining	2.66%
2123	Non-metallic ore mining	3.37%	3271	Manufacturing of products based on clays and refractory minerals	2.62%

3.4 Discussion of the Mexican Input-Output model

The building of an adapted and revised IO model to estimate the embodied energy of construction activities in Mexico is highlighted in chapter 1. Therefore, the aim of this chapter is to complete the first step of the overall research approach by estimating embodied energy coefficients through IOT and the development of a new simplified process to find energy paths in these tables. Thus, the creation of a new dynamic IO model able to perform this step was achieved. However, the inability to include renewable energy sources within the primary energy process represents a significant constraint in the assessment of non-industrialized building materials given that the breakdown of energy sources cannot be identified in the demonstration building material in chapter 6.

As mentioned before, over the course of the research three different versions of the Mexican Input-Output tables were used. As expected, compared with the Total Energy Intensities (TEI) derived from IO tables based year 2003 and 2008 (Eufrasio, 2013), the higher level of disaggregated sectors in the 2012 IO tables enable a clearer and more precise calculation procedure reducing assumptions from high to moderate when energy intensities in sectors are represented as shown in Appendix A-2.

For example, Figure 3.9 shows the breakdown of energy intensities of the residential sector estimated with the 2003 tables; it estimates a direct energy intensity (DEI or Stage 0) of 29.30% and indirect energy (IEI) of 70.70%, while the IO 2012 indicated a DEI of 38.48% and IEI of 61.52%. The stage 1, which represents the main phase to account the incorporation of building materials in IO models showed an increase of 4.73% in O-I 2012 in comparison with the previous version.

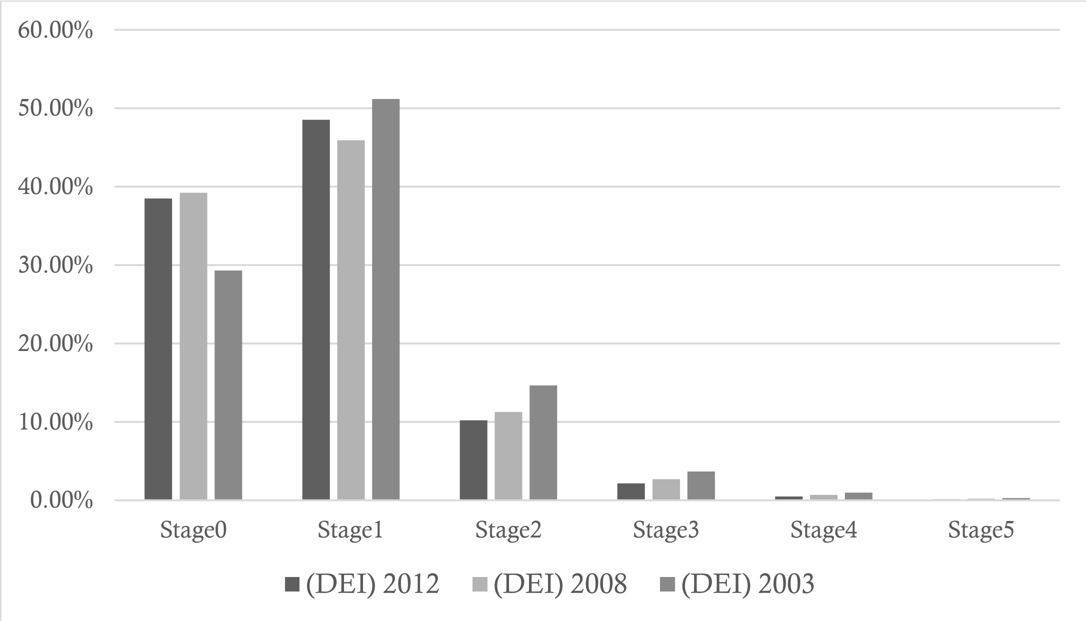

Figure 3.9 DEI Comparison of the Mexican residential sector by IO year

In simple words, the graph above indicates that while in 2003 the direct energy (including labour) to build a house was only 29.30%, in stage 1 where building materials are located, the percentage was around 51.20%. In contrast, in 2008 and 2012 the embodied energy estimated was between 47 and 48% in stage 1, and 37 and 38.48% in stage 0. As previously mentioned, this gap between figures of 2003 and the subsequent years is mainly attributed to their different aggregation levels in IOT. However, construction systems and house typologies could also be a factor to evaluate in this comparison.

On the other hand, as pointed out in section 3.2.1, the identified energy supply sectors were reduced from four to three by the author given that Mexican IO tables do not contain economic information about the gas supply sector. Thus, the economic sector related to the manufacturing of products derived from petroleum and coal was included by adding physical units of delivered energy of gas as shown in Table 3.2 according to procedures showed in Equation 2 and Equation 3. This drawback and work around is not exclusive to this investigation, Treloar (1998. p, 146) pointed out that *"these anomalies are likely to be common for input-output based hybrid analysis, where the magnitude of their effects are not known"*.

This omission of essential data is a critique in IO analysis given that although all energy inputs are accounted according to the first law of thermodynamics, the feedstock has different energy values according to the second law of thermodynamics (Cornelissen, 1997). Therefore, in this study, the inclusion of energy physical units covered the lack of technical coefficients in the economic IO tables, but eventually this will make it difficult to account for the proportion of CO_2 emissions from the feedstock of energy sources in the environmental impact assessment of any product.

On the other hand, given that the total energy intensities of the Mexican economic sectors were estimated through the Leontief inverse matrix and the expanded version of the power series of approximation, the uncertainty of results was reduced in comparison with Treloars' original model. In this work the obtained results of the total energy intensities were the same in both calculation procedures (see Appendix A-5 for comparison) while in Treloars' model small but significant variations in terms of validation are found between both calculation procedures as shown in page 250 of his thesis.

Therefore, in order to present, the mathematical validation of the Mexican IO model a comparison between this work and Treloar's work is presented below in Figure 3.10 and Figure 3.11 by using the Leontief inverse and the power series of approximation. The intention in each of these graphs is not to show a correlation but rather it means emphasizing the authentication of the mathematical procedure to build the IO model through two different techniques. In both logarithmic graphs, the procedure is correct, showing a clear diagonal trend. However, the already mentioned small discrepancies in Treloar's work are represented in a red curve in Figure 3.11. By comparison, the mathematical procedure of this thesis (Mexican IO model) is more precise than the model in which it was based (Treloar's model). However, the validation of the mathematical process, does not guarantee the validation of results, which should be analysed after the embodied energy estimation of the construction material is done in Chapter 6.

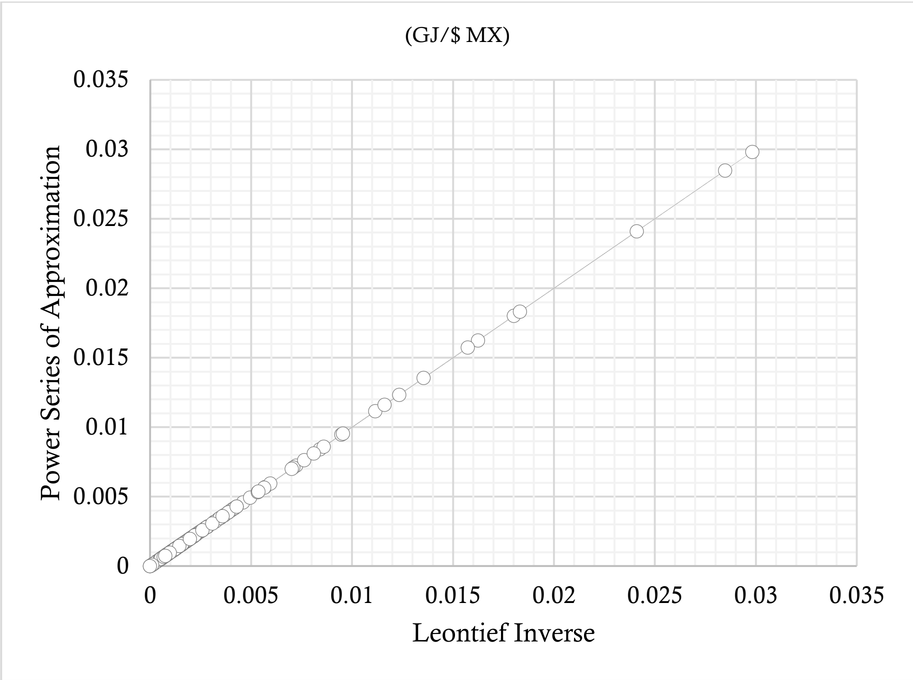

Figure 3.10 This study IO model validation, considering the Leontief inverse and the power series

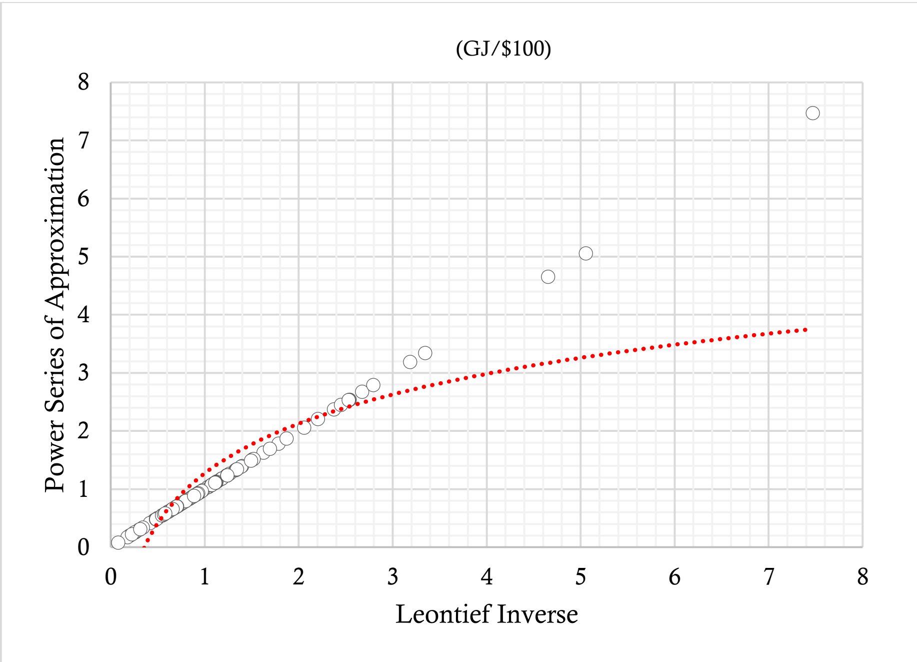

Figure 3.11 Treloar's IO model validation, considering the Leontief inverse and the power series

The reason why Treloar could not match his results between both procedures was because the Australian input-output tables used in his research were built with a conversion factor of GJ/$100, and in his work he did not remove this factor before to perform the match of the power series and the inverse matrix. Instead of this missing step, Treloar used a Gaussian algorithm provided by Professor John Boland from the University of South Australia resulting in the small variations previously mentioned, thus considering those results "as unsatisfactories for comparison of the completeness of total energy intensities" (Treloar, 1998. pag,63).

The development of the vertically expanded power series in this research helped to identify why Treloar considered the results of the power series as incomplete. This is because, in his approach, the mathematical point of view was emphasized over practical procedures, relegated those to a second place. The location of components in the input output model of Treloar's code algorithm (Treloar, 1998, Appendix C, pag.252-276) clearly shows that he used a simplified version of the power series of approximation. Table 3.6 below shows how Treloar's power series was built, the extended power series used in this research is so large that cannot be visualized for a comparison). The table below displays the calculation procedure of Direct Energy Intensities (DEI) and a summary of the twelve rounds (IEI), where indeed the hide information remained as a black box and needed to be disaggregated.

Table 3.6 Example of a simplified version of the Power series of approximation used by Treloar (in this case with Mexican data)

	Sectors		**Oilseed, legume and cereal growing**	**Vegetable growing**	→	**Extraterritorial and international organizations**
		ID	1	2	→	262
Energy supply sectors	**ID**	**CODE**	**1111**	**1112**	→	**9321**
Coal mining	21	**2121**	0.00000000	0.00000000	→	0.00000000
Electric power generation, transmission and distribution	25	**2211**	0.00001886	0.00001969	→	0.00001837
Manufacturing of products derived from petroleum and coal	66	**3241**	0.00155401	0.00038495	→	0.00025722
Direct Energy Intensities	Stage 0	**DEI**	**0.00157287**	**0.00040464**	→	**0.00455206**
	Stage 1	**IEI_1**	0.00022849	0.00019503	→	0.00141176

Summary and vertical display of 12th rounds of indirect energy intensities obtained by the power series of approximation.	Stage 2	**IEI_2**	0.00004666	0.00004357	→	0.00016041
	Stage 3	**IEI_3**	0.00001180	0.00001125	→	0.00004029
	Stage 4	**IEI_4**	0.00000324	0.00000306	→	0.00000994
	Stage 5	**IEI_5**	0.00000091	0.00000084	→	0.00000258
	Stage 6	**IEI_6**	0.00000026	0.00000023	→	0.00000068
	Stage 7	**IEI_7**	0.00000007	0.00000006	→	0.00000018
	Stage 8	**IEI_8**	0.00000002	0.00000002	→	0.00000005
	Stage 9	**IEI_9**	0.00000001	0.00000001	→	0.00000001
	Stage 10	**IEI_10**	0.00000000	0.00000000	→	0.00000000
	Stage 11	**IEI_11**	0.00000000	0.00000000	→	0.00000000
	Stage 12	**IEI_12**	0.00000000	0.00000000	→	0.00000000
Total Energy Intensities		**TEI**	**0.00186433**	**0.00065870**	→	**0.00617796**

In this study, the development of an iterative method to fully compute 12 successive rounds of upstream stages of energy coefficients took six months of trial and error and was extremely laborious. However, knowing the advantage of showing clearly the cumulative behaviour of indirect effects approaching toward zero explained by Miernyk, the obtained results were rearranged in excel spreadsheets with an additional transposed step that for this research should be mathematically expressed as shown in Equation 8 and Equation 9.

Equation 8

$$\textbf{Transpose of the Power series approximation} = (\boldsymbol{I} + \boldsymbol{A} + \boldsymbol{A}^2 + \boldsymbol{A}^3 + \boldsymbol{A}^{12})_{\boldsymbol{T}}$$

Equation 9

$$\textbf{Transpose of the Inverse matrix} = (\boldsymbol{I} - \boldsymbol{A})_{\boldsymbol{T}}^{-1}$$

The conceptual process developed during this study is illustrated below in Figure 3.12 and the practical process in excel spreadsheets is shown in Table 3.7. Although, it is evident in this table that an advance knowledge in excel software is necessary to build a dynamic input-output model, the level of difficulty is considerably reduced in comparison with Treloar's algorithm. Therefore, the adaptation and reproducibility of this technique can be more easily applied to Input-Output tables of any country.

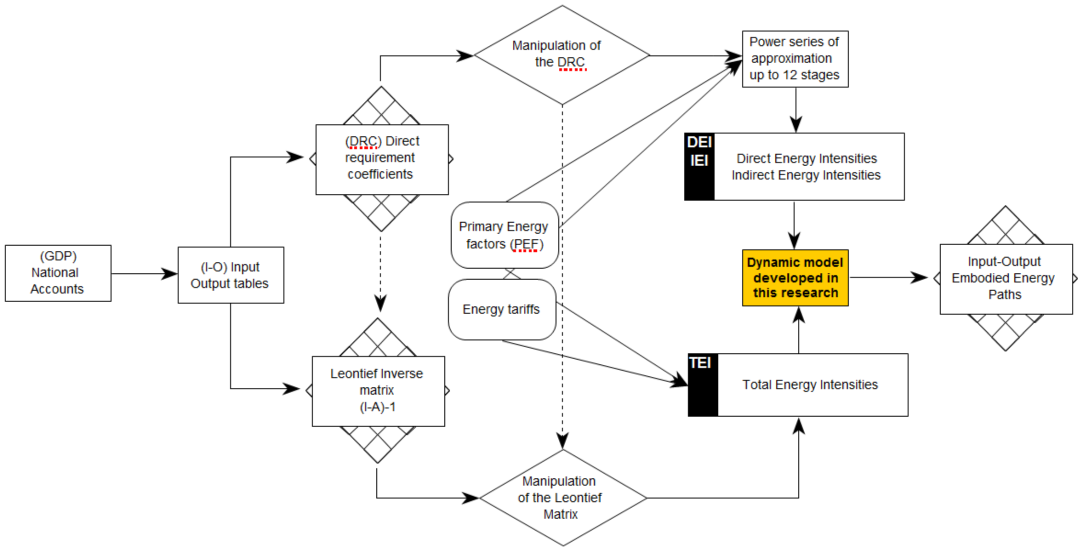

Figure 3.12 Mexican IO model process according Eufrasio (2015)

In order to highlight the significance of the new dynamic IO model to identify energy paths developed in this research, it is necessary to mention that according to (Miller and Blair, 2009, p.31) in large IO tables, compute time will vary depending on software programs. Furthermore, these authors cited some examples; in 1939 took 56 hours to invert a matrix of 42 sectors, and by 1969 a 100 sector matrix was inverted between 10 and 36 seconds.

In this research, the development of this new "dynamic model" presents a more holistic view in the structure of analysed target sectors within Input-Output tables. The analysis of entire economic sectors only takes less than one second to estimate both direct and indirect energy intensities and to identify their energy paths, thus fulfilling one of the aims of this research as a contribution to new knowledge. This contribution is highlighted in yellow colour in the above figure.

Table 3.7 Dynamic Input-Output model to estimate energy intensities and identify energy paths

Sectors	**Code**	**DEI or Stage 0**	**IEI-1 or Stage 1**	**IEI-2 or Stage 2**	→	**IEI-12 or Stage 12**	**=SUM(C2:O2)**	**=SUM(Q3:Q261)**
=LOOKUP(B2,B3:B261,A3 :A261)	**2362**	**=SUM(C3:C261)**	**=SUM(D3:D261)**	**=SUM(E3:E261)**	→	**=SUM(O3:O261)**	**=SUM(C2:O2)**	**=SUM(Q3:Q261)**
Oilseed, legume and cereal growing	1111	=IF($B$2=B3,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,2)	=HLOOKUP($B$2,Stage2,2)	→	=HLOOKUP($B$2,Stage12,2)	=SUM(C3:O3)	=P3/$P$2
Vegetable growing	1112	=IF($B$2=B4,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,3)	=HLOOKUP($B$2,Stage2,3)	→	=HLOOKUP($B$2,Stage12,3)	=SUM(C4:O4)	=P4/$P$2
Fruit and tree nut growing	1113	=IF($B$2=B5,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,4)	=HLOOKUP($B$2,Stage2,4)	→	=HLOOKUP($B$2,Stage12,4)	=SUM(C5:O5)	=P5/$P$2
Greenhouse and nursery growing, and floriculture	1114	=IF($B$2=B6,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,5)	=HLOOKUP($B$2,Stage2,5)	→	=HLOOKUP($B$2,Stage12,5)	=SUM(C6:O6)	=P6/$P$2
Other crop growing	1119	=IF($B$2=B7,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,6)	=HLOOKUP($B$2,Stage2,6)	→	=HLOOKUP($B$2,Stage12,6)	=SUM(C7:O7)	=P7/$P$2
Cattle raising	1121	=IF($B$2=B8,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,7)	=HLOOKUP($B$2,Stage2,7)	→	=HLOOKUP($B$2,Stage12,7)	=SUM(C8:O8)	=P8/$P$2
Pig raising	1122	=IF($B$2=B9,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,8)	=HLOOKUP($B$2,Stage2,8)	→	=HLOOKUP($B$2,Stage12,8)	=SUM(C9:O9)	=P9/$P$2
Poultry raising	1123	=IF($B$2=B10,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,9)	=HLOOKUP($B$2,Stage2,9)	→	=HLOOKUP($B$2,Stage12,9)	=SUM(C10:O10)	=P10/$P$2
↓	↓	↓	↓	↓		↓	↓	↓
Extraterritorial and international organizations	9321	=IF($B$2=B261,INDEX('Power Series'!$E$292:$JC$298,7,MATCH($B$2,TARGET)),0)	=HLOOKUP($B$2,Stage1,260)	=HLOOKUP($B$2,Stage1,260)		=HLOOKUP($B$2,Stage12,260)	=SUM(C261:O261)	=P261/$P$2
		=C2/$P$2	=D2/$P$2	=E2/$P$2		=O2/$P$2		

3.5 Summary

In this chapter, the development of a new dynamic Mexican Input-Output model is presented as the first step of this research to identify the main energy requirements in the Mexican built environment. The use of the 2012 based year version of the Mexican Input-Output tables was only moderately acceptable given that energy supply sectors (Utilities) were not well represented, hindering the incorporation of primary energy factors. Therefore, an alternative procedure was developed to provide the representativeness of the Mexican energy supply sectors.

In addition, an alternative system to extract energy paths from Input-Output models in excel spreadsheets was developed using an extended version of the power series of approximation matching results of twelve upstream stages with the Leontief inverse matrix. This step proved the hypothesis raised by Treloar stating that power series results and the inverse matrix should coincide near the limit. Therefore, it can be deduced that the extraction of energy paths could stop being considered as a 'black box' in hybrid Life cycle energy analysis of the built environment, which means that the dynamic IO model should be the best option for modelling EE coefficients.

The energy flows of the residential and non-residential building construction sectors showed that concrete and cement products are the most used building materials across the Mexican construction activities. The second most important building materials used in Mexico are those products based on clays and refractory minerals. While the former are products of industrial processes, fired clay bricks belong to an economic sector, which is mostly not industrialized, making it difficult to calculate with only the Mexican Input-Output model here developed, which does not account renewables.

At this point of the research plan, geographical considerations have not been considered. Therefore, in the next Chapter the identified and requested inclusion of this approach will be addressed introducing a bioregional ecological framework to IO processes, as a basic to understand missing factors frequently not included in embodied energy and life cycle analysis.

Chapter 4 Bioregion framework for embodied energy mapping

4.1 Introduction

Research on regional and geographical frameworks has identified the need to include ecological approaches, increase awareness of environmental impacts, and to address sustainability in construction related activities, as discussed in Chapter 1. Following the systems approach previously presented in the last two chapters, the overall goal of this chapter is to show the necessity for introducing a regional ecological framework to IO processes. The spatial life cycle analysis and embodied energy mapping of a building material as a partial answer to this need are described as a result in subsequent Chapters of this thesis.

Thus, the bioregional theory will be justified as a contextual framework for making sense of place in life cycle inventories of the built environment by addressing the following questions: What is bioregionalism?, What does a bioregion offer to LCA in terms of analysis? What is the current state of bioregional frameworks in LCA? Finally, the importance of considering and mapping building materials under the bioregional context will be established in order to choose the adequate mapping method to develop to provide a visual approach for energy consumption in LCEA.

4.2 Bioregional framework for embodied energy mapping

Historically the bioregional concept has addressed the management of social systems combined with physical natural defined regions (Gray, 2007). Although it is believed that this biocentric[4] concept had its origins in Scotland in the late 19th century with Patrick Geddes and John Muir, it was not until the 1960's when bioregionalism appeared definitively in some parts of the Unites States and Canada as a social movement and philosophical thought (Stevenson and Ball, 1998).

This way of thinking aimed to restore the natural bond between the human sense of belonging and the regional-scale ecosystem within which people live Gary Snyder and Peter Berg, considered the main exponents of this movement, stated that *"the successful growth of socially-just cultures rooted in the protection and restoration of ecosystems health required a deep understanding of cultural tradition"* (Aberley, 1999, p.13). Thus, in order to promote this cultural understanding of places they strove for a local self-sufficiency by moving away from artificial administrative boundaries, which are historically defined by political interest.

Over the years, bioregional definitions have been conceived in several ways by different authors (Berg, 2002, Gray, 2007, Tom Lynch et al., 2012). However, given the complexity of this concept as philosophical thought and social movement, a clear definition of a Bioregion will be always difficult to find (Booth, 2012). According to Tonn (2006, p.379). *"Bioregion is a large geopolitical area defined by its natural physical characteristics, not by man-made political boundaries"*. Similarly, as cited by Lynch (2012, p.3), Robert L. Thayer defines a bioregion as; *"a unique region definable by natural (rather than political) boundaries with geographic, climatic, hydrological, and ecological character capable of supporting unique human communities"*.

Therefore, in bioregionalism terms and based on their local knowledge, it is precisely those people who live in these communities who must define bioregions

[4] *Biocentrism refers to an environmental ethics thinking, which considers human beings and the rest of living beings in this planet with equal values as part of a whole. In this way, humans have the responsibility to respect the living nature and to protect it (Caciuc, 2014).*

boundaries according to their shared cultural and economic values. Public participation is a key factor during a bioregional planning process for the local development (McNaughton, 2003, Cox et al., 2014). Moreover, these similarities are also strongly related to natural communities or watersheds areas, which are the most cited consideration by bioregionalism in its initial boundary definition (Ryan, 2003).

Watersheds or Drainage basins are frequently named in ecology as biogeographical areas conceptualizing the term of place through the existent relationships between environment and communities (Ryan, 2012, p.86). However, given the distinctive characteristics of each watershed, the criteria for setting these natural physical limits in bioregionalism is not clear. Thus, bioregional boundaries definitions are often subject of controversy and criticism even among members of the environmental movement. For example, Kovel (2007) states the idea of bioregionalism as impractical and unrealistic.

Kovel identifies potential conflicts in the strict definition of bioregional boundaries since the vagueness of the concept of the area will eventually lead to conflicts, given that not all members of the community share the same ecocentric values. Additionally, as there is not system exempt of external influences, the required self-sufficiency of bioregions could lead to its isolation. On the other hand, the heavy reliance on only local knowledge to deal with environmental issues in bioregionalism is also criticized given its lack of pragmatism.

However, some years earlier, Goldstein (1999) had already identified these concerns and called for a sensible integration of bioregionalism with science in order to provide an impartial criterion that any sustainable assessment based on bioregionalism requests. In addition, Birkeland (2012b) states that although the definition of boundaries comes from two visions of this philosophy; the political sense of place and the need to fit the biophysical limitations, both should be important for policy making and system design.

Notwithstanding the challenges to bioregional definitions where *"precision is not essential"*, the crucial objective of such a definition will be always the protection, safeguarding and restoring of these ecosystems along with its economy (Hodge and Robinson, 2003, p.104). Furthermore, Graymore (2008, p.362) claims that such regional scales are considered as a key factor to promote sustainability in the environmental management of natural resources. Thus, under this context, decision makers and public participation can influence significantly to achieve this aim by sharing knowledge and taking decisions (James and Cato, 2014).

In this research, the critique about the precision of bioregional boundaries is not relevant given that it is expected that they might change over time and because this geographical context represents an opportunity to promote sustainability in the local production of clay bricks. However, the analysis of a single bioregion is not the ideal framework to truly understand how other neighbouring bioregions could influence the results in this research. Therefore, this only the first step to approach the environmental problem in the bioregion case study caused by clay brick production.

4.3 Bioregional mapping methods

Bioregional mapping tackles environmental problems, embracing both the natural and the built environment by integrating ecocentric and technocentric approaches. According to Ball (2002b) within the bioregional mapping process a first step is the development of a resource database that includes environmental, economic and cultural factors in order to be visually represented in a set of thematic maps as seen in Figure 4.1, these maps are subsequently redefined through public participation.

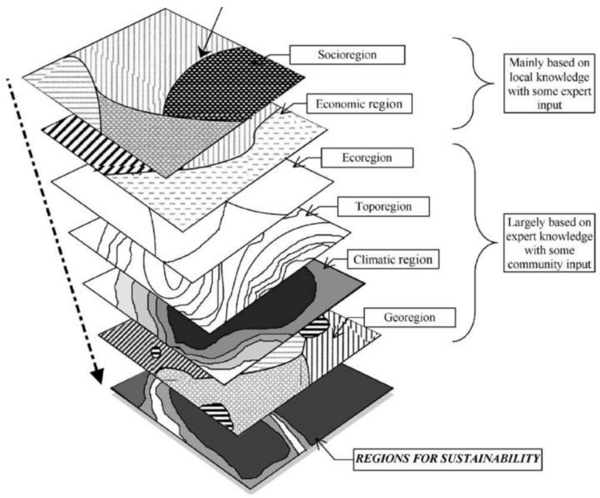

Figure 4.1 Bioregion mapping process (Ball, 2002)

In this context, bioregional maps are a key factor to fill the communication gap between the "expert knowledge" provided by scientists and the "local knowledge" attributed to native decision makers and community in general. According to Ball (1999) the purpose of mapping bioregions is to present a visual approach to display integrated data for environmental management and policies. This mapping process, however, is only a graphical tool presenting complex data such as embodied energy analyses in a simple way for general understanding.

McNaughton (2003, p.12) suggests there are three different scopes in which the bioregional mapping process is developed and could be applied; consultative, cooperative and self-directed.

Consultative maps are made by individual experts or in collaboration with other specialists if is necessary. Community members are involved in this process by sharing data; however, those groups do not effectively take part in the production of the maps. Usually, these types of maps are accepted as a reliable source of information; regardless, this is only the start of legitimating the sense of place in relation to a specific subject.

McNaughton also states that cooperative participatory maps are made by experts in participation with the community both during the collection of information and during the process of its representation on the maps. The expert regularly coordinates this procedure, despite the fact that more community involvement in this process would be appropriated.

Finally, the author described Self-Directed maps are those made by community member's with expert support. In this way, the community take decisions about what components should be incorporated into the maps. This system is the most demonstrative of community participation in terms of the sense of place, however, it may not provide all the data needed if the maps have specific requirements, best informed by experts.

4.4 Bioregions & Life cycle assessments

Although the intention to merge regional scales such as bioregions and LCA is relatively new, there are already some examples in other fields that show its potentials, such as in agrarian systems and food supply chains. According to Pradeleix et al. (2012), this approach provides a more accurate perception of realistic issues in comparison with traditional LCA, given that agricultural practices are linked to their natural and socioeconomic conditions.

Caputo et al. (2014) point out that in new food supply chain studies, different scenarios can be explored thorough LCA and bioregions in order to optimize the local production, processing and consumption to evaluate the self-sufficiency of food suppliers in a given region. In a different research field, a methodology approach by Barrett et al, (2013) was developed to assess both direct and indirect environmental impacts of gas and coal mining on bioregion water resources. One of the purposes of that study was to identify pathways of the interactions with results that provided knowledge and information to protect water resources in the study area.

Within the built environment, a practical example of a bioregional approach to LCA was recently carried out by Riddlestone (2014) in a case study in Brighton UK using an Australian software (eTool, 2009). One of the goals in that study was to minimize the total embodied energy of apartments by using only bioregional materials, equivalent to 78% in the reduction of gas emissions. According to the results, from the analysed 172 apartments, the embodied energy in this development was lower than conventional housing in that area by reducing 60% of gas emissions. Although, the target was not accomplished given that some materials were not locally available, the results of using bioregional materials were remarkable.

Previously, other successful case study located in Sutton UK, called Beddington Zero Energy Development (BedZED) was developed by BioRegional (2010). In this project, one the targets was the use of low embodied energy by considering natural, recycled and reclaimed building materials within a sourced radius of 60 Km (37 miles). 52% of the materials (bricks, blocks, aggregate and concrete) were found within a 35 mile radius, where 83% of the timber used in this project was certified. The above studies show increasing interest and that the relevance of considering bioregional approaches in building materials linked to LCA.

4.5 Bioregional materials

The consideration of bioregional materiality is a key factor towards a sustainability in the built environment given that regional materials are easily accessible, accountable and assimilated; thus the choice of these materials should help to avoid great distances in transportation, promote local awareness and fit into the natural landscape (Smith et al., 1998). According to Smith, in the late 1990's the direct environmental impact of transporting high quantities of building materials over great distances was already considered as an important factor when fossil fuels were used. For example, the embodied energy for the crushing of aggregates (0.037 MJ/kg or 0.01 kWh/Kg) is lower than the energy spent in transportation (Praseeda et al., 2014). In general typical energy associated in the transportation of construction materials are; 0.28 kWh/ton-km for long distance road (distances >50 km) and 0.75 kWh/ton-km) for distances ≤ 50km (Braganca, 2007p. 482). According to Adalberth (1997)p. 318 one of the reasons for the energy difference between short and long distances is because in longer distances lorries transport larger loads and because in short distances the transportation of materials is done on streets and city roads where more fuel is consumed.

Bioregionalism aims to promote the use of indigenous resources or locally manufactured building materials, which could encourage the economic development of locations according to natural and cultural values (Spath et al., 1999). As shown in the previous Brighton example, depending on the goal established and the regional physical characteristics, most of the times those materials can be found locally, with only a few exceptions when they cannot (Riddlestone, 2014). In terms of LCEA, the ultimate purpose in the use of bioregional materials is to promote the selection of low energy materials rather than materials with high-embodied energy to mitigate their environmental impact where possible (ICAEN, 2004).

Despite clear objectives for the use of bioregional materials, definitions are not always so clear given that the physical concept of a 'regional' material may vary from one building standard to another. The most accepted definition is given by LEED (2009), which is the most used worldwide standard. This certification introduced a credit system called NC-2009 MRc5 where criteria points are achieved by using regional materials. LEED defines that 'regional' materials are those that are obtained within a radius of 500 miles or 800kms from the construction site, and differentiating those regionally manufactured from those regionally extracted. Under this scheme, LEED prioritizes the former over the latter given that in manufacturing process more energy is consumed. However, it is still very common that raw materials are transported from more distant places (Scheuer and Keoleian, 2002), meaning more energy is used in transportation than the manufacturing process as shown above in Praseeda's study (2014)

Furthermore, Ochshorn (2010) points out that the arbitrary LEED criteria to support local economies by using indigenous materials is utopian, since it is unknown how the profits obtained for their sales are retained in the region for local economic support. According to Ochshorn, this approach of a profit-driven, global economic system based on artificial 500 miles boundaries is just a standard ideological fantasy, when it is clear that construction sites much nearer to manufacturing sources could easily obtain LEED points.

Figure 4.2 shows a typical difference between an artificial LEED 500 mile boundary and the bioregion area selected for this research. As seen in the map, LEED boundary clearly does not consider geographical differences, while, the bioregion selected for this research includes; watersheds, climate, biomass, etc. according to principles explained in section 4.2. The actual bioregion process for the case study selected will be presented in detail in Chapter 5, where socio economic and ecological approaches make sense to understand the true nature of local building materials. Thus, for the purposes of this study, bioregional materials will be those found within that area, however, a potential identification of raw materials from other bioregions could be also identified in a deeper origin classification of materials in further studies.

Figure 4.2 LEED and Bioregionalism concepts of regional materials

4.6 Mapping building materials

Mapping local building materials is an attempt to develop understanding and awareness about their availability and environmental impact in a specific bioregion. According to Birkeland (2012b), *"mapping material and energy flows on a* *bioregional basis will assist in determining the most ecologically appropriate systems of productions and construction for different regions"*. However, according to the author, to date, bioregional research is obstructed by an absence of existing information that can be adapted to its boundaries.

Mapping the spatial identification of building materials within bioregions is not a new concept. Whitehand (1967) carried out a regional survey to identify the use of traditional building materials in maps. He found that in addition to their physical availability, the distribution of these materials in a specific area depended on economic factors. Some years later, Fisk III (1985 p.1048) pointed out that the bioregion concept could be used as a biotechnology tool for the spatial identification of building materials and energy in the built environment by focussing on the economic inputs and outputs of local processes giving a flow representation of those activities. Thus, he claimed that working at the bioregional scale, the spatial identification of processes could be analysed through maps and could be easily associated with a bioregion's natural resources for environmental management. Fisk's work was the first attempt to merge bioregional and life cycle analysis approaches, but tools in that time were not powerful as today.

A more recent project for limited mapping of building materials at bioregional scale was carried out by Stevenson et al. (2002) in the highlands and islands of Scotland, where after six months of demanding and exploratory fieldwork some indigenous materials and almost 200 manufactured products were identified. This study also identified that, although local materials inventories are necessary to promote local sustainability, research in this area required government funding and was limited by this. Moreover, policy makers request environmental standardization of products but this standardization usually does not consider local variations. Finally, this study also suggested that there is not enough concern for major producers to support the "local sustainable argument" given that it plays against their expanding global business interests (Ibid, 2002, p.42).

A different approach to identifying local construction materials at a regional scale is presented by Fang and Azigui (2007) in the North West region of Cameroon. Funded by the local ministry of public works, that study identified construction materials for public works using field observations and remote sense techniques in GIS. According to the authors, in order to find these local materials, they must be grouped into three classes; rocks, vegetation and soils. The results showed a great variety of natural resources according to the characteristics of that region. However, given that this research aimed only to develop a physical accounting inventory, socio-economic and manufacturing process were not included for a better analysis, showing that a gap exists in the literature in this respect.

4.7 Summary

This chapter showed the relevance of bioregional theory as an ecological and geographical approach towards life cycle assessments. Despite controversies over physical boundaries selection, a consideration of the bioregional scale is considered essential to improve sustainability in environmental management systems. However, the current relationship between both approaches is only just starting in various research fields. Within the built environment, some attempts have been made to integrate bioregional approaches to material selection but the complete application with practical case studies has not been fully developed to promote ecological awareness.

Given the purpose of this research is to bridge the gap of LCA as a communication tool and its weak geographical consideration in ecological approaches such as bioregions, a new process for mapping local building materials is described in the following chapters in order to develop the integration of bioregional maps with life cycle energy. The following proposal attempts to form the second major contribution of this thesis, after the redefinition of embodied energy paths extraction. Thus, based on bioregional methods for mapping in section 4.3 and for the purpose of this study, the scope of the bioregional mapping process applied will be ‘Consultative’ given it does not involve public participation other than the manufacturer producers.

Chapter 5 **Bioregion case study**

5.1 Introduction

The inclusion of the bioregional mapping into LCA is one of the main aims established in Chapter 1 of this research in order to merge both approaches extending data results and their interpretation for decision makers. Mapping "bioregions" as such is not the main aim of this study, but it is necessary to provide the geographical context for visualizing and understanding in a broader context, the problems associated with the current narrow interpretation of LCEA results and how these can be overcome.

This chapter shows how three key objectives are needed to determine which of the building materials locally produced in the bioregion should be analysed.

The first objective of this chapter (**step 2** of the general research method outlined in section 1.7 of this thesis) will be the selection of a suitable bioregion case study area to provide the geographical framework requested for this research purposes.

The second objective (**step 3** of the general research method) and considering Ball's (2002b) bioregional mapping method, will be to perform an inventory of natural local resources for the supply of construction materials to the local built environment.

The third objective (**step 4** of the general research method) will be to provide a bioregional characterization of construction related activities in order to apply the capabilities of the IO model to incorporate energy coefficients into all the construction related economy units located within the case study.

Thus, a generic bioregional life cycle energy inventory could be the framework for a deeper analysis in a single building material in Chapter 6.

5.2 Mexico and the Cuitzeo basin/bioregion

As part of the so-called MINT countries, which according to some economist will be the next great economic markets in a near future (Boesler, 2013), Mexico is rapidly investing and growing its infrastructure. According to INEGI (2014a), the construction sector in Mexico grew up from 10300 construction companies in 1998 to 17063 in 2014 and this is particularly reflected in the significant increase of the housing stock during the last decade from 25 million of houses in 2005 to more than 39 million projected by 2030 (CONOREVI, 2011).

According to (Villaseñor G., 2005), the Michoacán state of Mexico contains one the most biodiversity systems in that country which is currently facing a high environmental impact because of anthropogenic activities (Aguilar et al., 2010). Cuitzeo bioregion sits within Michoacán and presents the greatest industrial development of that state with a high annual construction rate of new dwellings, where after 1998 more than 41000 of them have been built (Santacruz, 2011, P.16). These dwellings are undergoing a rapid typology transformation from ancient, vernacular to modern styles replacing traditional materials for industrialized products (Ettinger, 2010). Thus, the use of more processed building material is increasing the embodied energy intensities of the residential sector (Eufrasio-Espinosa and Stevenson, 2013).

Given its importance as an ecological area and unlike other bioregions in Mexico, the bioregional boundaries of the Cuitzeo basin have been already widely characterized by different authors[5]. Thus, physical features, biodiversity, socio-economic factors, infrastructure, and water management among other studies are considered as a strong asset for the purpose of this research. On the other hand, from a pragmatic perspective, there is a strong positive interest from the planning and environment state council concerning how to establish sensible regulations in building materials within this area to mitigate their carbon emissions.

[5] *The "Atlas of the lake of Cuitzeo" is a compilation of papers carried out by researchers from the Institute of Geography of the National Autonomous University of Mexico (UNAM) and Universidad Michoacana de San Nicolás de Hidalgo (UMSNH). (Cram et al., 2010)*

Therefore, for the purpose of this study, Cuitzeo is selected as a bioregional area for mapping results of the life cycle energy analysis of a building material. Thus, the chosen bioregion is the starting point to develop a bioregional inventory addressed to construction activities for embodied energy mapping. This process will be done on the basis of Ball's layers methodology explained in section 4.3.

The Cuitzeo bioregion is located in Mexico, within the Mexican Volcanic belt at 1800-3420 metres above sea level, between 20º7'2.90"N and 19º24'22.89"N parallels and 101°32'32.31"W and 101°38'3.50"W meridians in the states of Michoacán and Guanajuato. This bioregion covers an area of 3831.75 km^2 and it is part of one of the largest hydrological systems in west-central Mexico called Lerma-Chapala – an essential factor in relation to the manufacture of construction materials. Within this area is located the lake of Cuitzeo which is the second largest in Mexico with a variable area of 420-630 km^2 due to its high level of natural evaporation and the environmental impact which started in the Colonial period (Williams, 2014).

5.2.2 History

In Mexico and Mesoamerica, the use of natural building materials has a long and cultural tradition based on the deep knowledge of ancient ethnic groups. According to evidence found in many archaeological sites, this local knowledge was applied to land use management, which was the basis used for materials characterization for house building. Materials such as lime, stone, timber and adobe were commonly used in building activities according to climate, availability, vernacular, and regional construction practice. Unfortunately, as a result of Spanish colonization, much of this local knowledge was lost (Gama-Castro et al., 2012).

According to Williams (2014), the cultural identity of the Cuitzeo basin pre-dates the colonial era, when this area was an important part of the Tarascan Empire. During this pre-Columbian period, the Cuitzeo lifestyle revolved around aquatic and agriculture activities. This area flourished because of its wealth in a great variety of natural resources. These resources included an extensive wildlife and mineral production containing; salt, obsidian and lime among others. There was also a vast area of woodland with a significant variety of tree species, of which, unfortunately, due to urban growth and deforestation, only a few species have survived (Rojas-Moreno and Novelo, 1995).

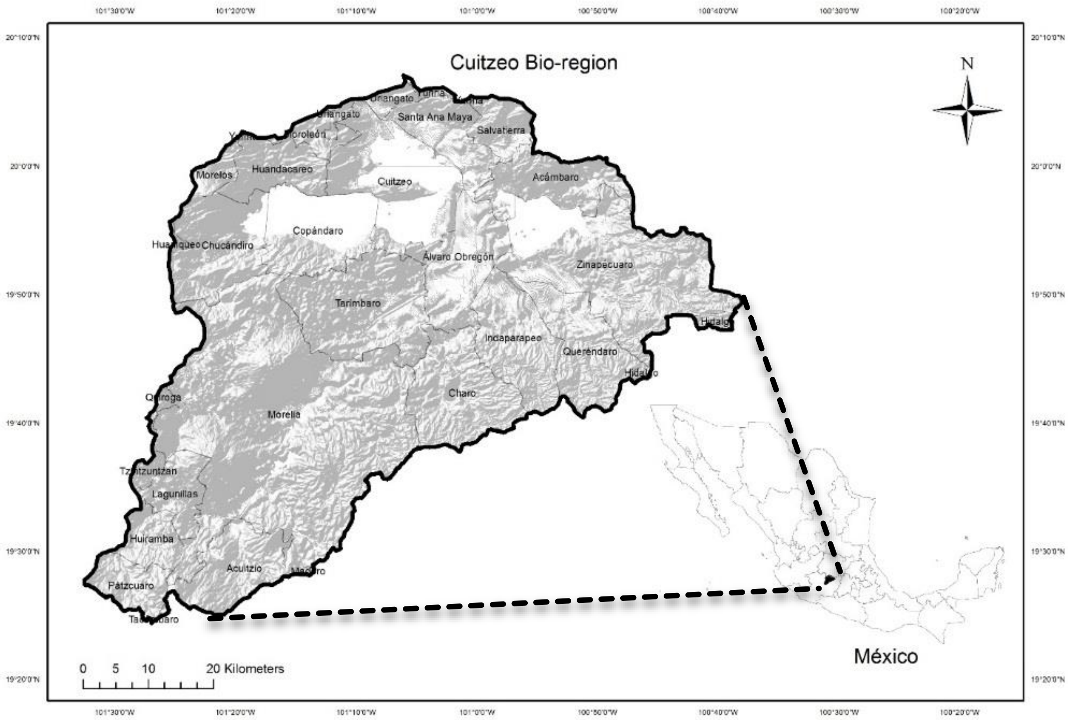

Figure 5.1 Cuitzeo Bioregion boundaries

The vegetation in this area was also unique with some indigenous species such as; carrizo (*Scripus validus, S. americanus and S. Californicus*), and tule (*Typha dominguensis, T. latifolia*). Both these species along with mud were important as natural resources in the construction of vernacular houses allowing a pleasant natural ventilation by permitting a constant air flow in summer (Williams, 2014). These traditional construction practices remained in some parts of this bioregion until approximately seventy years ago when there were still people living in tule houses (Bravo-Espinosa et al., 2012). However, the increasing cultivation of maguey[6], which had more economic value, replaced forested areas of tule until they almost disappeared from the bioregion landscape.

Based on evidence of 174 archaeological sites (SUMA, 2011,p.72), although the pre-Columbian bioregion landscape had an abundance of natural resources, it is well documented that the Tarascan community had an intensive trade and exchange of goods with the most powerful civilization of Mesoamerica; The Aztecs (Filini, 2004). Given that in any of these areas all the essential elements for their subsistence were produced, a complex network system was identified, which showed that these civilizations were not isolated and they needed each other in order to cover some of their basic needs. Ornamental items made with raw materials such as obsidian from sources of the Cuitzeo basin were also part of these trades (Williams, 2009).

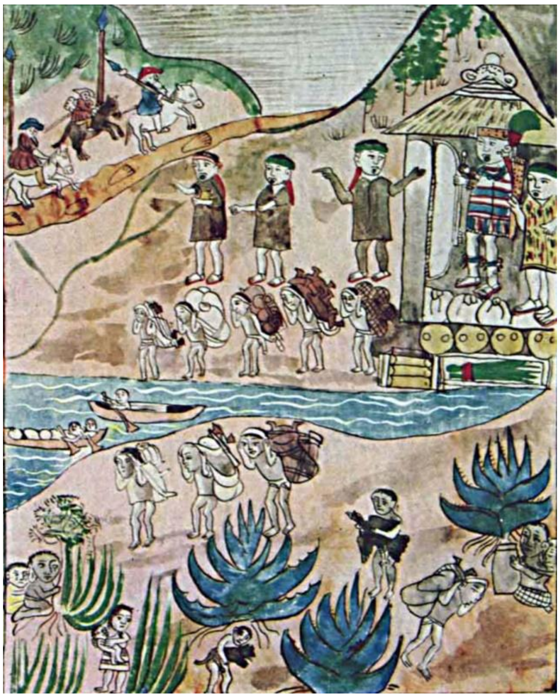

Figure 5.2 Arrival of the Spaniards to Michoacán[7]

[6] *Maguey also known as Agave is a native American plant with a major concentration in Mexico to which multiple uses has been given; as a raw material for textile products and for the distillation of beverages such as pulque, mezcal and tequila.*

[7] *This illustration is taken from the manuscript of 1540 "La Relación de Michoacán", and depicts the interaction between native people and Spaniards in the Cuitzeo bioregion. In the foreground of the image you can see maguey plants, while in the background a typical house made by tule and Carrizo can be appreciated.*

With the arrival of the Spaniards in this bioregion (Figure 5.2), the introduction of their non-indigenous building practices resulted in a new mestizo construction system. Thus, plant materials (Tule) traditionally used in roofs were gradually replaced by the now widespread use of clay tiles, more commonly used at that time in Spain.

As a result, new techniques and skills were acquired in the manufacturing process of this product, which had never been used before in Mexico. Although, Clay was used before as a plaster in native construction systems, the manufacturing of new adobe bricks became widespread in the region being a key factor for the development of colonial settlements. The use of these bricks in walls along with timber and clay tiles in ceilings were the basic materials of new colonial buildings (Azevedo, 2013).

Figure 5.3 Adobe replaced by industrialized building materials

As seen in Figure 5.3, Fired clay bricks and Industrialized-building materials (concrete) have been replacing postcolonial building practises and traditional building materials (adobe) in this region for the last 60 years. According to (Ettinger, 2010), the use of traditional materials, which are now expensive or not available anymore, is considered a luxury. Thus, in this transformation process, concrete, glass and aluminium among others have become the predominant materials in the Cuitzeo bioregion as symbol of modernity. Unfortunately, in this sense of modernity, local knowledge of traditional practices, local materials availability and even climatic considerations are now playing a second role in the construction lifecycle.

5.3 Bioregional characteristics

5.3.1 Cuitzeo climatic region

Given its extension, wind exposure and terrain differences, the temperature in the Cuitzeo bioregion vary from a place-to-place (see Figure 5.4), but predominating climate is temperate sub-humid with summer rainfall. The average monthly temperatures are found in the range of 14 to 18º C during the year accordingly altitude with a mean annual precipitation between 790 to 1343 mm, being the rainiest months from July to September (Leal-Nares et al., 2010). The hot season runs from April to September, when May and June are the hottest months while in October the cold season starts with temperatures lower than 14°C (Cram et al., 2010).

According to INEGI's climate classification, the climatic units within this area also present a slight variation according to their geographical location (see Figure 5.5). While near to Cuitzeo lake the climate is warmer, the predominant climate corresponds to the watershed are; C(w1)(w) Mild temperatures humid with average humidity in summer (see below the full list of climatic units). Only a small proportion of this area is considered temperate with abundant moisture during summer. However, it is expected that important changes in temperature in this habitat are going to take place during the course of the 21st century because of the global warming effect (Cram et al., 2010). Although, in this region not potential impacts have been analysed, the climate condition and possible changes could have a considerable effect on construction material production because weather-related impacts might cause erosion, flooding, etc. in which case, it would reduce the local availability of raw materials and the rising of their costs (Kruse, 2004).

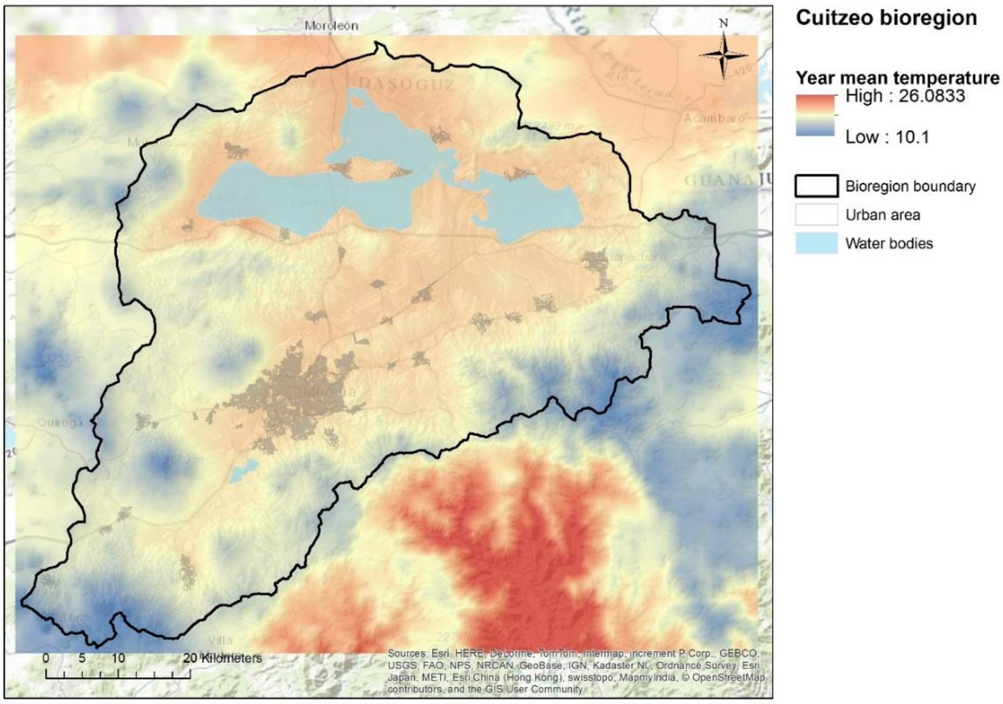

Figure 5.4 Bioregional annual average temperature

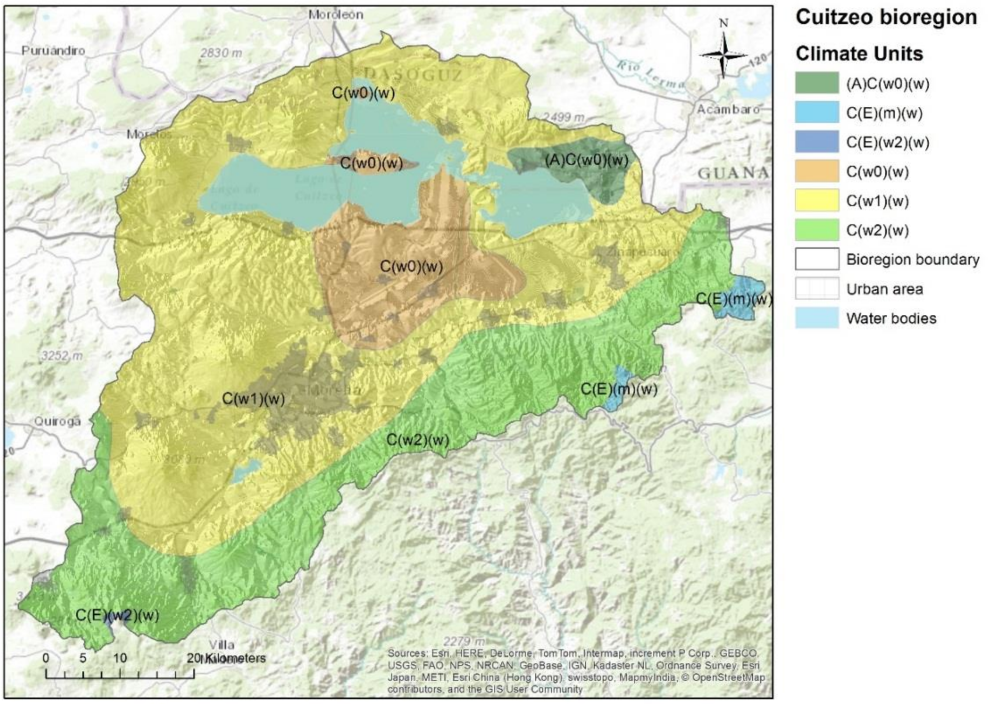

Figure 5.5 Bioregional climatic units

Bioregional climatic units

A (C) w0 (w), A (C), Semi-warm, w (w), semi-wet, 0, less humid, w, summer, (w), <5, <60, between 18 and 22.

C (E) (m) (w), C (E), Semi-cold, (m) (w), wet, N / A, N / A, m, abundant summer, <5, <40, between 5 and 12.

C (E) (w2) (w), C (E), Semi-cold, (w) (w), sub-humid, 2, wetter, w, summer, <5, <40, between 5 and 12.

C (w0) (w), C, Temperate, (w) (w), sub-humid, 0, less humid, w, summer, (w), <5, <40, 12 to 18.

C (w1) (w), C, Temperate, (w) (w), humid, 1, average humidity, w, summer, (w), <5, <40, 12 to 18.

C (w2) (w), C, Temperate, (w) (w), sub-humid, 2, wetter, w, summer, (w), <5, <40, 12 to 18

5.3.2 Georegion

Soils: According to González et al. (2010) and taking in account the International soil classification system (FAO, 2014), the soil biodiversity within the Cuitzeo bioregion is composed by five main soil units. This is particularly important in relation to the analysis of the chosen construction material carried out next in Chapter 6. However, data provided by INEGI, which is more general used in this study shows the following soil units. 10% of this bioregion area, which correspond to water bodies.

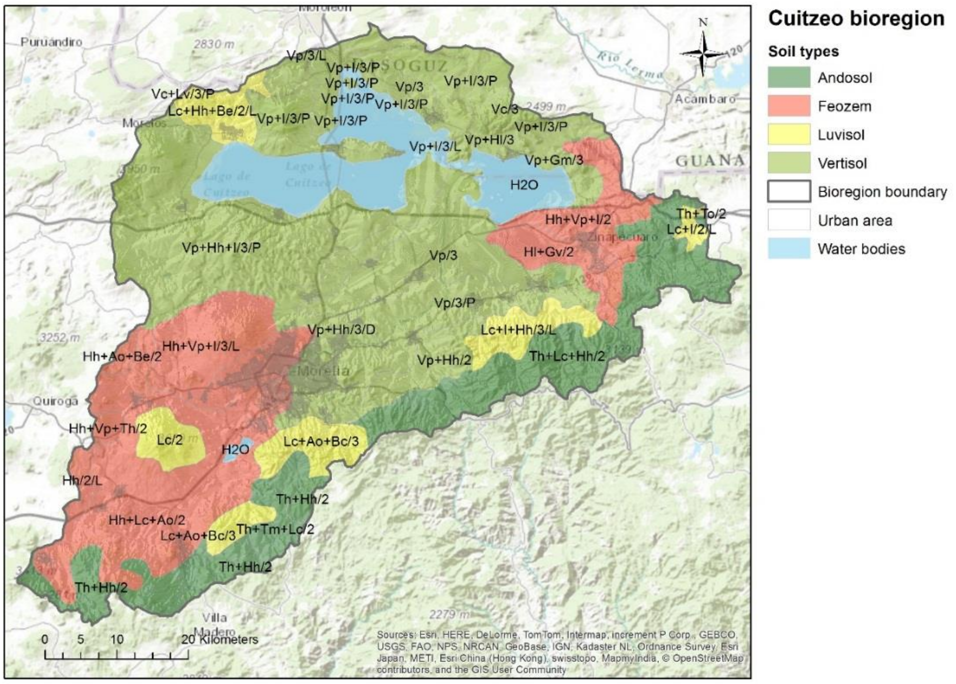

Figure 5.6 Bioregional soil types

Andosol; generally black in colour, covering 15% of this bioregion and are generally found between 2300 and 3100 meters above sea level (masl) on volcanic cones. Within these soils, the pine-oak forest is very common, but there are also andosol types, which can support some variety of agriculture in spite of the high level of phosphorus of these soils. No direct application to the built environment is found. ***Feozem*** or *Phaozem;* these type of soils are brown colour covering 24% of this area, these soils can be found between 2000 a 2350 masl in this bioregion. These soils present a high performance in uses related to agriculture, and sometimes there is found a thin accumulation layer of clay,. ***Luvisol***; these type of soils cover 8% of the bioregion and they are found between 2000 and 3400 masl. They are red or yellowish colour with a high content of clay, making them particularly suitable for brick production. Moderate performance in agriculture and the most important sawmills in Mexico are located within these type of soils (INEGI, 2004). ***Vertisol***; is the predominant soil in Cuitzeo bioregion covering 43% of the surface and they are located between 1900 and 2300 masl within this bioregion. They are mainly used for agriculture purposes. However, given the medium to high content of clays, they are also used in all type of housing construction activities when a proper treatment to reduce its expansion is used.

Rocks: Cuitzeo bioregion is located within the Mexican Volcanic belt and presents a natural tendency for igneous rocks, which are formed from the natural process of cooling molten magma. Within this area, local researchers along with administrative environmental organisations have carried out several studies about the classification of rock types with different levels of analysis (SUMA, 2011, Cram et al., 2010). In the manufacturing process of clay bricks in Cuitzeo bioregion, rock sediments and sand are used and mixed with clay, thus in this area, brick production depends mainly on the availability of depositional lacustrine and depositional superficial sediments.

According to INEGI's cartography, in this area predominantly the following groups of rocks, (Vc) Volcanoclastic 4.05%, (Igeb) Igneous extrusive basic 44.22%

and (Igea) igneous extrusive acid 25.49% and N/A 26.23%[8]. The availability of this local resource is well reflected in Morelia city, where quarries of sandstone (Ignimbrites) were exploited for the construction of Colonial buildings. The following table summarizes the bioregional availability of these rocks and their main uses in construction activities (Haldar and Tisljar, 2014, Smith et al., 2005).

Table 5.1 Bioregional rock types (source SUMA)

Rock	Rock type	Bioregional Percentage	Main uses in Construction
Basalts	Igeb	5.1 %	• Foundations • Engineering purposes • Decorative pavements • Aggregate
Basalt and Andesite	Igeb-Igei	3.7 %	• Slip resistant tile • Bricks • Pavers
Basalt and Dacite	Igeb-Igea	7.4 %	• Aggregates • Fill-in construction • Roadstone • Decorative landscaping
Andesite cone	Igei	8.3 %	• Fill-in construction • Aggregates
Volcanic cone		11.2 %	• Coarse aggregates
Dioritic subvolcanic bodies	Igii	0.2 %	• Aggregate • Stone for building facings, Foyers
Pyroclastic sediment	vc	5.0 %	• Agglomerates
Depositional Lacustrine		5.0 %	• Refractory bricks • Blocks and Cements • Insulating
Depositional superficial		24.6 %	• Gravel and sand
Andesite dome	Igei	1.0 %	• Aggregate • Fill-in Construction
Dacite and Rhyolite dome	Igea	2.6 %	• Fill-in Construction • Ornamental • Suitable as aggregate
Dacite dome	Igea	0.1 %	• Fill-in Construction • Building material
Rhyolite dome	Igea	1.7 %	• Suitable as aggregate • Fill-in construction • Lightweight Building material

[8] *In prehispanic times, volcanic rocks were the raw materials to build "Yacatas" in this region. The Yácata, was a ceremonial Tarascan building utilized as both a morgue and a home. The structure comprises of three sections whose ground arrangement is molded pretty much like a capital T: According to a compilation of writings by Carl Lumholtz in 1902, he described those buildings as follow; "The mound is built of stones, without mortar, in the shape of a 'T,' each arm about 50 feet long and thirty-two feet high. The western arm terminates in a circular construction, a kind of knob. The sides all rise in regular steps from the ground, and the level surface on top of the arms is only six feet wide, while the base is twenty feet broad. These encircling steps make the monument singularly symmetrical and graceful." (Lumholtz, 2005)*

		• Roadstone • Decorative landscaping
Ignimbrites	8.8 %	• Stone blocks • Decorative walls, paving. • Landscape
Monogenetic volcanic	7.5 %	• Suitable as aggregate
Water bodies	8.0 %	• N/A

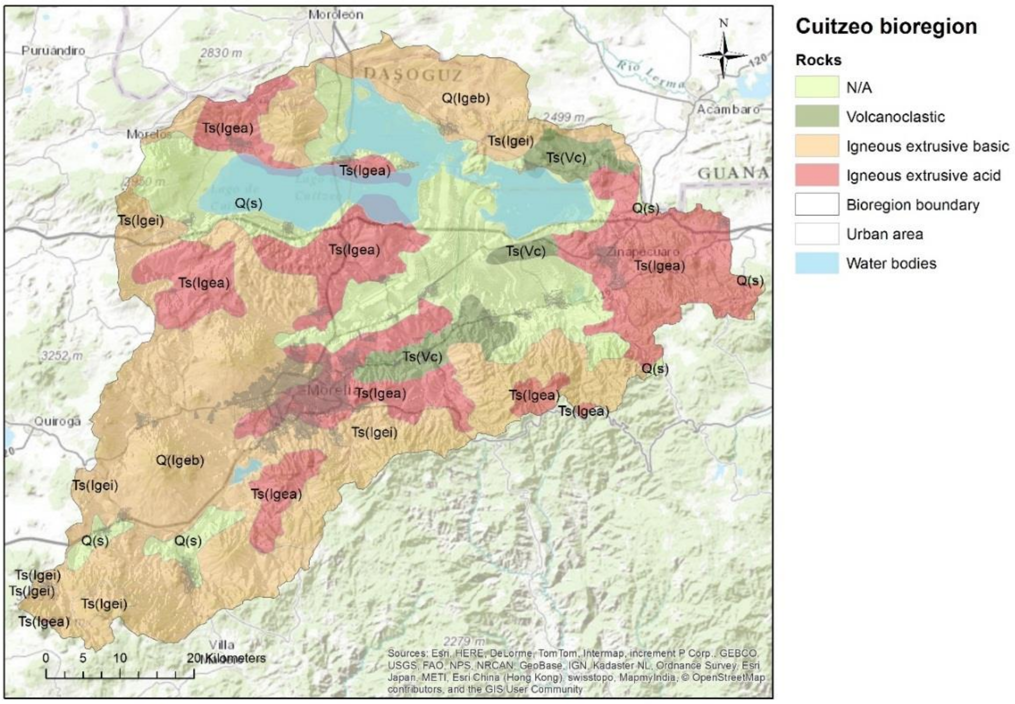

Figure 5.7 Bioregional rock types distribution

As pointed out in section 4.5, the mapping of geology allows the identification of indigenous resources, which could be used in the local manufacturing of building materials that encourage the economic development of the area. Although, for the purposes of this study no specialized identification techniques such as presented by Fang and Azigui (2007) in section 4.6 have been done, the information presented in table Table 5.1 helps to situate the potential of this bioregion as a rock products supplier. The results showed a great variety of natural resources according to the characteristics of the Cuitzeo region.

5.3.3 Land use

Although this bioregional area has been inhabited for hundreds of years, it is in the last century that the most dramatic change in land use has taken place. According to SUMA (2011) this change is due largely to the expanding urban area. This has led to forest and agriculture areas declining and a reduction in the availability of local natural resources. Furthermore, the transitions of land use from forest to agricultural and to urban areas alter chemical properties of clay soils turning them thicker, which reduce their quality for brick production (Rezaei et al., 2012). The map of land use characterization of this area (Figure 5.8) shows a predominant use of agricultural activities, and natural vegetation, which covered an area of 31% approximately. In terms of forest area, it covers 19.45% of the bioregion and the variety distribution is shown in Table 5.3.

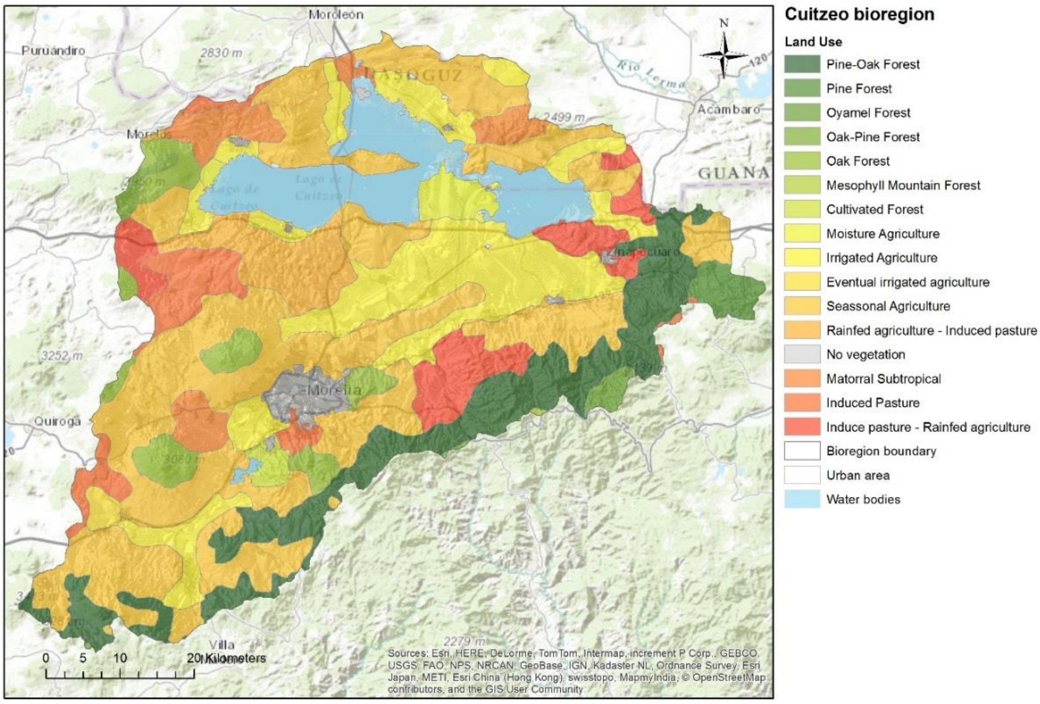

Figure 5.8 Bioregional land use distribution (2010)

Table 5.2 Bioregional land use (proportion)

Land Use	Area Km^2	%	∑ = Population	%	∑ = Dwellings	%
Pasture	155.20	4.05%	31420	3.07%	11251	3.08%
Agricultural	1989.24	51.92%	424470	41.42%	157911	43.28%
Agricultural-pasture	148.53	3.88%	9540	0.93%	3085	0.85%
No vegetation	2.24	0.06%	0	0.00%	0	0.00%
Urban	68.08	1.78%	494755	48.28%	162722	44.60%
Forest	745.15	19.45%	18253	1.78%	6412	1.76%
Water body	363.90	9.50%	1123	0.11%	327	0.09%
Scrubland	146.35	3.82%	26717	2.61%	17371	4.76%
Pasture-Agricultural	213.02	5.56%	18473	1.80%	5756	1.58%
Total	3831.72	100.00%	1024751	100.00%	364835	100.00%

Table 5.3 Bioregional forest distribution

Forest distribution	Bioregional Percentage	Main uses in Construction
Pine-Oak forest	12.17%	• Building material • Firewood • Doors
Pine forest	1.22 %	• Furniture • Building Structure • Wall cladding • Flooring • MDF • Engineering works
Oyamel (*Abies religiosa*) forest	0.54 %	• Roof beams • Wall cladding • Doors • Windows frames • Ceiling covering
Oak-Pine forest	0.50%	• Building material • Scaffolding
Oak forest	4.37 %	• Building material • Scaffolding • Flooring
Mesophyll Mountain forest	0.04 %	• Fences • Wooden poles
Cultivated forest	0.61%	• For tailored industry purposes
Total Forest area	19.45%	

The mapping of land use and its table of bioregional forest distribution presented above are also useful tools to situate the potential timber production within the region for construction purposes. According to the bioregional characteristics, the current forested area is relatively small and the identified variety of tree species could be used to improve the local productivity in sustainable construction. As stated by (Watson, 2014), there is a positive association between diversity and productivity, which could benefit socio-economic aspects within the bioregion.

5.3.4 Socio-Economic

Within the Cuitzeo bioregion there are 28 administrative municipalities of which twenty-three belong to Michoacán and five to Guanajuato state. According to historical data, the population in this bioregion has increased rapidly during the last 40 years In 1970 there were 380,780 residents living in that area, while the last census (2010) showed a total population of more than one million residents. Morelia city is the administrative and cultural centre of this area and the Michoacán state with the highest population density 72% of the bioregion and the highest urbanization level (see Figure 5.9). According to SUMA (2011).p.52 this urban area grew up to 600% in just 37 years. It is clear that this area needs considerable servicing in terms of indigenous construction materials where possible. At the same time, it is important to be able to define the natural limits to using these resources within an ecosystem.

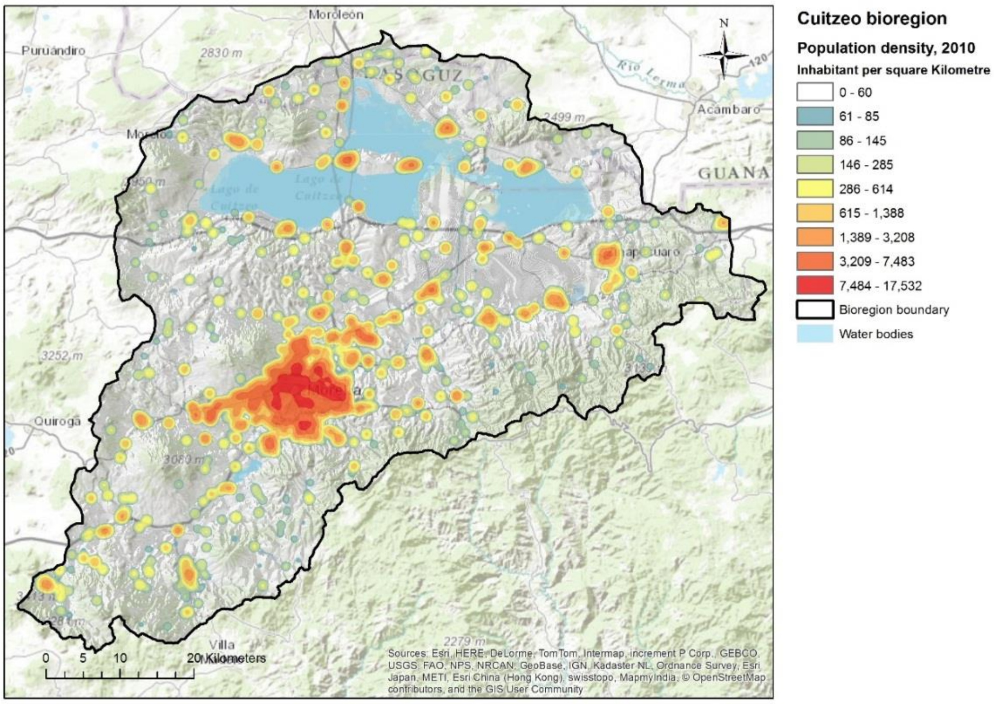

Figure 5.9 Bioregional density population census 2010

Unlike other Michoacán areas and despite its Tarascan[9] history, currently within the Cuitzeo bioregion there are no major indigenous communities and most people are considered mestizo [10] (Williams, 2014). As mentioned before, traditionally, the economic development in Cuitzeo bioregion was based on agriculture activities with up to 88% of the population involved in it during 1975. However, 15 years later, in 2000, only 30% of the population executed those activities, being the high migration intensity an important factor against (Bocco et al., 2012). As showed in section 5.2, these socio-economic pressures have had a

[9] *The Tarascan or Purepecha society is a pre-Columbian society of Mexico that prospered predominantly in the eastern area of the now state of Michoacan. Society started around the year 1200 AD and magnificence finished around 1600. His administration was monarchical and religious. Like a large portion of the pre-hispanic societies, they were polytheistic. The modifier "Tarasco" is an eponym considered deprecatory by the present day relatives of the individuals that made this society, they call themselves P'urhépechas.*

[10] *Mestizo is a term traditionally utilized as a part of Spain and Spanish America to mean a man of consolidated European and Amerindian genetic origin, or somebody who might have been considered a Castizo (one European guardian and one Mestizo guardian) in any case if the individual was conceived in Mexico or outside of Latin America. The term was utilized as an ethnic/racial classification in the casta framework that was being used amid the Spanish Empire's control of their New World settle.*

major impact on the choice and use of indigenous materials for construction, resulting in the use of higher-energy intensity materials.

Based on a study carried out by Sanchéz-Salazar and Casado-Izquierdo (2010), in terms of "distribution", (see Figure 5.10) the predominant economic activities in the bioregion of Cuitzeo are primary economic activities (green) concerning natural resources and the acquiring of raw materials, agriculture, forest or minerals to be mined. Tertiary economic activities represent the second most important sectors in this bioregion; tertiary economic activities involve commercial services that support production, distribution and general services. On the other hand, secondary activities or secondary production (yellow) take the third place in importance within this bioregional distribution. As seen in section 3.1, these activities represent the manufacturing and assembly process of raw materials into products.

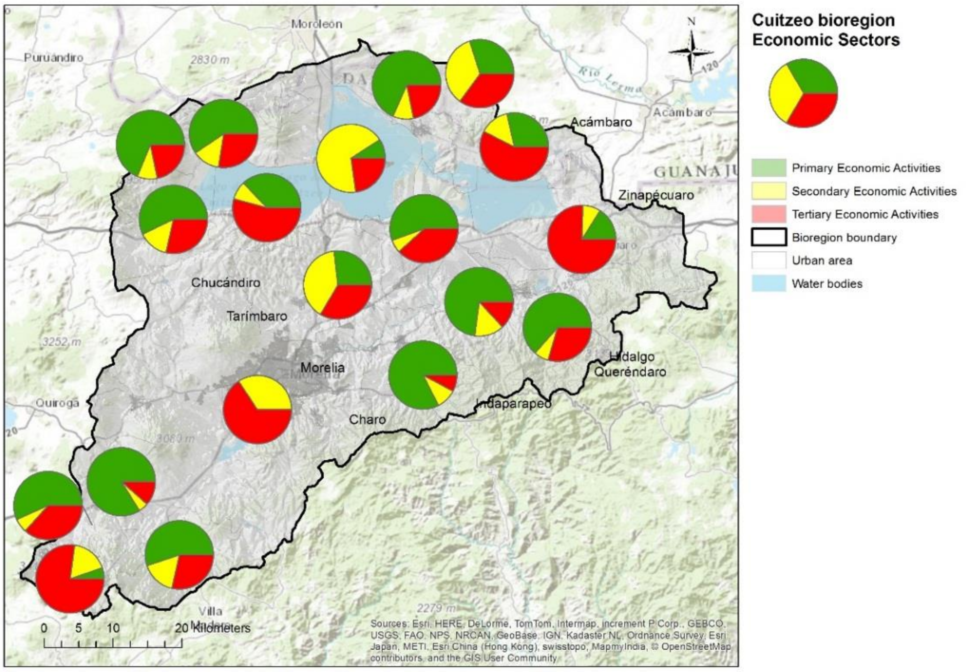

Figure 5.10 Bioregional distribution of main economic sectors (2015)

However, despite the previous description showing the predominant distribution of primary economic activities, the economic reality of different sectors is better depicted in Figure 5.11. This map shows the same economic sectors, but now in relation to their *proportional bioregional production*. This helps to locate the actual indigenous production as opposed to the more generalised picture previously described. The proportion is based on the gross production of all economic activities, which took place in the year 2005. Here, the bioregional primary production is only 4.78%, Secondary production 32.52% and Tertiary production 62.70%, which shows that local sourcing for the production of clay is declining.

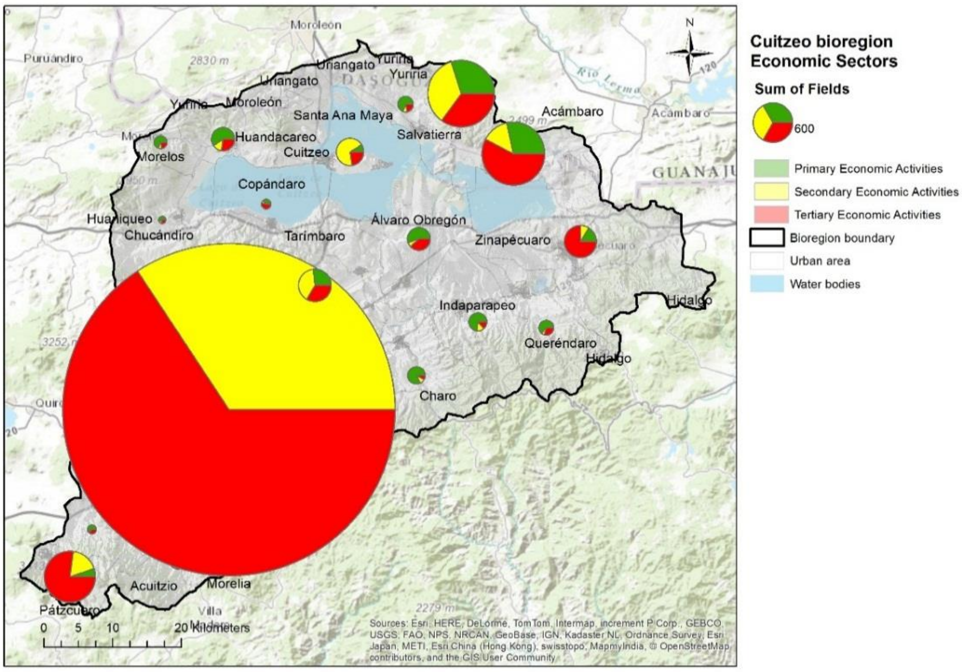

Figure 5.11 Bioregional proportion of main economic sectors (2015)

5.3.5 Environmental

The main economic activities now taking place in the urban area of Morelia are reflected in the land use change of the Cuitzeo bioregion as seen in section 5.3.3. Consequently, this concentrated economic and urban development is increasing the environmental pressure in this bioregion. A cited by Sanchez & Casado (2010, p.127), *"When the economy of a region specializes in (secondary and tertiary) "urban" activities the potential impact on the environment tends to be more intense than when the economy diversifies"*. In other words, this means that given the urban area of the bioregion of Cuitzeo has been expanding, the need to obtain raw materials should be now sourced in more distant places (other bioregions), breaking in this way the bioregional desires in the majority use of local resources. On the other hand, both the industry and the built environment are major contributors to the overall Cuitzeo environmental impact, given that their waste materials go straight to open landfills, which are not yet ready for recycling processes (Israde-Alcántara et al., 2009).

Based on the bioregional characterization and the mapping process presented above, this geographical framework provides a more holistic understanding of the Cuitzeo bioregion. However, in order to strengthen the concept of sustainability in the life cycle energy analysis of construction materials it is necessary to perform a highly detailed bioregional characterization for the subsequent life cycle inventory of construction activities.

5.4 Bioregional characterization for life cycle inventory of construction activities

5.4.1 Procedure

The graph presented in Chapter 3, section 3.3.1 showed the inclusion of energy intensities from the IO model across sectors of the Mexican economy. However, in order to apply the capabilities of the IO model to incorporate energy coefficients into all the construction related activities located within the bioregion case study area, a local inventory is a need.

The area for the life cycle inventory in the Cuitzeo bioregion was already described in this Chapter and is used as a boundary for the physical identification of economic units [11] and the development of a bioregional geo-referenced database. This bioregional database is based on a national database released by (INEGI, 2013a) called "The National Statistic Directory of Economic Units" (DENUE by its Spanish initials), which contains information about more than four million active establishments also known as economic units located within the Mexican territory.

[11] An economic unit is one that, produce or sells good and services in that area, which includes the name of the establishment, postcode, address, description of the activity, and the number of staff.

As with the Input-Output tables, the database is also codified according to the North America industrial classification system (NAICS), thus presenting an ideal opportunity for the subsequent incorporation of the energy intensities and the ability to use this concept more widely in the field of LCEA. Thus, all economic activities within the bioregion are counted using the clip function of geographic information system software ArcGIS 10.2. Subsequently, as shown below in Figure 5.12, this procedure is extended to allow the integration of embodied energy coefficients. For comparison, the same procedure is carried out taking into consideration Michoacan state's administrative boundaries to which the bioregion belongs and in relation to the total of national economic units.

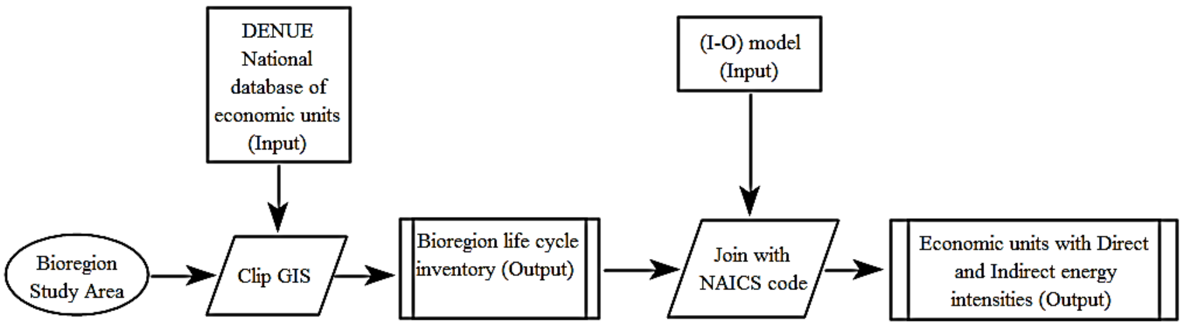

Figure 5.12 Procedure for a bioregional life cycle inventory based on economic units

5.4.2 Inventory

According to this inventory, the bioregional economic profile provides an overview of all economic activities taking place in this area, the economic allocations are represented in Figure 5.13. This graph shows clearly the trade of goods (Sectors; 43-46) as the main economic activities in that area (42.90%). The group of activities related to services (Sectors; 48-93) represent 45.38%, while the economic activities dedicated to the transformation of goods "industry" (Sectors; 22-33) represent only 12% of the total bioregional economic activities.

Table 5.4 below shows the identification of 55,545 economic units located within the bioregion, which represent 1.14% of all economic activities in relation to the total active establishments (economic units) found within the entire Mexican territory. The bioregional case study area is shared by two Mexican states in which 99.44% of the economic units belong to the Michoacán state and only 0.56% belong to Guanajuato, making this latter State largely irrelevant for this bioregional inventory. In other words, Michoacán is the only state administratively responsible of the bioregion, which can facilitate the decision making process. Finally, in accordance with section 5.3.4 of this research, it is quite remarkable that the exploitation of natural resources in this bioregion (Sectors; 11-21) is minimal representing only 0.14% of the total economic activities within the bioregion. It is important to understand why this is happening because it might be an indicator that construction activities in this bioregion are drawing on external resources to obtain building materials.

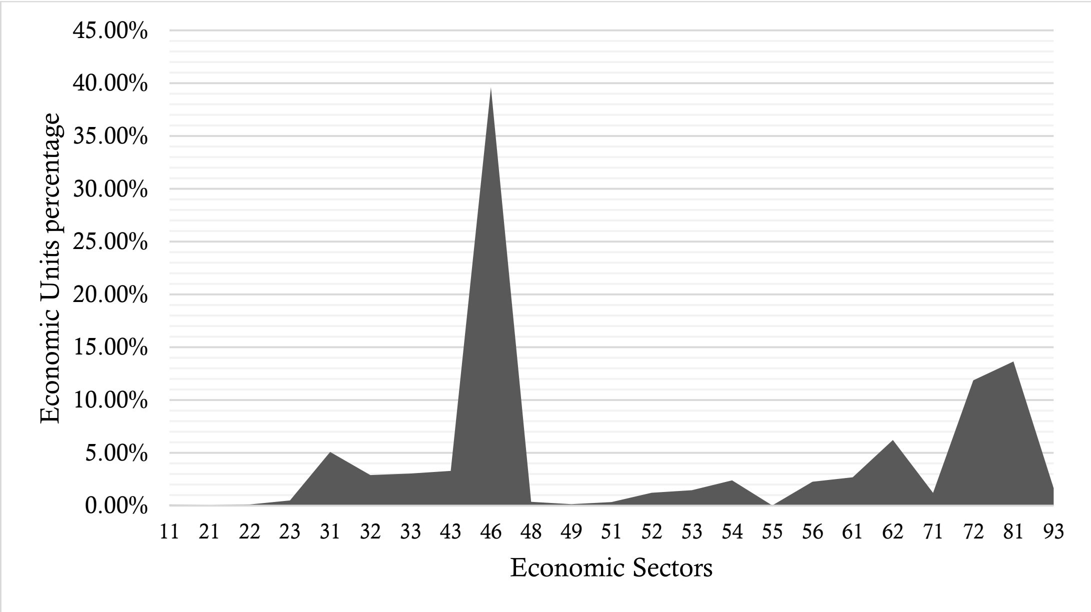

Figure 5.13 Bioregional economic profile

Table 5.4 Bioregional economic units

Sectors	Bioregion	Michoacán	Guanajuato	National
	Economic units	% belongs to	% belongs to	% in relation to
(11) Agriculture, Forestry, Fishing and Hunting	46	100.00 %	0.00 %	0.41 %
(21) Mining	29	86.20 %	13.80 %	0.95 %
(22) Utilities	58	100.00 %	0.00 %	1.24 %
(23) Construction	269	100.00 %	0.00 %	1.32 %
(31-33) Manufacturing industry	6109	99.52 %	0.48 %	1.18 %
(43) Wholesale trade	1824	99.39 %	0.61 %	1.19 %
(46) Retail trade	22005	99.15 %	0.85 %	1.07 %

(48-49) Transportation and Warehousing	270	100.00 %	0.00 %	0.86 %
(51) Information and cultural industries	184	98.91 %	1.09 %	1.03 %
(52) Finance and insurance	673	99.85 %	0.15 %	1.29 %
(53) Real state and rental and leasing	808	99.75 %	0.25 %	1.20 %
(54) Professional, Scientific and technical services	1326	99.92 %	0.08 %	1.35 %
(55) Management of companies and enterprises	6	100.00 %	0.00 %	1.30 %
(56) Administrative and waste management services	1254	99.60 %	0.40 %	1.23 %
(61) Educational services	1487	99.26 %	0.74 %	1.06 %
(62) Healthcare and social assistance	3449	99.82 %	0.18 %	1.68 %
(71) Arts, entertainment and recreation	667	98.95 %	1.05 %	1.08 %
(72) Accommodation and Food services	6588	99.77 %	0.23 %	1.16 %
(81) Other services except public administration	7580	99.69 %	0.31 %	1.04 %
(93) Public administration	913	99.78 %	0.22 %	1.11 %
Total	**55454**	**99.44 %**	**0.56 %**	**1.14 %**

In sections 3.3.2 and 3.3.3 it was already identified that within residential and non-residential building construction sectors in the Mexican territory, the two most important building materials in terms of their embodied energy are cement and clay brick products. Given that the third objective for this chapter (section 5.1) is to provide a bioregional characterization of construction related activities within this area, the results are also used to identify the most important construction material to analyse in the next Chapter. Therefore, after the general overview presented above, it is necessary to refine this identification in relation to those activities with the greatest influence in terms of quantities of establishments within this bioregion. Hence, from the previous 55454 economic units located in the above Table 5.4, the refined inventory of construction activities identifies 5,253 economic activities representing 9.46% of the total bioregion (See Appendix B-1). Within this new Bioregional built environment profile (Figure 5.14), the following characteristics are identified according to the NAICS coding system;

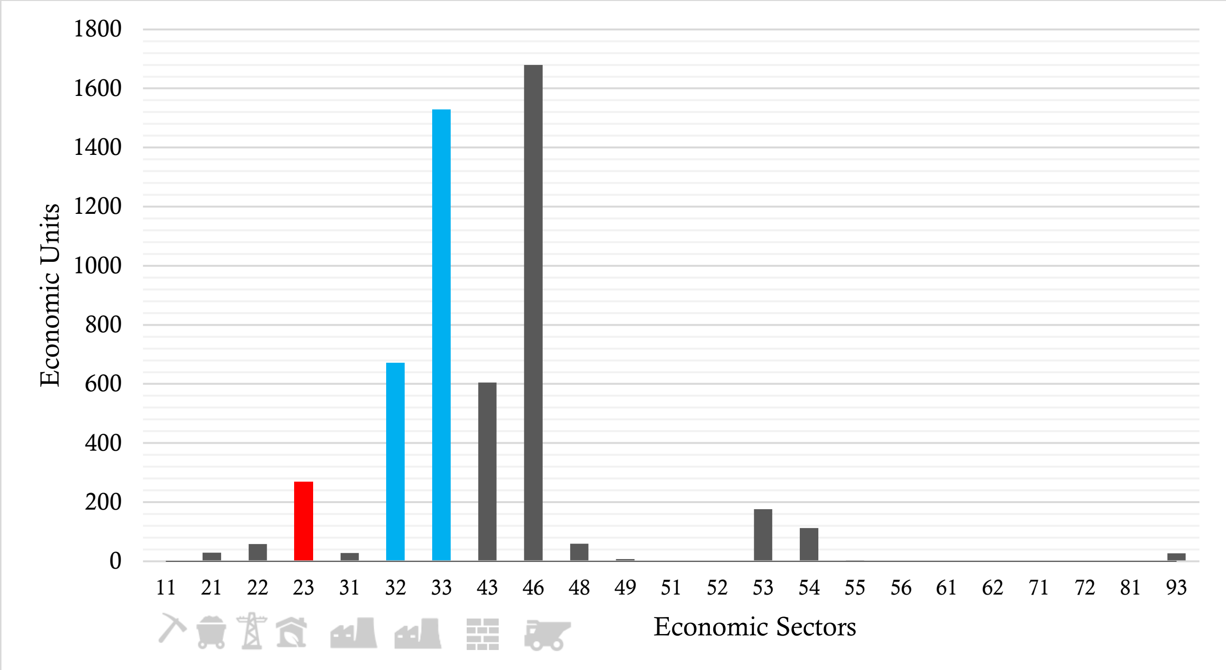

Figure 5.14 Bioregional built environment profile

The above graph shows that in (**Sectors; 11-21**), activities related to sector (11) were not identified within the built environment - this economic sector provides raw materials such as; earth, plant products, natural resins and firewood through the use and harvest of forest resources than later could be processed as wood products in sawmills, etc. On the other hand, the mining sector (21) also showed a small proportion of economic units dedicated to the extraction of raw materials, where the bioregional activity relates only to the extraction of sand and gravel mining used in construction.

Sector 22 represents utilities or of activities related to energy suppliers, within the bioregion this sector only shows the national energy grid, given that in this area there are only located electrical substations representing 1.10% of the total economic units in this area.

The construction **sector 23**, which is highlighted in red in the above graph, is relevant for its demand of building materials within the bioregion. This sector is split into three main subsectors (236, 237, and 238). From these subsectors, the Construction of buildings (236), which is dedicated to the construction of single and multifamily housing buildings, is the most important in terms of a number of economic units. The second most important subsector (237) is dedicated to the construction of services and infrastructure and finally, in third place is the subsector (238), which is involved in specialized or engineering works.

For the purpose of this research, the following sectors are significant given that manufactured construction materials are located within them. The manufacturing industry, **sectors (32) and (33)** are highlighted in blue light colour in the above graph and they display the second highest proportion, 42.43% of economic activities, which are related directly or indirectly with the built environment within the bioregional area. Those activities involve a great range of big and small industrial sectors or services, such as the integrated sawmills, Manufacturing of wood products for construction, concrete manufacturing, and the manufacturing of products based on quarry stone among others (See next page Figure 5.15).

As seen in the above figure, within the Cuitzeo bioregion, in terms of a number of economic units, the manufacturing of wood products is representative of this area. However, according to the energy intensities estimated with the IO model in section 3.3.1 this sector is not significant. The second most representative building material in terms of establishments dedicated to this activity within the bioregion is Non-refractory bricks manufacturing with 102 economic units, and this sector is the second most high-energy intensity in Mexico. On the other hand, in spite of the fact that concrete and cement manufacturing are the highest energy intensity products in the Mexican territory, within the bioregion, there are only 5 concrete manufacturing plants and 47 establishments dedicated to producing concrete pipes and blocks. For the purpose of this research and based on the previous data, it is suggested that clay brick is the most representative material to analyse with the spatial model in the next Chapter, however, for further studies it is possible to analyse any building material within the bioregion.

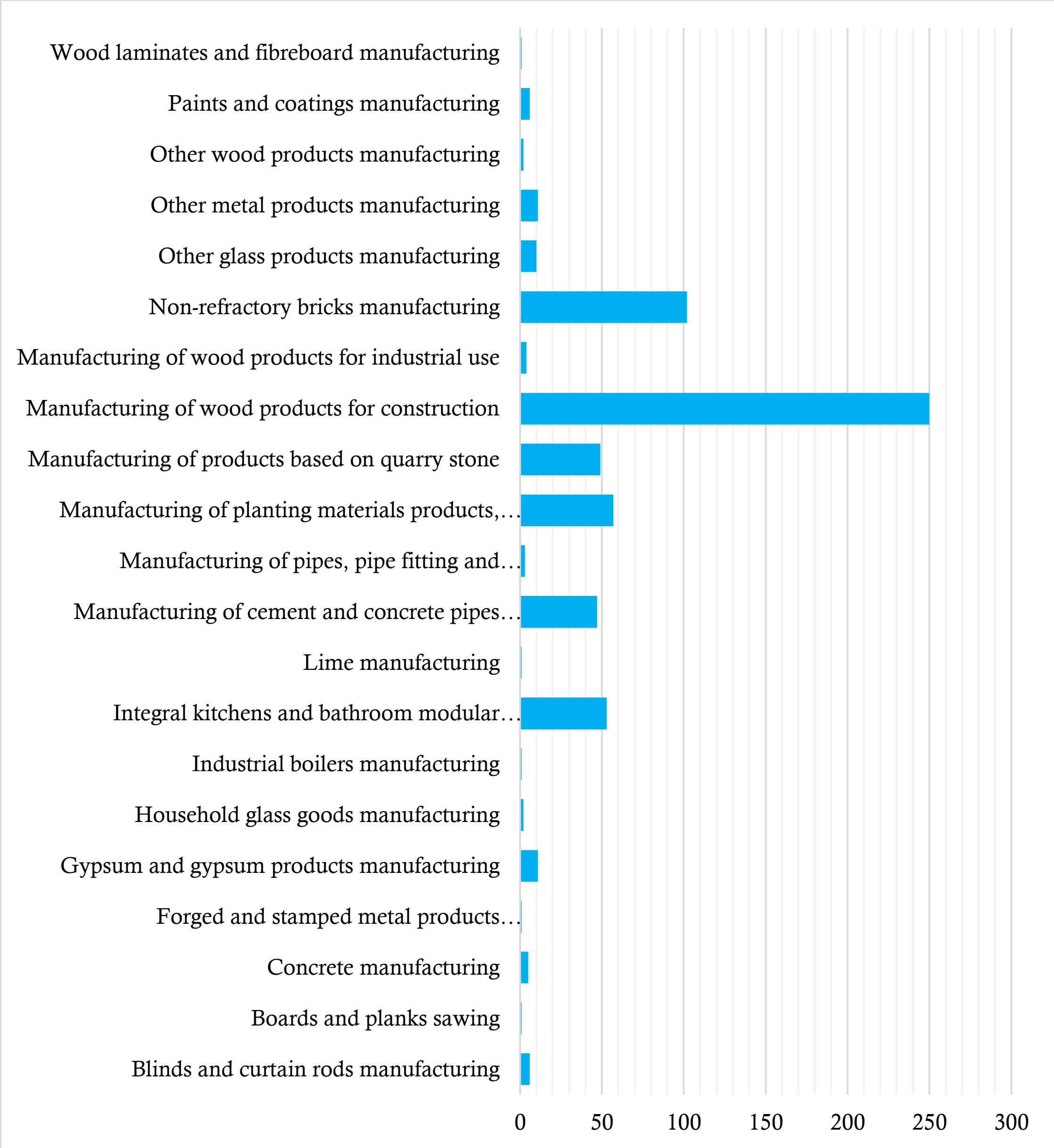

Figure 5.15 Manufacturing of construction materials by number of economic units (Cuitzeo bioregion)

Back to the rest of the sectors identified in Figure 5.14; (**Sectors; 43-46**) these are retail sectors dedicated to selling and supply products of primary and secondary activities (building materials, building components, etc) for their use in the construction industry. Both sectors represent the largest sector in the bioregional supply chain with 40.80% of the economic establishments. However, in this inventory it is uncertain if these building materials are manufactured locally or if they are brought from elsewhere in the country or other countries. Likewise, it is uncertain if local raw materials were used to produce building materials.

(**Sectors; 48-93**) Sectors 48 and 49 represents transport activities and warehousing related to construction industry. However, in the NAICS code system, they represent only external services (Rental services), thus, own transportation of the construction industry is not well represented. Thus, for the embodied energy analysis of clay bricks in the next chapter, transport must be included.

Based on the information presented in section 5.3 and for practical purposes in this work, a summary (Table 5.5) is presented below to show the potential vocation of the bioregion as a natural supplier of native resources to the local construction sector. The table could suggest that the bioregion area might be limited as a natural source of raw materials for the construction sector (at least for massive construction activities). Perhaps, this is because the tendency in land use in this area is now mainly restricted to agricultural, pasture and urban development as shown in Table 5.2. Thus, earth and plant based material products are limited, which could represent an issue in the manufacturing of clay bricks to be analysed in the next chapter.

Table 5.5 Potential vocation of the bioregion as a supplier to the local built environment

Bioregional built environment vocation	**Availability of local products or services**	**High**	**Moderate**	**Low**	**Null**
Primary sector	Timber products			✓	
	Organic products (plants)			✓	
	Earth products			✓	
	Mineral products (rocks)	✓			
	Mineral products (metallic)				✓
Secondary sector	Synthetic products (plastics)		✓		
	Bioregion own energy for transformation purposes		✓		
	Construction activities	✓			
	Transformation of goods	✓			
Tertiary sector	Distribution of goods Wholesale trade	✓			
	Distribution of goods Retail trade	✓			
	Transportation services		✓		
	Recyclability of materials				✓
	Reclaimed materials	✓			

However, as same as the subjective inventory of natural resources previously mentioned, the most precise inventory of economic establishments presents a panorama where the majority of economic activities in this bioregion correspond to the secondary (Manufacturing) and tertiary sectors (goods distribution). This would imply that the local construction sector consumes a significant proportion of building materials, which have to be brought from places outside of this bioregion given that the primary sector in Cuitzeo area is insignificant for building materials production. As an example, the manufacturing of timber products for construction, while in Table 5.5 is evident that its availability within the bioregion is low, Figure 5.15 shows that there a considerable number of local establishments manufacturing timber for construction purposes.

5.5 Bioregional Embodied energy visualization

Given that one of the aims of this research is to test the capabilities of the IO model to display energy intensities in thematic maps to improve the interpretation of LCEA results, this process is done in this study using Geographical information systems (GIS), and encoding the energy path algorithm developed in Chapter 3. The incorporation of energy data into the bioregional context was carried out using the NAICS codified system (INEGI, 2013b). This encoding method at regional scale allowed the integration of energy intensities in each one of the economic activities previously described. Thus, as suggested in section 5.4.1, the use of the national statistics directory of economic units (DENUE) played a key role for this purpose.

Having established the bioregional built environment profile and according to the procedure showed in Figure 5.12, the incorporation of energy coefficients into the economic units located in this bioregion is possible through excel spreadsheets. Therefore, energy coefficients are imported through the join function of GIS into the bioregional database (attribute Table 5.6) and once, energy has been incorporated; the obtained energy intensities can be used for two purposes;

First, to visually determine the initial embodied energy of any product (building material) locally or externally produced in this area. This process requires the price of building materials and physical units (Kg, piece, m2, etc.) according to IO methodologies, then, if there is available local data (LCA), this can be used to replace the direct energy intensity of these materials. Thus, a new more accurate and locational IO based hybrid analysis of building materials can be achieved.

Table 5.6 Bioregional database integrated with energy intensities and locations

Fid	Refers to the identified economic unit
Shape	Economic unit identified as a point data
Cve_ent	Code of the Mexican state
entidad	Refers to the name of the Mexican state
Cve_mun	Code of the municipality
municipality	Refers to the name of the municipality
Cve_loc	Code of the locality
locality	Refers to the name of the locality
ageb	Refers to an area identifier, where the economic intis is located
block	Refers to the block identifier, where the economic unit is located
Nom_estb	Refers to the commercial name of the economic unit
Detailed information of the economic unit	phone
	email
	Commercial address
	Number of staff
	Etc…
latitude	Geographical altitude coordinates
longitude	Geographical longitude coordinates
Clase_act	Refers to the NAICS code identifier in six digits
Desc_act	Refers to the NAICS code activity name
DEI	Direct energy coefficient from IO
Stage 1	Indirect energy coefficient from IO representing stage 1
Stage 2	Indirect energy coefficient from IO representing stage 2
Stage 3	Indirect energy coefficient from IO representing stage 3
Stage 4	Indirect energy coefficient from IO representing stage 4
Stage 5	Indirect energy coefficient from IO representing stage 5
Stage 6	Indirect energy coefficient from IO representing stage 6
Stage 7	Indirect energy coefficient from IO representing stage 7
Stage 8	Indirect energy coefficient from IO representing stage 8
Stage 9	Indirect energy coefficient from IO representing stage 9
Stage 10	Indirect energy coefficient from IO representing stage 10
Stage 11	Indirect energy coefficient from IO representing stage 11
Stage 12	Indirect energy coefficient from IO representing stage 12
TEI	Total energy coefficient from IO
MatPrice	Requires the price of the material
Unit	Requires the unit (Kg, piece, etc)
Mj/unit	Estimates and display the embodied energy of the product

Second, given that the IO model provides both direct and indirect energy intensities (see section 3.2.4), up to twelve upstream stages of the indirect energy can be successfully depicted in visual maps as seen in Figure 5.16 below.

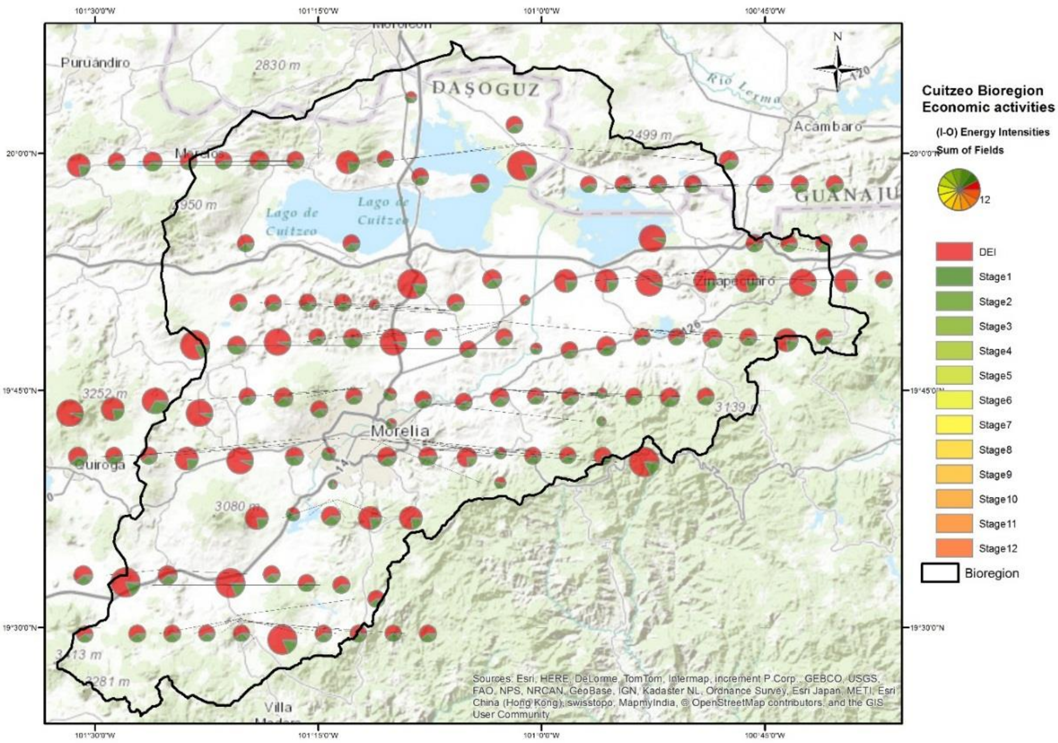

Figure 5.16 Bioregional embodied energy intensities of economic activities

Due to potential overlap, the map above only shows a schematic representation of energy coefficients (not embodied energy) incorporated into the bioregional database created in this chapter. This proves the capacity to store data from IO models within geographical areas. This capacity was suggested at the beginning of this research and has the potential to be applied in the embodied energy analysis of different economic sectors, which are producers of goods and services. Thus, the spatial energy model is particularly useful because within the built environment, it can be used to identify energy used in manufacturing process, it can also be used to set sensible standards for policy makers or to help in the selection of low-energy materials for architects and developers.

In order to prove this statement and as the main objective for this research, in Chapter 6 the manufacturing process of fired clay bricks within the bioregion of Cuitzeo will be analysed. This building material is considered representative for its large number of economic units within the area and for its high-energy intensity. However, as previously established, given that, neither in Mexico nor in this bioregion is there available data based on process analysis (LCA) for a more precise embodied energy estimation a physical life cycle inventory of this material will be needed.

5.6 Discussion of this Chapter

This chapter has proved the capabilities of the IO model to incorporate energy intensities into bioregional economic sectors as a framework for more detailed life cycle energy analysis in building construction materials. As pointed out at the beginning of this chapter, the aim of this study was not intended to map bioregions but rather to present the context of a geographical area to extend the sense of place, which is one of the shortcomings in life cycle inventories.

Following this, the historical background of Cuitzeo bioregion, its physical characteristics and the current socio-economic context showed that the bioregional identity as natural building materials supplier has been changing through the years. From the initial local use of tule in housing, stone in ceremonial Tarascan buildings of the prehispanic period, the use of local quarries of sandstone in the colonial period, to the current use of building materials from everywhere outside of the bioregion. This shows that materiality in places changes over time adapting to new building typologies demand and cultural preferences. Hence, in this research the analysis of a single building material namely, in this case, Clay brick only responds to its current significance within the Cuitzeo bioregional context.

One objective of this chapter was to build an inventory of natural local resources in order to identify the bioregion as a natural building material supplier for the local built environment. Thus, Maps presented in section 5.2 provided the bioregional context suggested by Ball (2002b) and in a very generic way they were used to identify the requested local resources for construction purposes. Unfortutely some of the datasets used to build these maps have not been updated by INEGI since 2010, thus, the information presented in section 5.3 should be considered only as a representative and not decisive to validate an inventory of local resources.

The identification of construction related activities within the bioregion was a key objective to link energy coefficients with local economic establishments. In this case, the synchronization between the IO model and the National Directory of Economic Units (DENUE) proved to be effective as suggested in section 1.7, given that they share the NAICS coding system.

However, in order to match the coding system between the IO model and the economic units, manual corrections had to be done because while IO has a codification system of four digits (see Table AP.A1 of the Appendix A-1), the DENUE database is built in six digits. This correction has a moderate effect in the incorporation of energy coefficients into the economic units (establishments) given that according to the level of commodities aggregation the reliability of results can drop and some assumptions have to be made (see Table AP.A2 of Appendix A-2). After this process, the well-known capabilities of IO analysis are extended at bioregional scales in order to maximize its use to identify interrelationships between economic sectors.

In this research, the above process is considered as an alternative and new approach to performing regional IO analysis, given that traditionally, local IO models required for regional aggregate economic data for this purpose (Cicas et al., 2007). As mentioned in section, 3.2.1 of this thesis, in order to build the Mexican IO model the available IO tables represented national aggregate data and an analysis at bioregional level is often considered not precise. However, the availability of regional and interregional economic data is not very commonly available to build regional IO models (Geschke et al., 2014). The accuracy of the bioregional IO model presented here in comparison with traditional procedures to build regional IO models cannot be verified in this research because of these issues, and requires further evaluation in further studies.

In terms of the representation of energy intensities in thematic maps, this chapter proved that this objective can be achieved following the entire mapping process already presented. The potential of this visualization tool for multiple uses was also pointed out in section 5.5 and differs from other energy visualization tools given that they can only depict information. An example of this was pointed out in section 1.3.3 of this thesis, where the spatial tool presented by Pullen (2007b) showed its capabilities to spatially display embodied energy in land parcels at urban scale by incorporating data from different sources in spreadsheets. However, the spatial model itself was not able to perform calculations and did not represent different upstream stages of the LCEA. Thus, in order to prove this statement, in the next Chapter the manufacturing process of fired clay bricks within the bioregion of Cuitzeo will be analysed through a hybrid process calculation using the GIS spatial tool.

5.7 Summary

In this chapter, a new approach for embodied energy mapping at a bioregional scale has been presented, taking into consideration bioregion framework theory. It has been shown that this approach provides a holistic visualization for life cycle inventories of the built environment through geographical considerations. Thus, the sense of place in LCA is complemented with a Visio-ecological approach, which although increasingly recognized in some disciplines, is still not well considered by hard science disciplines.

According to bioregional principles and using Geographical information systems as a tool, a descriptive and systematic characterization of a bioregional life cycle inventory was presented. Within this context, historical, physical, and economic characteristics provided the sense of place to situate the vocation of this area as a supplier of natural and manufactured building materials for the demand of the local construction sector.

Following this, the capability to link energy data from the IO model with economic bioregional construction activities was proved by means of the NAICS encoding system. However, the full potential of this embodied energy mapping tool will be described in the next Chapter with the life cycle energy analysis of fired clay brick manufacturing in the same bioregional area. This step will evidence the proposed systematic process to carry out new life cycle inventories displaying energy intensities as a visual framework for results interpretation.

Chapter 6 Fired Clay Brick Production: demonstration of spatial LCEA model

6.1 Introduction

Following the objectives covered in earlier chapters, this chapter will complete the process for evidencing the new embodied energy mapping proposed for this research, through the case study of a single building material. Based on the energy paths of the input-output Model (National Level) and the number of economic units found in the bioregional case study, a study of the traditional production of fired clay bricks in the Cuitzeo bioregion has been selected. The case study provides the final step to illustrate the Visio-spatial framework described in Chapter 5 and display embodied energy intensities in LCEA.

As demonstrated in Chapter 3, fired clay brick is the second most used building material in Mexico and belongs to an economic sector which is not particularly industrialized, making it difficult to calculate using hybrid based Input-Output methods. Therefore, for this case study, a Process-based hybrid was selected to perform embodied energy calculations in a cradle to gate system boundary. Thus, data of direct energy consumption for brick producers is requested from them and indirect energy data from the Mexican IO model is used for calculation procedures. However, given that there was not enough available input data to perform this study, field work is carried out to ensure a reliable life cycle inventory, where energy paths from IO analysis proved to be a practical tool to shorten the time during the data collection process.

The field work obtained information from 48 of the 102 brickwork sites identified in the Cuitzeo bioregion through the bioregional life cycle inventory developed in the last chapter. The results were extrapolated with GIS techniques to perform a spatial analysis and to visualize energy consumption patterns during different stages of the clay brick production in this bioregion. This type of spatial representation of results is particularly important for those needing to select construction materials from a given territory.

6.2 Background of target sector

The selection of the target sector was established using the general methodology of this research as step (5) in order to apply the capabilities of the Mexican IO model into the case study of a single building material produced in the bioregion. Although concrete and cement are the largest material products used in the Mexican construction sector, for the purpose of this research fired clay brick is selected because within the Cuitzeo bioregion, fired clay brick production represents; 1) more economic units (102 against 6 of cement). 2) The interest of this thesis results by local authorities for local policies. 3) A more challenging sector to analyse given the non industrialized manufacturing process in clay brick production.

Clay bricks in Mexico presents a very dynamic and varied manufacturing industry where both technical and artisanal processes are used in their production. According to Cardenas (2012), from the total national production of fired clay bricks, 70% of the brickwork sites are still using artisanal techniques in their manufacturing process, while only 30% of them base their production in industrialized systems. In spite of this differentiation in the manufacturing process, it is estimated that artisanal production only represents between 30 to 50% of the total national production.

On the other hand, Ortiz-Herrera (2012) points out that traditional clay brick production in Mexico is surviving without a clear future given that this sector is not improving its manufacturing processes. This can be seen in the very rudimentary kilns, low efficiency burning techniques and uncontrolled fuels used. Furthermore, many of the brickwork sites that used to be located in remote locations, are now absorbed within urban areas, representing a major issue in health problems for the general population and environmental management for policy makers.

Cardenas (2012) stated that over the last two decades, there have been some unsuccessful initiatives addressed to mitigate the environmental impact of the Mexican fired clay brick production, given the lack of information to perform analysis and the poor coordination by the participants in these initiatives. The usefulness of GIS spatial analysis is that could account the proximity of production processes to residential areas allowing in this way a further potential analysis of their environmental impact.

Although, officially there are no exact figures of the number of brickwork sites in Mexico (INE, 2011) (CEC, 2011), according to the DENUE database used in this research there is a total of 9364 economic units identified throughout the country (INEGI, 2014b). Geographically the highest density of clay brick production is found in central Mexico (Figure 6.1) given that in this area is also where most construction activities are taking place. This high production of traditional fired clay bricks was identified in the life cycle inventory of Chapter 5 and is reflected in the Cuitzeo bioregion with 102 establishments (locally known as Galeras).

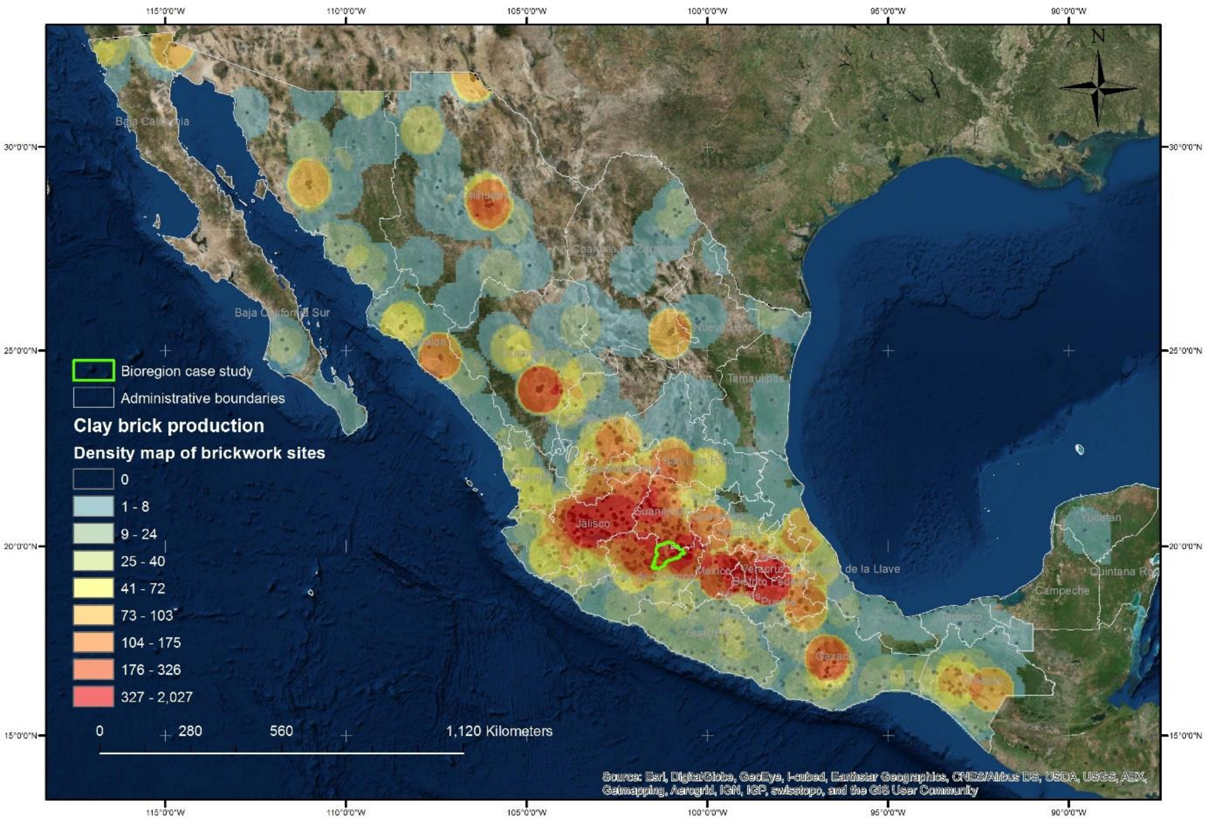

Figure 6.1 Density map of fired clay brick production in Mexico

According to the economic census carried out by INEGI in 2009 and a physical inventory performed by the local Ministry of Planning and Environment (SUMA, 2012), it is estimated that within the Cuitzeo bioregion the average annual total economic production of brickwork sites only reached $ 151,989.00 of Mexican pesos. However, according to this governmental entity, there are signs that this activity is affecting soil properties and near water bodies. The labour force in clay brick production involved directly more than 400 workers, of which 96.85% were males and just 3.15% of them females.

Because of the nature of this family business in which 56.47% are owners and family members that are not considered employed, only 35.33% of the total workers of this activity are considered staff who are receiving formal payment. However, this labour force represents seasonal employments who need to do alternative jobs to cover their fundamental needs during the rest of the year. Putting the above information into context, during the year of the economic census (2009), the minimum wage for that area was only $51.95 Mx equivalent to $3.91 USA dollars per day. Finally, although, it is argued by SUMA (2012), that fired clay bricks production in the Cuitzeo territory represents an important economic sector to support its economy, it is not clear if profits of this activity remain within the area, which according to bioregionalism principles should underpin the socio-economic local development.

6.3 Input-Output energy paths of the clay brick sector

The first step of the case study Life Cycle Energy Analysis draws on the innovative development of the dynamic Mexican economic Input-Output model (Chapter 3). The NAICS code assigned for this economic activity is 327121 and is named "Non-refractory bricks manufacturing". This encoding system allows the identification of energy flows also known as energy paths in the supply chain of this manufacturing activity. According to step 6 of the research general procedure, energy paths provide an initial overview of the total energy requirements in the supply chain of this sector in order to determine both direct and indirect energy consumption.

Table 6.1 Fired clay bricks, Initial embodied energy in GJ/$MX

Sector 3271	Embodied energy GJ/$MX		
DEI or Stage 0	0.00364	**Stage 7**	0.00000
Stage 1	0.00055	**Stage 8**	0.00000
Stage 2	0.00008	**Stage 9**	0.00000
Stage 3	0.00002	**Stage 10**	0.00000
Stage 4	0.00000	**Stage 11**	0.00000
Stage 5	0.00000	**Stage 12**	0.00000
Stage 6	0.00000	**TEI**	0.00430

The above (Table 6.1), shows the total energy requirements of clay brick production in Mexico. The direct energy intensities represented at stage 0 of upstream stages involve the highest amount with up to 84.82% of these requirements, while 14.96% of the indirect energy is found between stages one and two. Thus, for clay brick production the rest of the upstream stages with 0.49% of energy requirements are not significant enough to develop life cycle energy studies with a process methodology (Appendix C shows the complete energy paths table).

According to the energy paths estimated for this activity (Figure 6.2) the two most important sectors to further investigate would be 2123 'Non-metallic ore mining' and 4841 'General freight trucking'. While the 2123 sector involves; sand, gravel, tezontle[12], tepetate[13], clay and other refractory minerals mining, the 4841 sector accounts for local transportation services. In other words, according to the results

[12] *Tezontle is a product of volcanic residues and is one the most common aggregate materials used in Mexico given its low weight.*

[13] *Tepetate is an earth material with high content of clay, also with very common use in the construction sector of Mexico.*

extracted from the Mexican IO model, the above-mentioned sectors are those that provide more energy toward the production of clay bricks in Mexico. However, even though supplier energy sectors were clearly identified according to input-output capabilities, the fired clay brick production in this bioregion belongs to an identified informal economic sector where artisanal manufacturing process use both fossil and biomass fuels. This represents a limitation to the Mexican Input-Output model developed, given that according to this methodology procedure only primary energy sources are considered. Hence, any other source of energy for the fired brick production was excluded or not identified in this model.

Taking into consideration this limitation inherent of IO models, rather than use an IO based hybrid analysis alone to estimate embodied energy, a Process-based hybrid analysis was selected, and given that, input-output analysis uses economic rather than physical units, to unify criteria analysis, MJ/Kg was chosen.

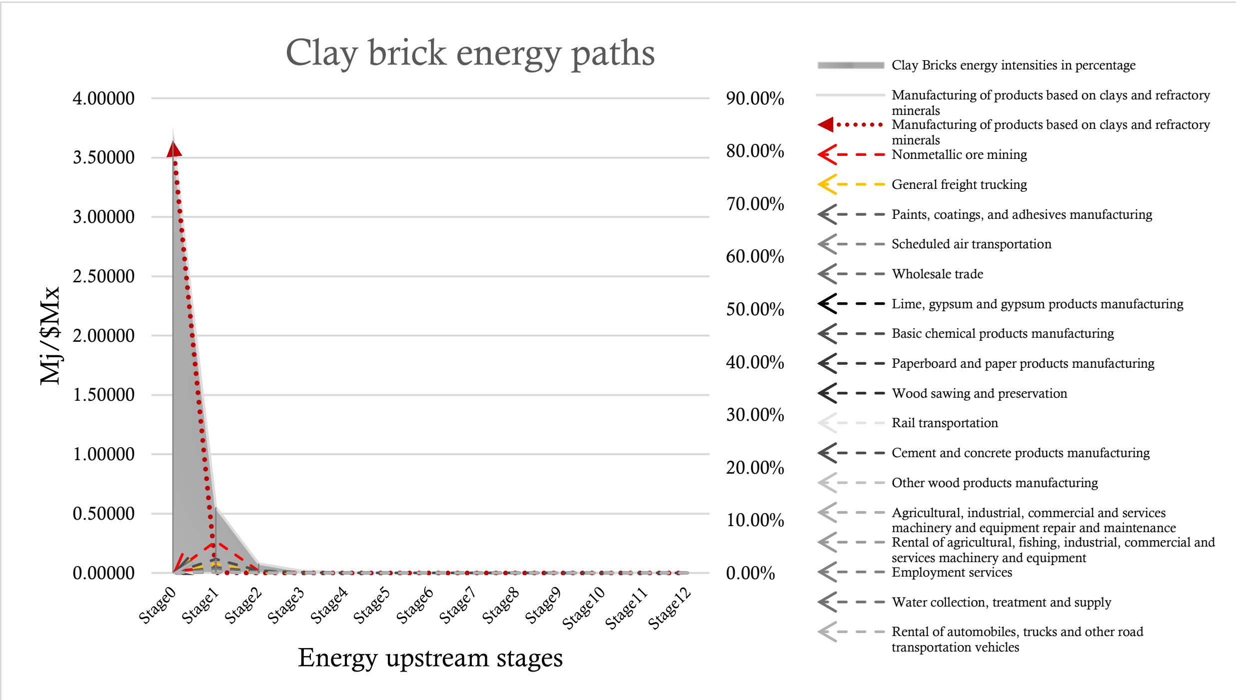

Figure 6.2 Clay bricks energy upstream stages

6.4 Availability of LCA data

After the probabilistic overview and limitations that Input-Output presented to identify energy paths in the manufacturing process of fired clay bricks, and the lack of Mexican databases in LCA as established at the beginning of this thesis, it was recognized that further data collection was needed for the case study. Hence, taking into account one of the objectives of this research process (step 7) potential participants (Local producers) were identified and approached to obtain first-hand data for this analysis and avoid uncertainty.

(Stevenson et al., 2002) have pointed out the difficulties of obtaining valuable information for small producers through postal questionnaires or telephone interviews. In this case study, the bioregional database showed that most of the potential participants do not have access to media systems (land lines-Internet access) for communication. Hence, a personalized direct approach to producers was the only option to obtain the necessary information.

6.5 Field work for data collection

Based on the identified energy paths and taking into account lessons from the literature review about time-consuming life cycle inventories, a further desktop study showed that in order to perform an efficient fieldwork, two upstream stages were enough for data collection (stage 0 and 1, in fig. 2). Thus, two people (including the author of this thesis) carried out the life cycle inventory process, (step 8) of the research process, during a month spent in several 'Galeras' located in the case study area. However, only 48 of them, which represent 47% of the total bioregional inventory decided to take part in this study.

This case study presented a major challenge for data collection given existing socio-economic and cultural conditions in this area. On one hand, there was a strong atmosphere of mistrust among brick producers in terms of delivering information about their manufacturing process. This caution was due to social instability in the bioregion and Michoacán state, where the current war between the government and drug dealers provokes side effects such as kidnapping and extortion to producers of goods and services, including the brick manufacturers. On the other hand, small local manufacturers work under poor socio-economic conditions that do not allow them access to an adequate education, thus, they ignore or barely know about the energy requirements during their manufacturing processes. Therefore, in order to deal with both technical and socio-economic problems for the efficient data gathering for this study, it was necessary to gain an immediate confidence of producers and turn their local knowledge into technical information used to perform the life cycle energy analysis later on.

Snapshot 1 Fieldwork showing informal clothing of author (left hand side)

In this study, besides the geographic identification of the Galeras, the data collectors already had knowledge about local customs in the Cuitzeo bioregion. Hence, the direct approach to producers was carried out by using informal wearing of clothing and using colloquial language to gain their trust. The owners or managers of the Galeras were asked to read the invitation letter (see invitation letter: Appendix C-3) and to sign the consent form to participate in this research (Appendix C-4). Although, initially many of them refused for fear of being identified by the local environmental agency for potential regulation violations, it was explained that information was confidential and they would not be identified in the results.

During the process of data gathering, numerous brickwork sites were visited within the bioregion and it was noticed that many of them were no longer operating. Finally, those producers who decide to take part agreed to contribute with the empirical knowledge that their daily activities gave them. In this way, rather than overwhelming them with complicated and long interrogations, they were interviewed according to the life cycle questionnaire form for data collection (Appendix C-5) with short and easy questions developed for their ease of understanding. Although some brickwork sites had to be visited more than twice, this process was successful given that once located, the respondents took only around an hour and a half to complete the questionnaire in each Galera. The delivered information allowed the performing of the energy analysis and exploration of the socio-economic environment related with this activity.

Finally, as mentioned before, although during the data collection process half of the total galeras did not provide information for this research analysis, it could be considered that the missing information does not affect the results presented in the following pages. This is because as can be seen in Figure 6.11 the bioregional galeras are located in small clusters that share the same manufacturing process and acquire the raw material from the same places. In the data collection process all the clusters of galeras have been visited. Thus, it is considered that in this research the total bioregional systematic manufacturing behaviour has been accounted.

6.6 Life cycle energy analysis

6.6.1 Context:

The seasonal manufacturing process of traditional fired clay bricks in the Cuitzeo bioregion is not so different from other places around the region, however, presents certain variations that were analysed in this study. According to SUMA (2012) and verified during this inventory taking, given that this is an artisanal activity there is not a standardized process in their production. Traditionally, manufacturing process techniques have not changed over time and technology support is practically zero. The work force of this activity often involves only family members, which help to contribute to the welfare of the family, but as mentioned before, sometimes they are not paid. The main raw materials used in this bioregion are; clay, tepetate[14], manure, water, sand and ballast, which are mostly locally available located at short distances from the brickwork sites (see Figure 6.3). These raw materials are in some cases stored outdoor subject to weather conditions in which material deterioration is very common.

Raw Material	Average Distance in Km
Clay or tepetate	1.86 KM
Black earth	4.27 Km
Sand	50.11 Km
Manure	7.86 Km
Sawdust	25.35 Km
Water	1.00 Km
Firewood fuel	22.05 Km

Figure 6.3 Average transportation distance between Galeras and Raw materials sources

[14] *The term Tepetate refers to a hardened horizon, whether compacted or cemented, which is commonly found in volcanic landscapes of Mexico. Tepétlatl derived from the Nahuatl word composed by the roots tetl that means stone and petlatl, petate. For its high content of clay, it absorbs large amounts of water, has low fertility and hardens when it loses moisture. You can find underlie the surface or emerge in some areas. Because of their features it represents a major obstacle to the development of agricultural activities, but it has some uses in the construction industry (Gama-Castro et al., 2007). Because the porous tepetate makes it an excellent material to absorb water, also it serves as insulation, in the Cuitzeo basin is used to make bricks*.

(Snapshot 2).

The predominant energy sources used in the burning process are biomass fuels; such as firewood, and sawdust, which are already residual products of the wood industry.

Occasionally coconut husks and corncobs are also used. In terms of fossil fuels, gasoline and diesel are required in less intensive processes such as mixed and prepared of clay pastes. It is also remarkable that in some parts of the bioregion, industrial waste (Old tyres) is still used for burning processes, despite the intense pollution and toxicity this creates for the workers and the ecosystem.

Snapshot 2 Biomass energy sources

Production: According to this inventory, in the Cuitzeo bioregion the average annual production is 108,020 brick pieces per Galera, which is equivalent to 2,250 square meters of walls. From the 48 Galeras interviewed for this inventory, the average burning process takes 23:30 hrs, while the average oven capacity is 12,337 bricks per burning process. During the burning process, the average waste is 445 brick pieces per Galera, equivalent to 4.4% of the production, which according to

Venta (1998) is a reasonable percentage in this manufacturing process. In general, each Galera makes nine burning processes per year, with a lower frequency between June and September given the rainy season in that area, in contrast, the industrialized brick production is steady during the entire year.

Technology: Although the manufacturing process is handmade and considered artisanal, over the years some attempts to introduce technology have been carried out in order to mitigate carbon emissions by improving efficiency in production. According to some producers, both government and researchers have proposed different solutions, such as orientation workshops, introduce of mixers, changing of furnace type and even the use of fossil fuels.

However, for many reasons none of these solutions worked and eventually the producers returned to their traditional manufacturing process. One of the producers said; "*Workshops are useless because instructors provide theoretical solutions to improve our processes, but in practice these are expensive, beyond our budget*" "*Bricks did not burn nice with gas based furnace and the resulting colour was not attractive for costumers*".

(Snapshot 3)

Nowadays, in some parts of the bioregion, the only "technology" support is found in the mixing process with the use of recovered automobile's engines, which according to them is sufficient for their production purposes.

From the 48 Galeras interviewed in the inventory, 83.33% expressed not interest at all to invest in new technology, and the rest of them intend to buy an old car engine for mixing process.

While some of the producers are not clear how more technology would be useful, the rest think that technology does not work for their manufacturing purposes.

Snapshot 3 Mixer technology, reclaimed automobiles' engines

With respect to transportation methods, 41.66 % of the producers interviewed in this study have at least one multipurpose vehicle, which was used for collecting raw materials and product delivery. The two most used vehicle types in the case study area are type A, Dump trucks, and type B, Double-wheeled pick-up (Snapshot 4). Most of these vehicles are models older than 10 years with different payload capacities and their fuel requirements are mainly Diesel and Gasoline. On the other hand, given that in the Cuitzeo bioregion, most of the brickwork sites are located at or near to clay quarries sites, it is very common that the workers themselves manually perform the digging process. Thus, only in some cases are mechanical diggers hired from time to time for this process as seen in Snapshot 4.

Snapshot 4 Transportation vehicles type A (left) and type B (right)

6.6.2 Energy analysis:

Fired clay bricks were initially analysed with a process analysis method in order to estimate their direct energy and subsequently estimate their indirect energy requirements with the input-output model developed in chapter 3. (See Equation 10)

According to the Process Analysis procedure developed by Crawford (2011), this method simplifies data collection process and reduce time in this process. The procedure uses both IO and LCA process delivered embodied energy hybrid coefficients at building material level. In this way, the potential incompleteness (truncation) that Process Analysis presents is removed and aggregation issues of IO are minimized. In order to integrate physical and economic units, both the weight and the price of clay bricks units were required. The following equations only show the process for energy analysis, but the same procedure is applied to the estimation of CO_2 in equations 10, 11, 12 and 13.

Equation 10 Process based hybrid analysis

$$\boldsymbol{EE_m} = PER_m + \left(TEI_n - \sum_{i=1}^{I}(DEI_n)\right) X\ \$mx_m$$

Where:

$\boldsymbol{EE_m}$ =	hybrid energy coefficient of the basic material in MJ/Kg;
$\boldsymbol{PER_m}$ =	material process direct energy requirement per unit of material, MJ/Kg;
$\boldsymbol{TEI_n}$ =	total energy intensity of the input-output sector n, representing the material in MJ per $mx;
$\boldsymbol{DEI_n}$ =	direct energy intensity of the input-output sector n, representing the material production process in MJ per $mx;
$\$\boldsymbol{mx_m}$=	total price of the basic material.

Equation 11 PERm

$$\boldsymbol{PER_m} = E_{mp} + E_{mt}$$

Where:

$\boldsymbol{E_{mp}}$ =	direct energy requirement of the manufacturing process per unit of material, MJ/Kg;
$\boldsymbol{E_{mt}}$ =	represents embodied energy of material transportation;

Equation 12 Emp

$$E_{mp} = \sum_{i=1}^{N} ft_i\ XfEE_i + E_O$$

$\boldsymbol{E_{mp}}$ =	direct energy requirement of the manufacturing process per unit of material, MJ/Kg;
$\boldsymbol{N}$ =	represents the number of manufacturing processes;
$\boldsymbol{i}$ =	is the manufacturing process of concern;
$\boldsymbol{f_t}$=	type energy source used in the manufacturing process;
$\boldsymbol{fEE}$=	for calorific value of energy source in MJ.
$\boldsymbol{E_o}$=	operational energy.

Equation 13 EE by transport

$$E_{mt} = \sum_{i=1}^{N} S_w \, X \, T_t \; X \, tl_1 \; X \, 2d_i \, X \, fc_i \, X \, fEE_i$$

Where:

$\boldsymbol{E_{mt}}$ =	represents embodied energy of material transportation;
$\boldsymbol{N}$ =	represents the number of materials;
$\boldsymbol{i}$ =	is the material of concern;
$\boldsymbol{S_w}$=	Specific weight of material of concern;
$\boldsymbol{T_t}$=	Transport type payload capacity;
$\boldsymbol{tl}$ =	for the number of truck loads;
$\boldsymbol{d}$ =	for the distance travelled from the extraction site to the manufacturer or from the manufacturer to the delivery point in Km;
$\boldsymbol{f_c}$=	for truck fuel consumption, (l/km);
$\boldsymbol{fEE}$=	for fuel calorific value, MJ/l.

6.6.3 Results:

According to levels of energy analysis described in section 2.2.1, this study covered two upstream levels with a cradle to gate system boundary, which represents extraction of raw materials, transportation and energy sources used in the manufacturing process. The winning process in this bioregion is a hand made activity and the rest of the raw materials are sub-products of other processes. Hence, the main process in fired clay bricks and the supply of the raw materials were subject to this analysis and the indirect energy is taken from IO according to equation 1 procedures.

The obtained results are presented below in Table 6.2, showing bioregional statistics of this manufacturing process (full lists of results are located in Appendix C-2).

Table 6.2 Bioregional Embodied Energy & Fuels of fired clay brick production

Embodied Energy, Bioregional Statistics of Fired Clay Bricks – MJ/Kg				
No. records	Average EE	Standard Deviation	Maximum EE	Minimum EE
48	3.09	1.78	8.64	1.07

Feedstock/Fuels Breakdown by main process - %								
	Firewood	**Sawdust**	**Gasoline**	**Diesel**	**Electricity**	**Tyres**	**Coconut shells**	**Other**
Per Galeras	91.66	22.91	33.33	10.41	12.50	10.41	6.25	10.40
Bioregional	85.74	12.74	1.25	0.14	0.11	0.01	0.00	0.00

In accordance with the initial IO analysis, the direct energy used during the main process or upstream stage 0 presented the largest energy requirement in the manufacturing of traditional fired clay bricks with 95%. On the other hand, stage 1 required of 3.23% of the total energy requirements. The distribution of the embodied energy in MJ/Kg per brickwork site is shown in Figure 6.4, where 3.09 MJ/Kg is the bioregional mean with 62.5% of the Galeras below this value. The maximum record of embodied energy was 8.64MJ/Kg and the minimum 1.07MJ/Kg with a standard variation of 1.78.

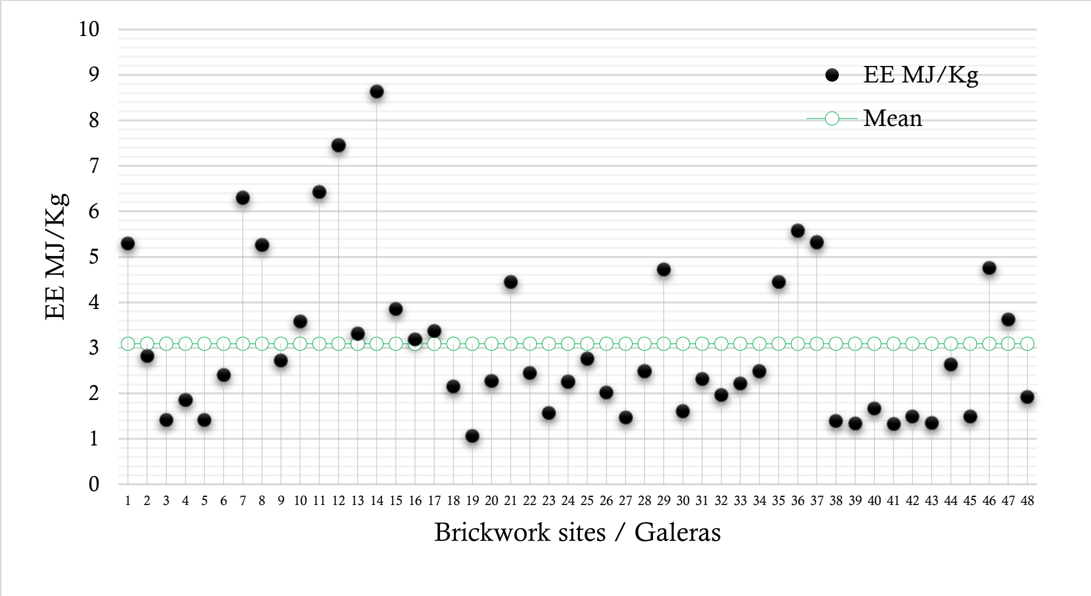

Figure 6.4 Scatter graph of Bioregional Embodied Energy in clay brick production

In this study, the estimation of energy consumption by the transportation of raw materials and the delivery of the final product (Clay bricks) was initially carried out through a process energy requirement methodology using direct information provided by the Galera's owners. The estimation of embodied energy in transportation (Equation 1) varied significantly from material to material according to different factors such as their specific weight, transport type, load capacity, fuel used and distance. The rest of the indirect energy requirements were derived from stages 2-12 of the input-output model.

Although, the scope for this case study (Cradle to Gate) considered the embodied in transportation involved all those raw materials supplied to the brickwork sites, an additional estimation in transportation for the delivery of clay bricks was also developed for a further analysis (see Table 6.3). Taking into consideration all the factors described above, it is estimated an average of 1.76MJ/tonne/km is needed for transporting units, which are diesel based and 1.57MJ/tonne/Km for gasoline based vehicles. However, in transport units with a larger payload capacity this energy requirement may decrease to 0.85MJ/tonne/km.

Table 6.3 embodied energy of Materials by transport type

Material	Weight Volumetric	Unit	Transport type	Capacity	Unit	Transport Total capacity	Unit	Transport Fuel type	Tank Capacity Litres	Km/Litre	LT/Km	Fuel MJ/Lt	MJ/km	MJ/tonne/Km	Co2Kg/Lt
Tepetate	1300	Kg/m3	A	7.00	m3	9.10	Ton	Diesel	200	2.5	0.4000	36	14.40	1.58	2.6
Tepetate	1300	Kg/m3	B	2.69	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Tepetate	1300	Kg/m3	B	2.69	m3	3.50	Ton	Diesel	140	6	0.1667	36	6.00	1.71	2.6
Tepetate	1300	Kg/m3	A	14.00	m3	18.20	Ton	Diesel	200	2.5	0.4000	36	14.40	0.79	2.6
Sawdust	300	Kg/m3	A	7.00	m3	2.10	Ton	Diesel	200	2.5	0.4000	36	14.40	6.86	2.6
Sawdust	300	Kg/m3	B	11.66	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Sand	1500	Kg/m3	A	7.00	m3	10.50	Ton	Diesel	200	2.5	0.4000	36	14.40	1.37	2.6
Sand	1500	Kg/m3	B	2.69	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Clay	1750	Kg/m3	A	7.00	m3	12.25	Ton	Diesel	200	2.5	0.4000	36	14.40	1.18	2.6
Clay	1750	Kg/m3	B	2.00	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Ballast	1350	Kg/m3	A	7.00	m3	9.45	Ton	Diesel	200	2.5	0.4000	36	14.40	1.52	2.6
Ballast	1350	Kg/m3	B	2.59	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Pine wood	500	Kg/m3	B	7.00	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Oak wood	600	Kg/m3	B	5.83	m3	3.50	Ton	Gasoline	140	6	0.1667	32	5.33	1.52	2.3
Clay brick	3.4	Kg/piece	B	1000.00	piece	3.40	Ton	Gasoline	140	6	0.1667	32	5.33	1.57	2.3
Clay brick	3.4	Kg/piece	B	1000.00	piece	3.40	Ton	Diesel	140	6	0.1667	36	6.00	1.76	2.6
Clay brick	3.4	Kg/piece	A	5000.00	piece	17.00	Ton	Diesel	200	2.5	0.0000	36	0.00	0.85	2.6

6.6.4 Bioregional Embodied Energy high and low values

Given that in embodied energy studies there is no precedent to set high or low limits for rating systems (Gavotsis and Moncaster, 2014), an arbitrary embodied energy factor of ±1.42MJ/Kg has been initially selected taking as a reference the bioregional average of 3.09MJ/Kg of the sample and 20% factor of the standard deviation. In this way Embodied Energy threshold, limit values (Eev) within a range of 2.84MJ/Kg are established as a baseline in environmental indicators for possible regulations, in this case study area.

Once the threshold factors were set up, the results showed that 58.33% of the bioregional brickwork sites were located within the mean range, 16.66% above the established limit and 25.00% presented of them are located under the low threshold value. Thus, for the purpose of this study the above results should be only considered as temporary given the limited basis on which the deviation level was established.

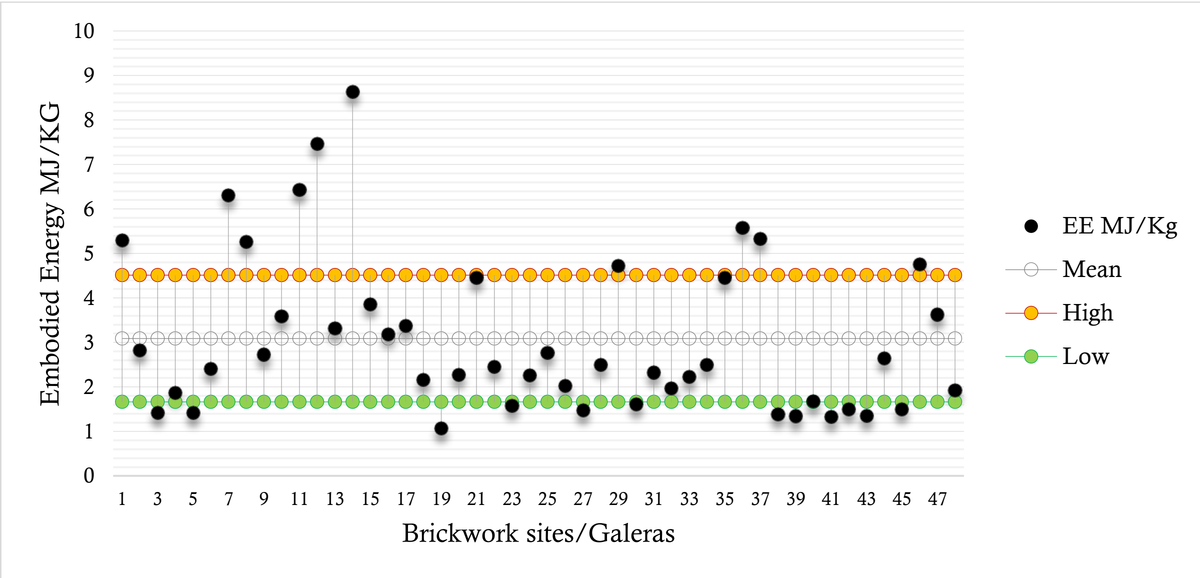

Figure 6.5 Bioregional Embodied Energy Threshold Values

6.7 Mapping embodied energy and spatial representation of results

6.7.1 Method

According to Pullen (2007a), the representation of values as presented in Table 6.2 and shown in Figure 6.4 is criticized in LCA given that they are deterministic and present only mean values for the embodied energy of the analysed construction material. Therefore, the deterministic approach is not enough to provide information about the uncertainty or distribution of individual embodied energy coefficients, which could mislead in the process of decision making to establish environmental policies. In this bioregion area, it is expected that even slight variations in the manufacturing process, transport, etc, of traditional fired clay bricks could be a key factor to understand in a deeper way problems associated with this activity.

Thus, in order to test how the proposed spatial model could display embodied energy factors and after the embodied energy is estimated, the obtained results in excel spreadsheets have been incorporated in the bioregional life cycle inventory (database) through the NAICS code system and the geographical location (latitude & longitude) in which each Galera is identified. This step was to visualize different stages of the manufacturing process in thematic maps in order to identify patterns of energy requirements and the environmental impact within this place. This process is presented below.

The embodied energy results were interpolated through GIS Spatial analysis using the inverse distance weighted (IDW) technique (Equation 14, below) to display this local categorization into thematic maps that later could be used as a baseline for indicators of sustainability. IDW is a deterministic interpolation method used for spatial analysis in order to determine cell values using a linearly weighted combination of a set of sample points of a variable (ArcGIS, 2003). In other words, this method is used to estimate the unknown EE values in any point of the bioregion given the obtained EE results at the sampled location (Galeras). For this spatial analysis, there are several methods to perform these types of analysis, and for the purpose of this study IDW was selected because it is straightforward to interpret (Lu and Wong, 2008).

Equation 14 Inverse Distance Weighted

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i \, Z(s_i)$$

Where:

$\hat{\boldsymbol{Z}}(\boldsymbol{S_0})$ =is the value we are trying to predict for locations_0;

$\boldsymbol{N}$= is the number of measured sample points surrounding the prediction location that will be used in the prediction;

$\boldsymbol{\lambda_i}$ = are the weights assigned to each measured point that we are going to use. These weights will decrease with distance;

$\boldsymbol{Z}(\boldsymbol{s_i})$ =is the observed value at the location s_i.

On the other hand, in the spatial representation in thematic maps symbolised is more appropriate to show the use of energy fuels within the bioregion, the embodied energy per Kg, per Piece and per Burning process to finally display the total annual average energy requirements and its carbon emissions.

6.7.2 Spatial embodied energy representation

6.7.2.1 Embodied energy per Kg

In a building material's embodied energy estimations, the most common embodied energy unit is expressed in physical units (Megajoules of energy required to produce a Kg of clay bricks) given that it is used for comparison and standardization purposes. As seen before, the process based hybrid analysis showed 3.09 MJ/Kg as an average embodied energy value throughout the bioregion with a standard deviation of 1.780. However, within the bioregion, the following Figure 6.6 displays this differentiation more appropriately between regional brickwork sites, identifying the surroundings of Zinapécuaro city as having the highest embodied energy consumption with up to 8.55MJ per Kg, while in the northern part of the bioregion, significantly lower embodied energy values are identified with a range of 1.45-2.31MJ/Kg.

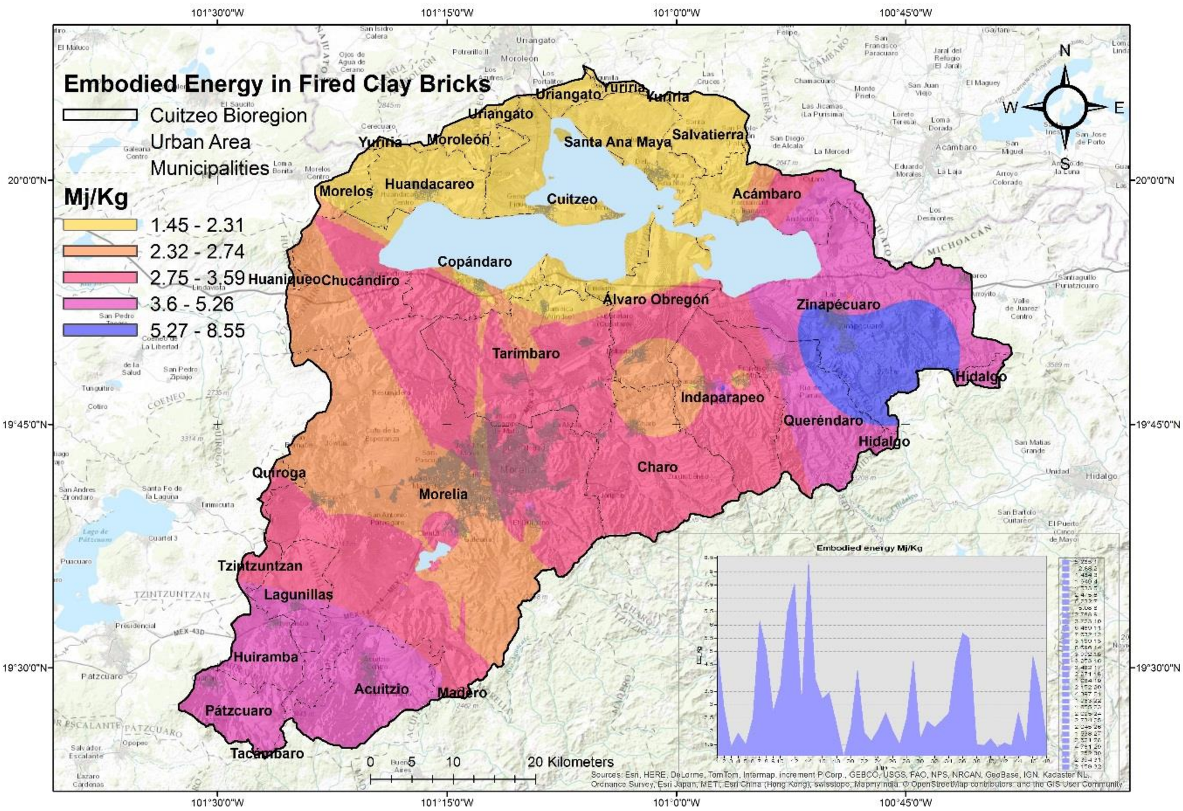

Figure 6.6 Embodied energy map of clay bricks expressed in MJ/Kg

The map also shows that the average embodied energy is geographically distributed mainly in the central part of this region where the locations such as Indaparapeo, Jesus del Monte, Santiago Undameo and Tenencia Morelos present similar energy consumption levels in a range from 2.75 to 3.59Mj/Kg. These locations are also, where more brickwork sites are located. As mentioned before the average Embodied energy estimation in MJ/Kg in this area is consistent with other international studies (see discussion section Table 6.4). However, in most of these studies, geographical considerations are not taken into account, the manufacturing process is not clear and the breakdown of energy sources is not identified. This study validates the previous findings, with much greater precision and detail. Thus, the implications of represent the EE in MJ/Kg in this type of map are; 1) it allows the clay brick consumers the opportunity to easily visualize potential best options to choose a low energy clay brick product. 2) it shows to local policy makers, potential brickwork sites that can be targeted to improve their manufacturing practices.

6.7.2.2 Energy sources:

As had been previously estimated, firewood and sawdust are the main sources of energy used in the main process of brick production. The map below (Figure 6.7) shows the breakdown distribution of their demand within the region. All these sources of energy are responsible for the so-called direct energy in the brick production. The size of the pie charts represents the quantity of energy used, while their colours represent the proportion of each energy source used by producers. It should be noted that that firewood is used all over the region with the exception of the North part (N) of the bioregion in the location of Santa Ana Maya, where sawdust is the main raw material for burning process. This place is also notorious for the use of diesel and industrial waste (old tyres) to assist in the ignition of sawdust.

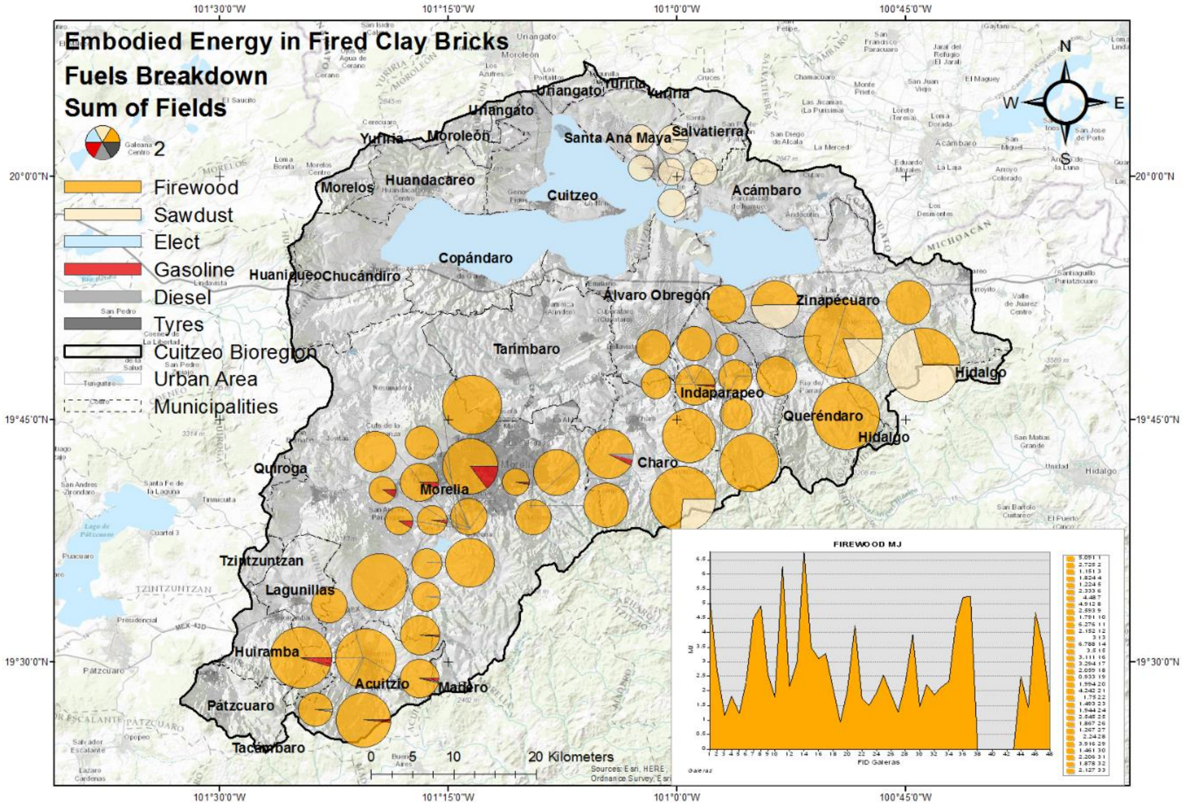

Figure 6.7 Embodied energy map of fuels breakdown

On the other hand, gasoline is used mostly in the central area of the bioregion (around Morelia) and in some brickwork sites of the Acuitzio town (SW). The requirement of this fossil fuel is mainly due to the use of old car engines for mixing process as previously mentioned. In the production of clay bricks within this bioregion, the use of electricity is not significant given that the production process does not require it. Other biomass energy sources such as cobs and coconut husks are used in the northeast (NE) of the bioregion. However, their quantities are irrelevant within the clay brick lifecycle. Finally, according to the size of the pie charts is clear that Zinapécuaro (NE) and Acuitzio (SW) are the places where clay brick producers consume more energy, which in this case is associated to bricks physical dimensions.

Overall brick producers use biomass energy sources because it is cheaper than fossil fuels. However, given their economic capabilities, they consider that biomass is also expensive, but this type of energy source can be found not so far from brickwork sites. The main reason to use firewood and sawdust is by tradition because it is what their parents taught them. Even though the clay brick production in the Cuitzeo bioregions is based on the use of firewood, a quarter of the producers are using additional the sub products already mentioned. However, this is not a widespread practice. Unfortunately, the use of industrial waste products such as old car tyres is still a common practice within the area, all these sub-products are used in the clay' burning process.

Although, most brick producers are using biomass in the manufacturing processes, they think this is expensive. In the past Gas and Diesel were used, but the increase of prices and the lack of identification with traditional processes act as disincentives.

6.7.2.3 Embodied energy per Brick

As expected, the energy requirements to produce a brick in the Cuitzeo bioregion vary significantly from place to place given the wide range of brick physical dimensions (MJ/Kg*size). Figure 6.8 shows clearly this differentiation in embodied energy, which is expressed in mega-joules per brick, and whereas the regional average is 9.37, the standard deviation is 6.21MJ.

Although, it seems obvious that the embodied energy content on a piece of a brick is related to its physical dimensions, standardization practices in LCA mostly consider this energy in MJ/Kg as represented in Table 6.2 and seen in Figure 6.6. However, the fact is that Clay brick consumers are most interested in the energy/size of the brick rather than its energy/weight content. Given that during the data collection process of this research both weight/dimension and unit price were asked to the participants (see appendix C5), both energy per price and weight has been accounted. Thus, when we see Figure 6.8, which represents the embodied energy per piece, the selection process of a low energy product could well change. The light yellow colour represents a more practical way to display the best places within the area, where brick consumers can obtain a low energy product.

Within the bioregion, two areas are clearly identified where more embodied energy per brick is required. The first spot is located again in the East part of this region, around the location of Zinapecuaro where there are bricks containing up to 28.75Mj and the second spot is identified in brickwork sites in the location of Acuitzio with an average of 15.10Mj/brick. Finally, the map below shows what the energy requirements per brick in the rest of the bioregion could be expected. The locations in the North are those, in which the lowest values 4.3-7.03MJ/Brick are found, while the central part of the region (Morelia city) present embodied energy levels according to the regional average.

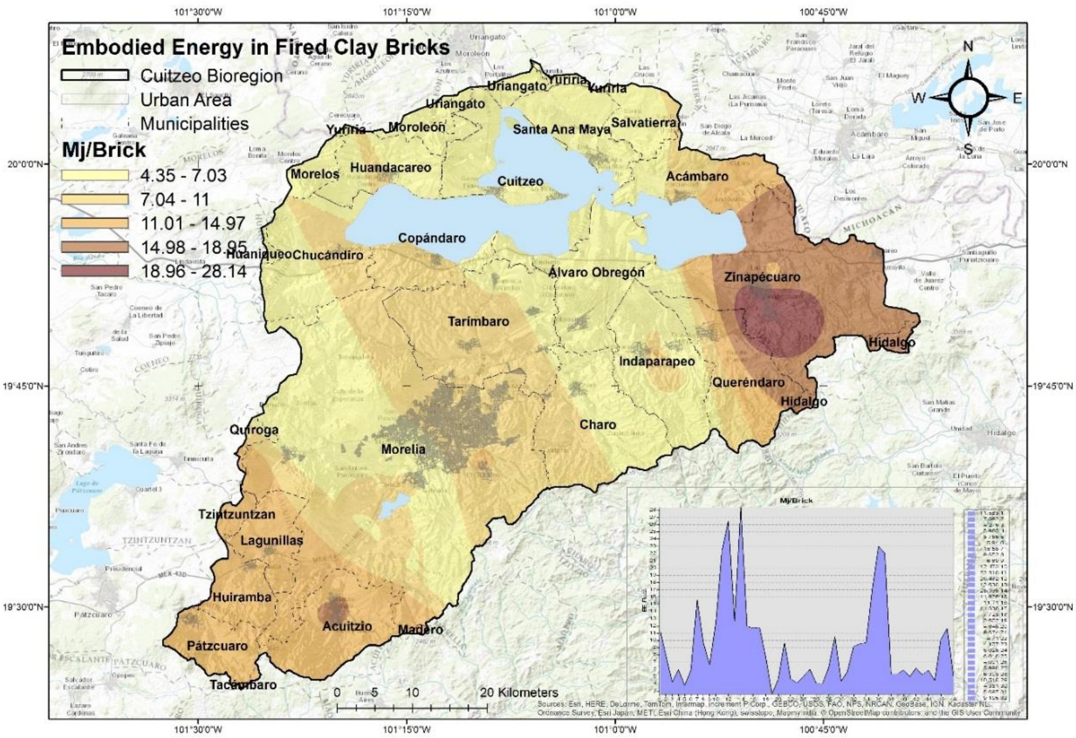

Figure 6.8 Embodied energy map MJ/Brick

6.7.2.4 Burning process:

The energy used during the manufacturing burning process represents the largest embodied energy of clay bricks in this area. Within the bioregion, the average energy consumption is 94.070GJ per burning process, while the standard deviation is 63.890GJ. The following map (Figure 6.9) depicts more appropriately the current pattern of this process in the region. The eastern part of the bioregion is the one with a higher consumption of energy with up to a maximum of 397.23 GJ required per burning process, given that in this area is where both firewood and sawdust are used together for this purpose (Figure 6.7). On the other hand, the lowest average energy requirements are located around two areas; Santa Ana Maya (N) and Acuitzio and Santiago Undameo (SW). In both places, the low energy is directly associated with their low brick production and the small kiln capacity.

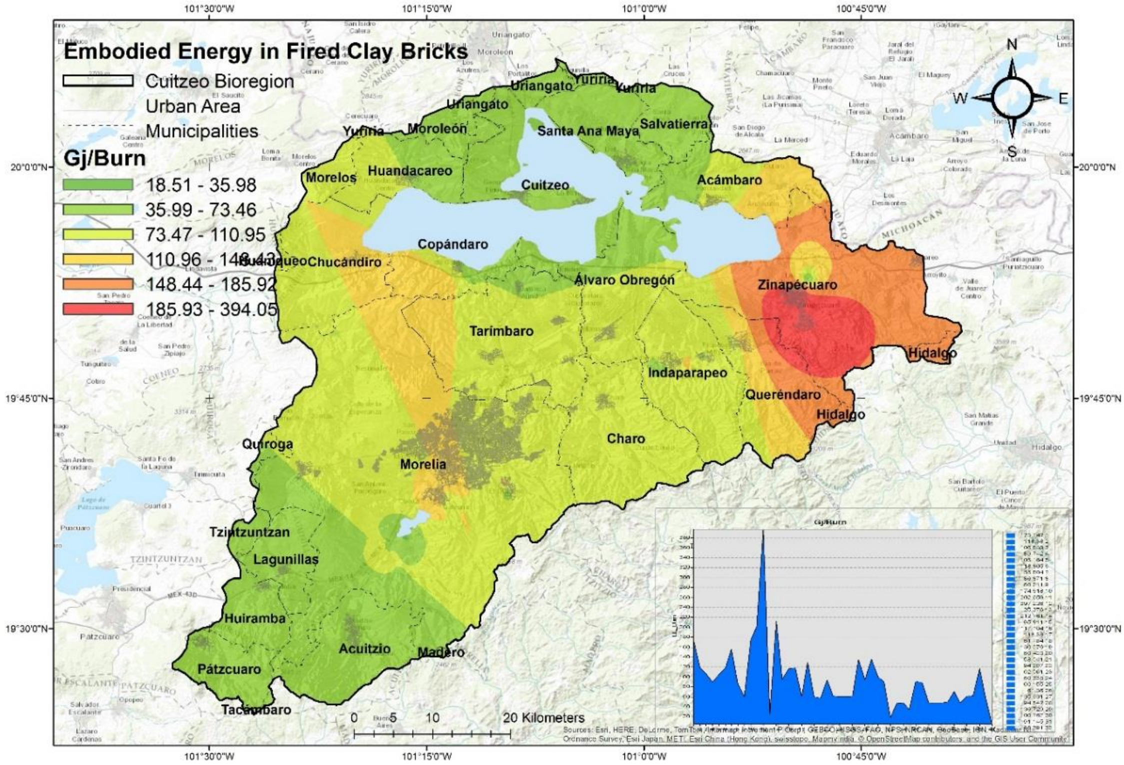

Figure 6.9 Embodied energy map GJ/Burn

6.7.2.5 Embodied energy by transportation:

As would be expected in terms of transportation, the use of local raw materials and short transport distances to brickwork sites, (see appendix) the energy requirements for this stage represent only 3.23% of the total annual embodied energy in the production of clay bricks in this bioregion.

Unlike the above maps, where high-energy patterns are clearly identified in the main process, Figure 6.10 indicates those places where the energy consumption in transport is not so large. For example, around Acuitizio Galeras (SW), the average energy transportation is found within an average of 3.39GJ per year, while brickwork sites located in Indaparapeo (red spot), the energy consumed by transport activities is the largest in the bioregion with an average of 44.32GJ/year.

The main reason is because about 60% of producers do not possess their own transport vehicle and in this way they depend completely on external transportation services. This also has significant economic implications given that the price of bricks is reduced to the carrier, who becomes an intermediary of the product. These intermediaries end up producing more profits than the producers themselves do.

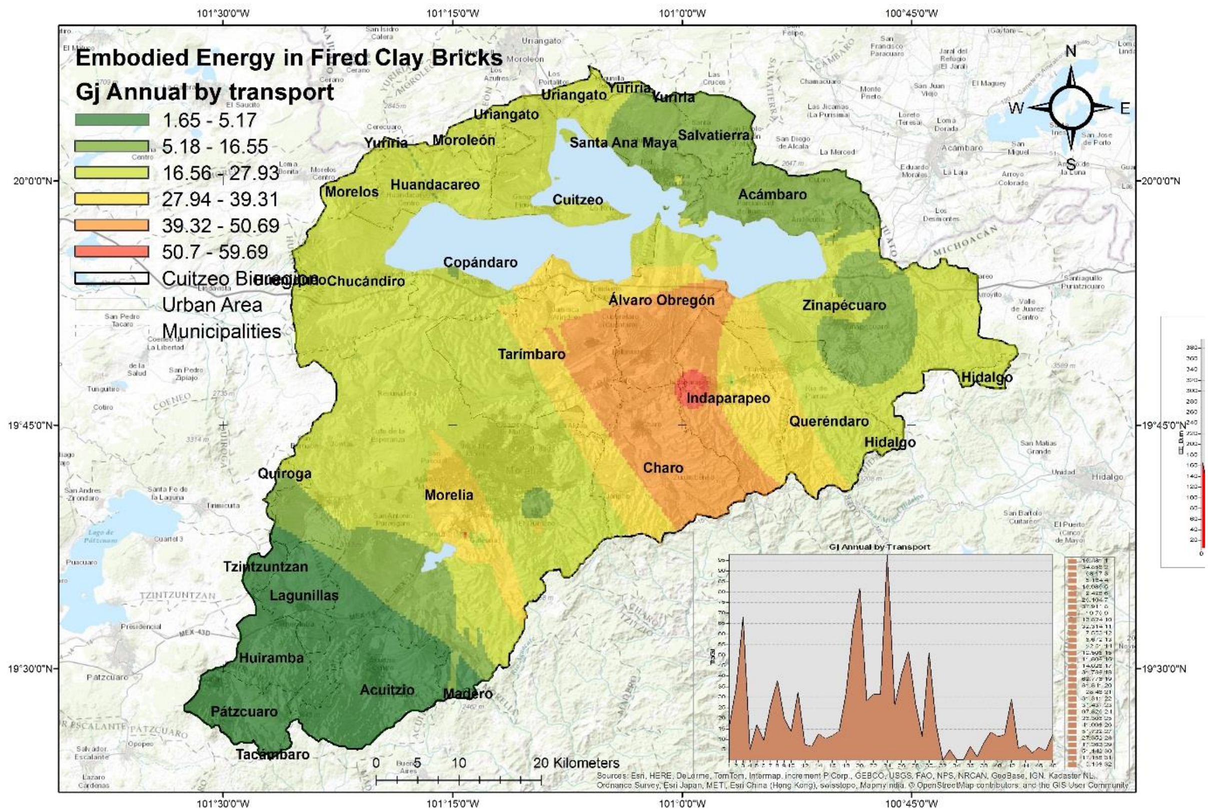

Figure 6.10 Embodied energy map of annual transport in GJ

6.7.2.6 Bioregional annual energy requirements:

Figure 6.11 next page displays the average energy requirements during a year period by fired clay brick production activities in Cuitzeo bioregion. The total energy consumption estimated for the 48 Galeras/Brickwork sites analysed was 40447.85GJ, with a bioregional mean of 842.66GJ per Galera. Hence, if the 102 Galeras identified are considered, it can be estimated a bioregional total energy requirements of 85951.32GJ per year for brick production.

Although the map is not displaying this figure, it can show the energy patterns that missing Galeras would present. The schematic representation of the Galeras, inside and outside of the bioregion are also depicted in this map, where even though they are dispersed through the area the obtained data represent the total geographical area. Basically, the east (red/orange) area of this bioregion is where in general more energy is consumed by brick producers, while green dark areas would be those places of the bioregion with lower energy requirements.

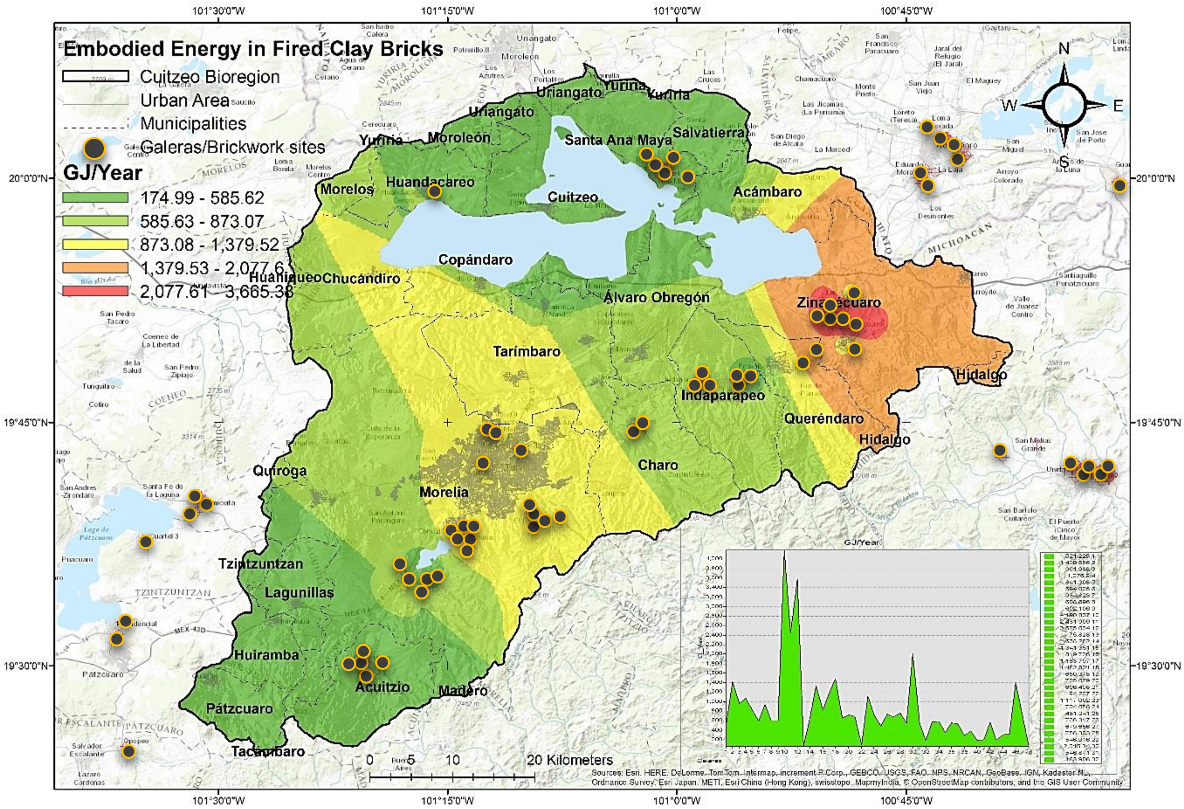

Figure 6.11 Embodied energy map GJ/Year

6.7.2.7 Bioregional annual CO2 emissions:

Finally, the following map Figure 6.12 represents the environmental impact of the 48 Galeras analysed within the case study area. This estimation did not include any greenhouse gases other than CO_2 and is expressed in tonnes per year. 4753.21 of total/tonnes of CO_2 per year was estimated, given in this way an average of 99.025 tonnes of CO_2 per Galera. As would be expected and consistent with the previous map the same geographical pattern is presented. A range of 153-380 tonnes of CO_2 is released every year in the east of the bioregion, while the North and the Southwest will show a range of 21-72 tonnes of CO_2 per year. In this way, if the average is extrapolated to the rest of the brickwork sites identified in this bioregion an approximate grand total of 10,100.55 tonnes of carbon dioxide emissions is released annually by this manufacturing activity.

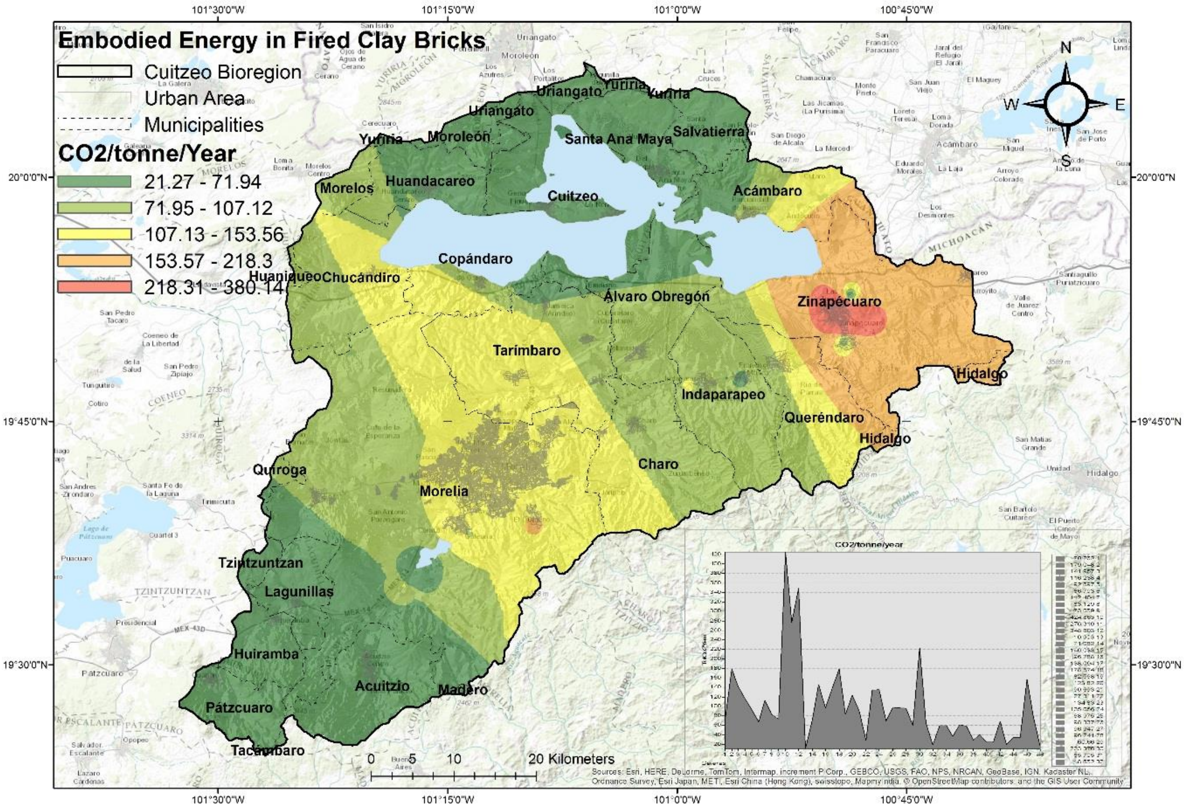

Figure 6.12 Embodied energy map CO2/tonne/Year

For a better understanding of the above map, the small histogram of results located at the right/bottom of the map is extended below:

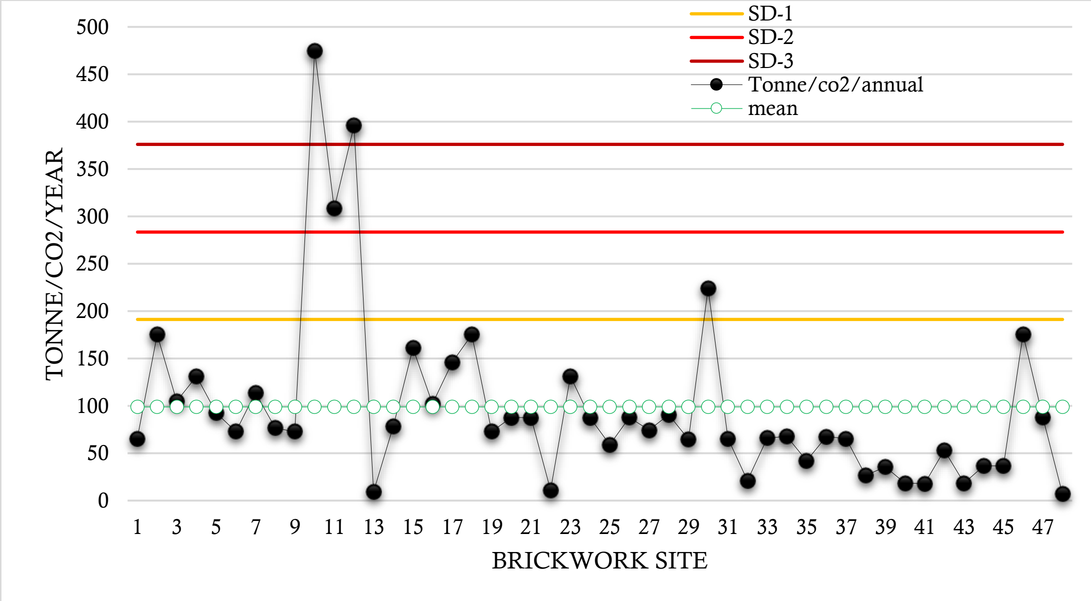

Figure 6.13 Histogram of annual tonnes of CO2 emissions

This figure shows annual tonnes of CO2 per Galera/Brickwork-site and the green dot/line is the already mention mean with 99.025 tonnes of CO_2 per Galera. The first yellow line (SD-1) represents one standard deviation, the second red line (SD-2), two standard deviation and (SD-3) three standard deviation. In a normal statistical distribution, the Galera located between SD-1 and SD-2 indicates that this producer is releasing more than the bioregional normal amount of CO_2 emissions, while Galeras located between SD-2 and SD-3 represent even higher quantities, Galeras above of SD-3 are performing extremely bad in terms of tonnes of CO_2 emissions per year.

The above map is a good example how the geographical visualization of the results could lead to take better decisions in LCEA, where some mitigation actions should be done to reduce the producers CO_2 manufacturing emissions. However, during the data collection process, in this bioregion only 54% of the producers said that they are aware of the environmental impact associated with their manufacturing processes, 39.58% of these producers rejected this fact and 6.25% just ignore it, arguing that this process has been done for many years and nothing bad has happened.

6.7.2.8 Summary of maps and results

The group of thematic maps presented above proved the capabilities of the newly developed SLCEM to display embodied energy intensities in different steps of the manufacturing process of a non-industrialized building material. The use of geostatistics (IDW) also proved to be of great help to interpolate and display geographical EE results when data is missing or not collected.

The data visualization approach complements the typical representation of values in LCAE, simplifying the understanding of embodied energy coefficients as a baseline for decision makers in environmental policies. However, for sustainable purposes, the results could only be moderately interpreted, given that they only show a technocentric representation of problems associated with the manufacturing process of fired clay brick in the Cuitzeo bioregion, without quantifying social problems.

On the other hand, the LCEA provided interesting results, which are summarized next;

- Fired clay brick is the second most intensive energy supplier material found within the Mexican built environment.
- In the Cuitzeo bioregion, the average annual production is 108,020 brick pieces per Galera, which is equivalent to 2,250 square meters of walls.
- The average embodied energy in fired clay bricks in the Cuitzeo bioregion is estimated in 3.09 MJ/Kg, which is a similar figure to other studies in different countries (see discussion section), however, this figure should be only considered for comparison within the case study area.
- 98.48% of the total energy requirements in the manufacturing process of fired clay bricks in the case study area come from biomass energy sources, which is considered good because fossil fuels are not consumed in this specific bioregion.
- Annually, the embodied energy estimated in the transport of this material (cradle to gate) represents 3.23% of the total energy requirements. This low percentage shows how the use of only bioregional raw materials can play

an important role to reduce EE in transportation. In this case study, it is possible that clay bricks could be sourced from further afield rather than the most polluting galeras within the bioregion.

- From the 102 brickwork sites located in this bioregion, it is projected a total of 85951.32GJ energy requirements per year.
- An estimated equivalent of 10,100.55 tonnes of carbon dioxide emissions are released annually by this manufacturing activity. However, the informality of this activity can produce higher or lower emissions, which are difficult to estimate.
- The labour daily income wage for that area is only $51.95 Mx, equivalent to $3.91 USA dollars or £2.02 UK pounds per day, which clearly shows the poor economic conditions in which this activity is developed.
- 81.25% of brick producers say that this is not a profitable business and only 4.17% of them are optimistic about the future of this manufacturing activity.

The discussion of EE and visualization results are presented in the following section.

6.8 Discussion of this chapter

6.8.1 About the analysis method

As pointed out at the beginning of this research the IO based hybrid analysis method was identified as the best option to perform embodied energy estimations for the purpose of this thesis given the capabilities of the revised Mexican IO model and the lack of a Mexican database in terms of embodied energy in building materials. These type of databases are usually built based on traditional process analysis methods (LCA), an example of this is the Inventory of Carbon & Energy developed in the UK by Jones (2010).

However, during the analysis of the bioregional-fired clay bricks manufacturing, the initial analysis method was reconsidered after the examination carried out in section 3.4, which indicated that the split of energy sources would not be properly identified by means of the IO model. Therefore, it was decided to change the procedure method to a process based hybrid analysis. It does mean that rather than performing a top-down process analysis, it was necessary to perform a bottom-up approach. In simple words, it was necessary to perform a physical life cycle inventory within the bioregion area and to collect first-hand data.

In this step, the identification of energy paths in the IO model speed up the process of gathering data from local brick producers in spite of their lack of knowledge in energy matters. The delivered information allowed the energy analysis estimation procedure and the understanding of the production context. However, for energy analysis, the obtained empirical information had to be converted into technical data. This process took longer than expected given that all type of conversions were required as shown in section A of the “LCI Data collection Form” (see Appendix C-5). For example, when a brick producer was asked about the quantity of any input (raw material), the producer was free to answer in any unit (Kg, Lts, M^3 , etc.), if he/she did not know the exact quantity, the cost of the material and the capacity of the delivered transport were enough. The same principle applied to time periods (Year, month, week, etc,).

The flexibility of the data collection form was designed to facilitate the interaction with illiterate brick producers, and given that in embodied energy hybrid methodologies both physical and monetary data are required, any answer was valuable. Thus, the desk work was addressed to unify criteria in energy units.

As shown in section 6.6.3, results in energy analysis of any building material based in process and process hybrid analysis (LCA) are generally presented in physical units (MJ/Kg) in order to be used for product comparison. However, the accuracy of this type of analysis will be always lower than IO based hybrid analysis as pointed out by Crawford (2008). The accuracy of results in hybrid methodologies is still a constraint to validate embodied energy, this limitation in reliability depends on the level of inventory and sources of data to perform the energy analyses.

Crawford is one of the few researchers who has attempted this type of validations with a method called "Gap analysis" addressed to assess IO based hybrid methods; however, this authentication technique is still dependent on IO completeness. Given that in this research a PA based hybrid method is used, the gap analysis is not considered, instead of this, Crawford suggests a comparative analysis between the two main methods.

In this research, the comparative analysis is presented in a logarithmic chart (Figure 6.14), where it is clear (more points located in the top and left side of the graph) that the reliability of this study depends on embodied energy intensities obtained from the data collection inventory/PA and not only from the IO model. As mentioned before, given that the Mexican IO model does not account energy from biomass sources it was necessary to support the estimations in the hybrid analysis with first hand data (energy in physical and economic units) from clay brick manufacturers. According to Wan Omar et al. (2014, p.32) in this type of analysis, PA determines the reliability of data to overcome limitations and to reduce uncertainties in hybrid results.

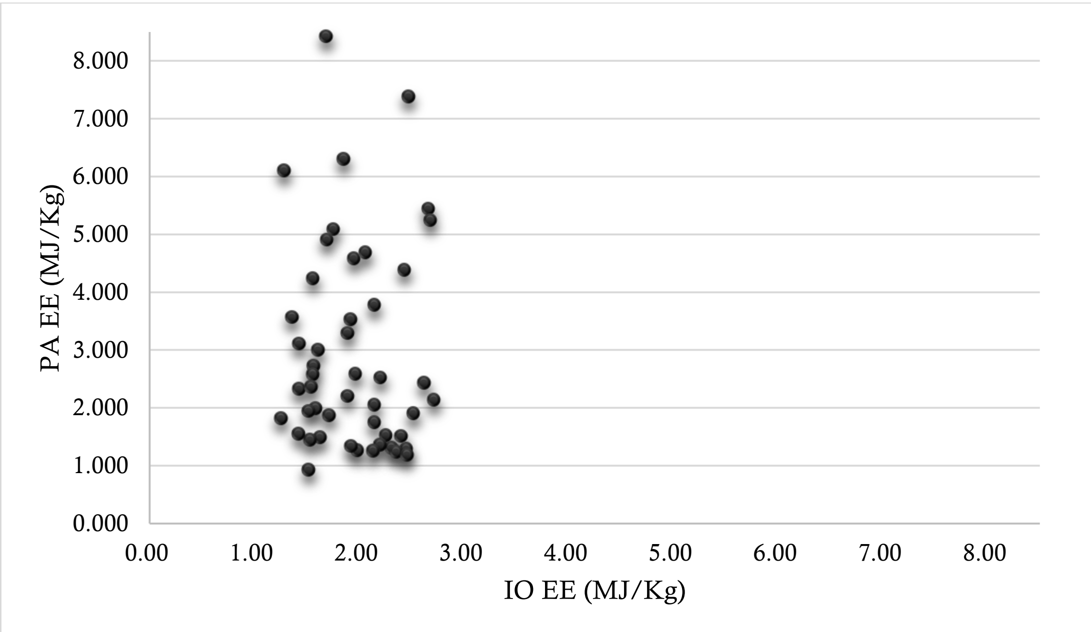

Figure 6.14 Logarithmic comparison between PA and IO embodied energy results

However, in the literature, embodied energy results have shown significant variations due to several considerations such as energy sources, and manufacturing processes that are used in every industry, region or country. The inconsistency of these factors to compare results has been already explained in chapter two and is widely identified by different authors where even the chosen methodology provides different results (Dixit et al., 2010, Crawford, 2011, Pullen, 2007a). As an example of these inconsistencies is an earlier work of the above metioned authors (Wan Omar et al., 2012), where indirect energy was obtained from Malaysian IO tables and Direct energy was obtained from a UK database (Hammond and Jones, 2011).

In this study, unfortunately, inconsistency is not an exception, given that in theory, a simple IO analysis would provide higher embodied energy results than a traditional process analysis and lower results than a process based hybrid analysis as shown in Figure 2.3, Section 2.3.6 of this thesis. However, as can be seen below in Figure 6.15, in this study, process analysis provided higher EE results than the simple IO analysis method in each brickwork site, highlighting in this way, the discrepancies previously described.

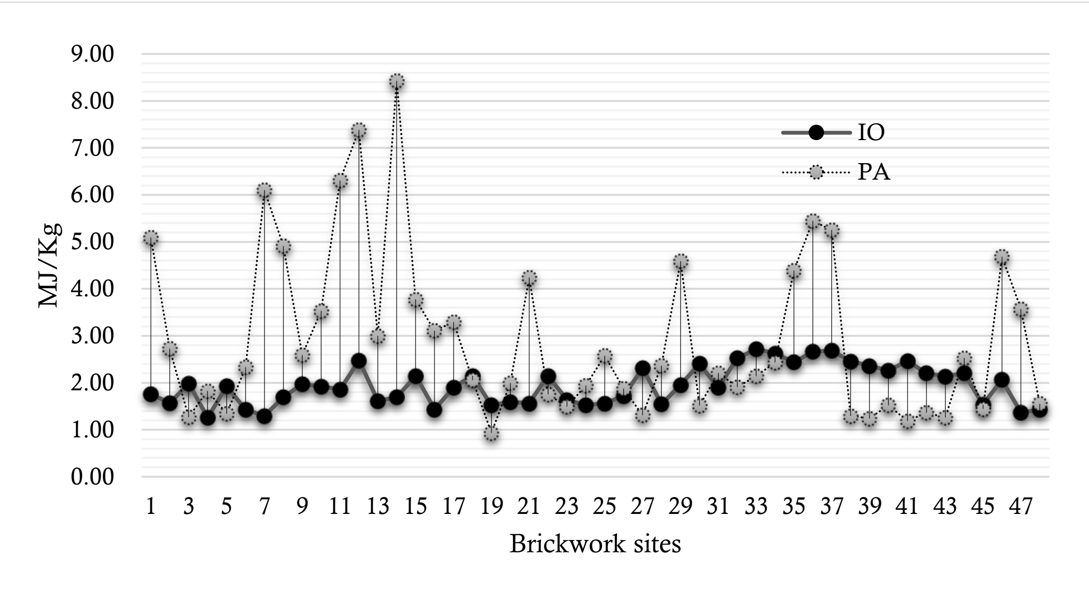

Figure 6.15 Comparison between PA and IO embodied energy results by individual Galeras

Figure 6.16 below shows, the bioregional average variation of results once the PA based hybrid method was incorporated. It was estimated an average 1.95 MJ/Kg in IO, 2.94 MJ/Kg in PA and 3.09 MJ/Kg in PA-IO. This chart shows a 33.67%

of results variation between PA and IO, and 36.90% between PA-IO and IO. According to Table 2.1 presented in Chapter 2, the potential variation of results between IO and PA are expected to be found within a range of 50%. However, IO results should be bigger than PA.

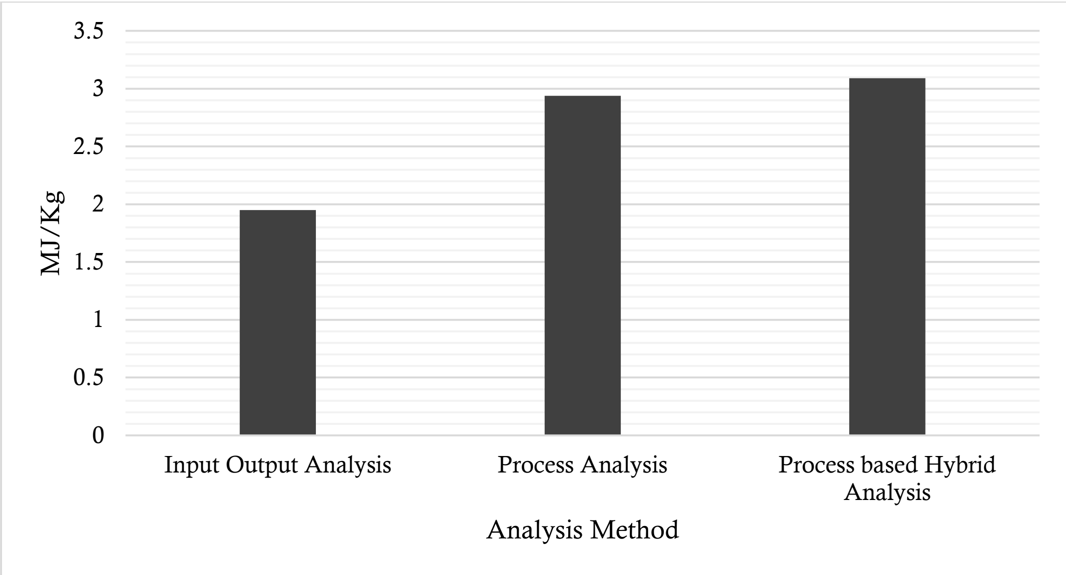

Figure 6.16 Average variation of results in embodied energy of clay bricks by different methods

In this study, the reason why IO methods provide lower embodied energy results is because fired clay brick products in the Cuitzeo bioregion and in general within entire national territory are consuming up to 98% of energy from biomass sources in their manufacturing process and around 77% in the burning process. As pointed out in section 2.4.5 there is a general consensus by EE authors that in IO analysis the aim is to estimate the embodied energy of construction materials by only accounting energy belonging to fossil fuels sources, which is inaccurate. Thus, it is suggested in this study that for non-industrialized materials the consideration of *all* energy sources should be included given that the use of biomass or alternative energy sources is more relevant to those activities than accounting only for fossil fuels. Furthermore, it is precisely the massive production of non-industrialized materials in developing countries where biomass fuels are used, which presents a challenge for further research in LCA/LCEA.

In this case study, the reliability of results is based on the consideration of first-hand data accounting direct energy and the incorporation of IO indirect energy factors for the rest of the upstream stages. For reference purposes, this work's results could be only compared statistically with other international studies, the Table 6.4 below shows results from other EE analysis found in the literature, and the results here obtained show consistency with them. However, energy sources, manufacturing process, analysis methods and sources or data are different in all cases and results cannot be validated

Table 6.4 Clay brick embodied energy, other studies

Author	Product	Manufacturing process	Country of study	Method	Source of data	MJ/Kg
Alcorn and Wood (1998)	Ceramic brick, old technology	Not industrialized	New Zealand	Process-Based hybrid analysis		7.7
	Refractory brick	Industrialized	New Zealand	Process-Based hybrid analysis		5.7
Baird et al. (1997)	Ceramic brick			(Unknown) second hand	Second hand	2.5
(Moedinger, 2005)	Brick fired	With fossil fuels	Italy	Process analysis	First hand	3.6
		With renewable fuels				1.3
Hammond and Jones (2011)	Bricks General		United Kingdom	Process analysis		3.00
	Clay in general		United Kingdom	Process analysis		3.00
	Clay Bricks		Australia	Process-Based hybrid analysis		5.44
Ramesh et al. (2012)	Fired Clay	Not industrialized	India	(Unknown) Second hand	Second hand	1.31
Praseeda et al. (2014)	Burnt Clay Bricks		India	Process & IO		2.42
Kumbhar et al. (2014)	Fired Clay Bricks	Not industrialized	India	LCA, Process analysis	First hand	No Specified
Hernandéz (2014)	Fired Clay Bricks		Mexico	Process analysis	Second hand	3.42
This work	**Fired clay bricks**	**Not industrialized**	**Mexico**	**Process based hybrid analysis**	**First hand**	**3.09**

In the literature and in this study, embodied energy results are only an approximation of the energy consumed in the manufacturing of good and services. There is no study available, which can validate at 100 percent the reliability of its results. However, it does not mean that the analysis of EE is fruitless in the built environment, this only implies that this concept is still in development and it is still have not fully understood, given that EE is an abstract concept, which is interpreted according to the analyst's point of view.

6.8.2 Spatial representation

According to Kanevski & Maignan (2004, p.3) there are several techniques for spatial data visualization, thus one of them was initially considered as an exploratory testing option. Within Geographical information systems, the Inverse distant weighted technique (IDW) is an interpolation technique, which was selected because, is a simple and straightforward procedure used in geographical information systems to display complex data.

IDW proved to be very useful as an exploratory tool to display energy factors in the bioregional clay brick production. In addition, this method allowed expansion of the information obtained from 48 brickwork sites to the rest of the bioregion in this manner, compensating unknown data from the rest of the Galeras. The spatial representation of energy requirements in different stages of the clay brick production was also possible showing a clear idea of how energy is consumed in different stages of this manufacturing process through the entire bioregion.

Therefore, this approach also proved to be useful to reduce uncertainty in the interpretation of embodied energy results such as the geographic identification of the fuel breakdown, where the predominance of biomass fuels in the main process of production was clearly identified through the bioregion. However, even though energy measurement is well incorporated in this exercise, there are no spatial autocorrelations and spatial regression considering the socio-economic factors, which should be included in this research, thus restricting the thematic maps as a deterministic representation of the results.

Deterministic analysis in spatial modelling is a type of model or a part of a model in which the outcome is completely and exactly known based on known inputs (ESRI), this is the most common representation of data as shown in studies carried out by (Pullen, 2007a, Tornberg and Thuvander, 2005, Jones et al., 2007).

Therefore, in order to extend the capabilities of spatial analysis studies within a bioregional context in further studies, it is suggested that in upcoming studies, results can be anticipated with the full potential of GIS through decision oriented or simulation maps. Simulation maps can be derived in an accurate way from statistics following the theory of probability described by Hengl (2007)p.13, while decision orientated maps are developed based on machine learning algorithms, which is a group of computational, mathematical and statistical methods able to learn from previous examples and select optimal conditions from a given target (Kanevski, 2008).

Finally, in order to show how the representation of EE results in thematic maps can extend their interpretation in LCEA for decision-making process an example is presented, According to some authors (Hammond and Jones, 2011, Crawford, 2011), the criteria for comparison has to be based on physical units (MJ/Kg). The UK ICE inventory shows results expressed in (average 3.0 MJ/Kg, maximum 6 and minimum 0.6) and the UK brick development association takes these figures as a reference for sustainable comparison (brick.org.uk, 2015). However, the lack of a geographic context in these figures could limit the interpretations of the results for product selection or local standardization for environmental policies.

Based on the same criteria, in the Cuitzeo bioregion case study, the results showed in Table 6.2 and map (Figure 6.6) present and display energy requirements in physical units (MJ/Kg). Thus, this criterion of homologizing results should be used for sustainable comparison within the bioregion. However, the consideration of the group of thematic maps presented in in section 6.8.2, (visualization of EE per brick, per burning process, the breakdown of energy sources and total energy consumed annually within the bioregion) represent a wider consideration of these results.

Within the bioregional context, maps showing EE results per brick and fuel can be used by local construction developers to identify brickwork sites where a low-energy brick is produced. Maps showing energy sources and EE per burning process can be used by brick producers to identify bioregional differences in manufacturing process affecting the consumption of higher quantities of energy in their own Galeras. Although energy alone could not be an incentive for producers, if they realize that more energy is equal to more investment and less profit in their business, they could well consider this type of maps.

Thematic maps showing EE in transport, annual energy consumption and CO_2 emissions per brickwork-site can be used for decision-makers in order to identify potential spots (Galeras), which can represent an environmental threat within the bioregional area. In this way, rather than propose general policies, specific and tailored strategies can be applied for a faster tackling of these problems. Therefore, in this type of informal manufacturing activities, the consideration of the above factors can provide a more holistic interpretation of results in local developers, brick producers and policy makers by understanding the geographical considerations that have long been requested in LCEA.

6.9 Summary

This chapter completed the process for embodied energy mapping proposed for this research. The fired clay brick production case study provided the final step to merge spatially embodied energy within a bioregional area suggested to extend the comprehension of life cycle inventories results.

The embodied energy method selected was a process based hybrid analysis with a cradle to gate system boundary. The level of accuracy in this analysis was acceptable given that first hand-data was used to estimate direct energy and indirect energy was covered with energy coefficients from the Mexican Input-Output model. The new extraction method to identify energy paths proved to be a practical tool to shorten the time during the data collection process from 48 brickwork-sites located within the bioregion.

According to the objectives for this research, the embodied energy results from the surveyed brickwork “Galeras” were extrapolated with GIS techniques in order to perform a spatial analysis within the geographical area. Thus, the visio-spatial model proved to be useful to generate thematic maps, which allowed visualize energy consumption patterns during different stages in the manufacturing process of the clay brick in the Cuitzeo bioregion. Therefore, the objective of this research to extend the interpretation of results in LCEA was achieved.

Chapter 7 Conclusions

7.1 Introduction

This thesis did not follow a single straightforward method for its realization but required a multi-methodological research approach for its development, which is comparable to a system within a system in life cycle approaches. It is on these grounds that not one but several contributions to the discourse are presented in this thesis for the interpretation of the proposed spatial life cycle energy model.

This chapter presents the general summary, and considers the discussion of key findings and the main arguments presented in previous chapters of this thesis in relation to the general aim and objectives set out in Chapter 1. The conclusions determine whether the general aim has been achieved and if research questions have been answered by critically highlighting both limitations and strengths in the develoment of a Visio-spatial life cycle energy model of building materials within a bioregional context.

7.2 Research Summary

The literature revealed that despite the popular acceptance of LCA approaches to tackle current environmental problems related to the built environment, this assessment technique has shortcomings as a communication tool for decision-making and much remains to bridge this gap. The review of the LCA literature illustrated current technical issues associated with its methodologies, and the lack of consistency in the interpretation of results, including particular methods developed exclusively by the same experts who carry out such LCA studies.

By trying to reduce the complexity of following multiple variables, a simplified and more straightforward version of LCA emerged. This practical approach was developed to identify the path of physical energy used in different scales of analysis. However, this life cycle energy approach (LCEA) and the poorly understood embodied energy concept also inherits some of the problems associated with the main LCA version. Thus, the definition of LCEA system boundaries and the selection of calculation methods are still not agreed, raising in this way more challenges for life cycle approaches and their criticized standardization process.

In order to improve the efficiency of life cycle approaches as a communication tool for decision makers using a participatory process, the inclusion of socio-economic factors and the promotion of energy awareness in construction activities has been requested in response to the sustainable development principles established by the Bruntdland commission. In response to these requirements, various bioregional approaches and new energy visualization tools have been proposed theoretically deal with the subjective as well as objective assessments of sustainability in relation to materiality. However, both approaches have not reached their potential yet.

In this context, the development of a practical Spatial Life Cycle Energy Model (SLCEM) was proposed to assist in the comprehension of complex information related to embodied energy through its representation in thematic maps. Thus, in theory this new tool would be able to identify more clearly variations in the manufacturing process of building materials within a selected bioregion to be used as a support for decision-making in relation to developments and local environmental policies.

Therefore, this study explores how a bioregional framework could be integrated into a spatial life cycle energy analysis, how the model could incorporate embodied energy intensities for a more realistic analysis of good and services and finally how the proposed model could be applied as a tool to visually display embodied energy in a spatial sense across a land zone, or bioregion, in this case .

In Chapter 2, a literature review explored the accessibility to databases, the complicated nature of calculation procedures and the shortcomings in variations of results, which are still conditioning the reliability of LCEA. Additionally, the review found that although theoretical recommendations by the IFIAS can be applied to simple manufacturing process in the construction industry, the practical analysis of buildings requires further work to take account of their entire lifespan once system boundaries and methodologies are agreed. Currently, hybrid methods are the most accurate procedures to estimate the embodied energy of goods and services given they can combine economic and physical energy coefficients by matching energy paths. However, it was found that a clearer and simplified process to extract energy paths from IO tables was necessary to improve this process.

In Chapter 3, the objective of this study was to develop a new, more dynamic Input-Output model, which reflected the current economic interactions within the Mexican built environment in order perform a more accurate LCEA of buildings/materials. Chapter 2 presented the current state of energy analysis and calculation procedures, while Chapter 3 took those considerations along with the availability of input-output tables for the Mexican economy to develop the proposed model for this research. Critically, the equation for IO analysis in LCEA was adjusted to take into account an old problem raised by Treloar and several authors, by simplifying the extraction process of energy paths in input-output models used in the energy analysis of the built environment . The main discussion of the development of this new model was carried out in Section 3.4.

In Chapter 4, the general system approach set out in Chapters 2 and 3 was augmented by a defined Bioregional approach with the aim to re-establish the natural relationship between the human sense of belonging and the regional-scale ecosystem where they live. Thus, a bioregional perspective was presented to describe the potential role of this ecological approach to reinforce the use of indigenous resources or locally manufactured building materials through LCEA. However, the relationship between LCEA and Bioregionalism in research studies is only just starting with only few practical cases, where ecological awareness of environmental impacts related with the built environment has been addressed. In this thesis, the particular approach identified for aiding that purpose was the mapping process of local building materials to achieve the integration of bioregional maps with LCEA.

In Chapter 5, the preliminary bioregional framework was developed in a practical way in order to present a precise visualization of particular life cycle inventories taking into account geographical considerations, which although increasingly recognized, are still not fully considered by hard science. This was achieved by linking the key bioregional principles of energy use and economic factors linked to manufacturing and delivery processes, with Geographical information systems, and a descriptive characterization of the case study was thus presented through thematic maps. No attempt was made to cover all Bioregional principles. The Cuitzeo bioregion was selected as a supplier of building materials in order to explore deeper the bioregional implications of the new IO analysis method through the case study of a local produced fired clay brick building material.

The completion of this research was carried out in Chapter 6 through the analysis of traditionally manufactured fired clay bricks as a Case Study. This product is important because it represents not only the second largest building material but one that has a significant environmental impact in Mexico. This provided the final step to spatially display embodied energy values deemed necessary to extend the understanding of life cycle inventories results in geographical regions. The initial proposed IO hybrid calculation method for embodied energy was changed for practical purposes to a process-based one, which in turn demanded a physical life cycle inventory. Thus, reliability of results was based on the realities of these manufacturing processes combined with the accuracy of the new extraction system of energy paths from the Mexican IO model. This extraction system proved to be a practical tool to shorten time during the data collection process.

According to the objectives for this research, the results were analysed spatially to successfully visualize energy consumption patterns during different stages of the clay brick production within this bioregion. However, much remains to complete its function of including socio-economic factors.

7.2.1 Objectives and general aim

In order to determine if the objectives and the general aim has been achieved a summary table of achievements and constraints is presented below to help evaluate the overall contribution of the thesis and identify remaining work to be done.

	Steps/Objectives	Summary of achievements and constraints
✓	1 Develop a LCEA model National Level. Given the absence of data in Mexico related to life cycle inventories to analyse the built environment, the initial step of this research will be focused on the development of Mexican embodied energy coefficients through Input-Output methodologies. This process uses the North America industrial classification system and will provide both direct and indirect energy factors through excel spreadsheets using input output tables of the national economy.	• This objective was successfully completed according to data availability. • The development of a simplified system to find energy paths is an asset of this step and a contribution of this research.
		• The integration of primary energy factors needs to be improved given that energy supply sectors in Mexican Input-Output are not disaggregated enough to properly identify carbon emissions from different energy sources. Thus, energy coefficients were well identified, but CO_2 emissions were not.
✓	2 Select a Bioregion case study area. After the systematic approach (IO) developed in step (1), the second step in this research will be the selection of an appropriate bioregion case study area in Mexico. The selection of a suitable and in some degree already categorized bioregion will be considered an asset to provide the geographical framework	• The selection of the Cuitzeo bioregion proved to be useful for this research given that it was not necessary to start from the scratch.
		• A deeper bioregional context should be considered to justify the analysis for a specific case study area

	needed for the integration of a bioregional approach. This process will be performed with different sources and GIS Software.	
✓	3 Bioregional Characterization The third step will be the integration of the bioregional approach. Hence, a more tailored characterization of natural local resources will provide the so far unknown bioregion possibility as a supplier of natural resources to the local built environment. This step will help to anticipate what type of construction materials used in the bioregion are produced outside of this area. This process will also be carried out with different sources and GIS Software for resources identification.	• The bioregional characterization was supported by the analysis of previous studies. • A life cycle inventory of natural resources was explored to help identify the possibility of the bioregion as building material supplier to the local built environment. • A bioregional inventory of economic units dedicated to construction related activities was developed.
		• This inventory of natural resources is very general and cannot be considered as mandatory for other research purposes. • Although, the bioregional characterization provides an idea of materials that have been brought to the bioregion for construction purposes, this work cannot identify their origin.
✓	4 Develop a bioregional database. This step will provide a Bioregional characterization of construction related activities based on current economic units identified within this area. Given the national statistics directory of economic units (DENUE) has an extensive database codified	• The DENUE database in the form of a bioregional inventory of economic units was successfully integrated with the IO model through the NAICS code system. This step is also a strong point of this research to perform tailored life cycle analysis.

	according to the same system used in the Input-Output model a tailored life cycle inventory will be created in order to incorporate energy coefficients developed in step 1. Hence, excel spreadsheets will be used to export data to GIS software.	• Manual corrections must be made in IO tables in order to match the six digits of the DENUE database. With this process, the reliability of results can drop and some assumptions have to be made.
✓	5 Select target sector to analyse This step will be applied into a case study in chapter six, according to the expected capabilities of the dynamic input-output model to analyse different targets sectors. Within this step, the selection of a building material produced in the bioregion will be made based on its energy intensity and numeric representativeness.	• The selection of a non-industrialized manufacturing process proved to be useful to test the limitations of the IO model developed in this research. • The consideration of fired clay bricks was appropriate given its representativeness within the bioregion and its high energy intensity. • Given the importance of cement and concrete products within the Mexican built environment, the research case study should be orientated to analyse that sector in further studies. • According to expected capacities of this methodological process, the study of a single building material is acceptable, however, the analysis of complex entities such as buildings represents a major challenge to be tested.
✓	6 Evaluate the supply chain of the target sector This step will assess the supply chain of the selected building material, through the economic energy paths of the Input-Output	• Based on energy paths of the IO, this objective did not represent a major problem and was completed • The level of energy analysis was determined in this step which requested data for two

	Model developed in step 1. Therefore, results will be useful to determine the level of downstream stages needed to collect data according to LCI/process needs.	upstream stages in the production of clay bricks. • Given the cradle to gate scope selected for this research, downstream stages such as the use, recycling or reclaimed were not considered.
✓	7 If available use LCA data, If not, connect with local producers. According to step 6 results, within step 7 a Life cycle inventory is necessary to analyse a specific target sector (building material). Given Mexico lacks of LCI in building materials, it is assumed that data collection will be needed. Therefore, taking into account potential results of the energy paths of the analysed construction material the most important data collection could be identified.	• This step was necessary given the lack of information and the inability to be analysed by the IO. However, rather than being a disadvantage in this research was an opportunity to obtain first hand data. • Current socio-economic conditions and geographical considerations made it difficult to obtain data from the 102 brickwork sites identified in this bioregion, only 48 of them provided information.
✓	8 Data collection or life cycle inventory. This step will request data collection from building materials producers to obtain first hand data to estimate direct energy intensities based on process analysis method. Results will be use later in step 9 for a hybrid analysis	• Knowing the level of analysis required for this building material and the limited understanding of local brick producers in energy matters, the process to obtain information for the energy analysis was satisfactory. • The life cycle inventory form, should be redefined and better designed to facilitate the integration of results with energy values.
✓	9 Perform hybrid energy analysis.	• The initial IO based hybrid method proposed to this step was replaced by a Process

	According to IO based hybrid methodologies, this step will carry out the life cycle energy of the selected building material merging IO data and results from step 8. Thus, a top-bottom analysis will be performed through excel spreadsheets.	based hybrid method. It does mean that a bottom-up analysis was performed. (more analysis time). However, based on first hand data and the methodological support of the IO model, the development of a Process based hybrid analysis can be considered accurate and reliable.
		• As stated before, obtaining data was an efficient step in this research. However, the conversion of producers' empirical knowledge into technical data took longer than expected.
✓	10 Spatial analysis and display of results. Once the life cycle energy analysis is completed, the results will be export to GIS software for mapping embodied energy results to support this study. Following this process, a spatial analysis using geographic Interpolation techniques will be carried out to display visual thematic LCEA Maps for the chosen bioregion.	• The spatial analysis proved to be useful to extrapolate obtained results in areas where data could not be obtained. • The presented thematic maps expanded the sense of place in LCA and helped to visualize patterns in manufacturing process within the case study area.
		• Only one extrapolation technique was used during the spatial analysis, limiting in this way its validation. • Although CO^2 emissions are displayed, the full environmental impacts was not achieved.
✓	11 Interpretation of results. The final step will be the interpretation of results using the set of maps developed in step 10	• The interpretation of results was acceptable considering the advantage of visual information displayed on maps. • It is believed, that with minimal instructions any person can read this type of

	map and establish his own criteria to select a brickwork site with a low-energy product. • It is also assumed, that local policy makers would be able to easily spot potential conflict areas within the bioregion, where high energy consumption in manufacturing processes are taking place. • This type of analysis, allows a fair comparison between producers.
	• The resulting thematic maps, should be redefined according to public participation in order to further validate bioregional principles. • There was no interpretation or validation of results by clay brick producers and policy makers, making this study a theoretical investigation only.

7.3 Conclusions

7.3.1 Hypothesis

This research investigation originated from the hypothesis that:

"From conceptual to pragmatic considerations, a Visio-Spatial Life Cycle Energy Model (SLCEM) aims to make simpler the understanding of LCA results (embodied energy) through its visualization in thematic maps. However, this systematic model would first simplify the complex extraction system of energy paths in IO models in order to situate high energy-intensities construction materials in Mexico. Then, this approach would be able to introduce energy data within a geographic bioregion to perform a life cycle inventory for the spatial LCEA of a representative local building material. Finally, the visualization of results could help to identify energy intensities during its manufacturing process to extend the sense of embodied energy results interpretation."

By completing the objectives to answer the hypothesis, this study has confirmed the hypothesis as follows:

(1) *How can Treloar's extraction method for energy paths be simplified for a more practical use in the Mexican IO model?*

The development of a dynamic IO model application efficiently simplifies the extraction process of energy paths through a systematic transposing step (suggested by Miernyk) in the new rearranged extended version of the power series of approximation by using only excel spreadsheets. Thus, the refined energy paths from the IO model can identify high-embodied energy construction materials across the Mexican territory.

(2) *How can embodied energy data be integrated within a bioregion framework to perform a more sensitive energy analysis of a local product?*

The particular aspects of embodied energy data have been integrated into a bioregional life cycle inventory framework through a unified codification system as used in this study. The NAICS codification system can incorporate both direct and indirect embodied energy coefficients into local establishments (economic units) dedicated to the production of goods and services used within the bioregional built environment.

(3) *How can visualising EE results in thematic maps extend the sense of interpretation in LCEA?*

The spatial representation in thematic maps of embodied energy intensities in building materials has been achieved through GIS. The proposed Visio-spatial life cycle energy model was able to identify more clearly variants in the manufacturing process of fired clay bricks within the selected Cuitzeo bioregion. Thus, visualizing embodied energy in thematic maps could well accelerate the usefulness and help to fill the existing gap in LCA as a communication tool for decision-making processes by reducing geographical assumptions commonly found in LCA.

However, there is still a need to answer how in practice this tool can help to improve the local manufacturing processes of clay bricks or how it can be successfully used as a support for decision making in local environmental policies related to this bioregional representative construction material.

7.3.2 Research contribution

The study developed in thesis has made three key contributions:

- By considering Treloar's theoretical IO hybrid model and Pullen's practical recommendation in PA hybrid energy models, this thesis has developed a dynamic and simplified transposition system in which the expanded version of the powers series of approximation represents a step further to find energy paths. This is an asset for input-output based hybrid methodologies and a significant contribution of this research.

- The coding of economic sectors is regular practice in input-output tables. However, its matching with physical economic units or establishments is not. In chapter 5, section 5.4 represents a contribution of this research by producing a new life cycle inventory, which maximizes the use of integrated codification systems applied to geographical areas. The newly developed database in the form of a bioregional inventory of economic units was successfully integrated with the IO model through the NAICS code system. This step is also a strong point of this research to perform tailored geographical life cycle analysis.

- The consideration of a bioregional framework to display embodied energy intensities in the life cycle energy analysis of building materials (In this case study, clay bricks) is the most significant contribution of this research. The wider representation of embodied energy factors in thematic maps is an asset, which provides a more holistic interpretation of results to choose low-energy products, for a bioregional comparison of manufacturing processes and as benchmark for policy-making by understanding the geographical considerations that have long been requested in LCEA.

7.3.3 Scope and limitations

- This research was based on a Mexican framework although the principles underlying it can be directly applied to Canada and United States by sharing the same industrial classification system (NAICS code). The principles could also be adapted to other countries, which use Input-Output tables in their national accounts.

- Like previous studies in embodied energy, the integration of primary energy factors needs to be improved, given that energy supply sectors in Mexican Input-Output are not disaggregated enough to properly identify carbon emissions from different energy sources. Thus, energy coefficients were identified in the resulting IO model, but CO_2 emissions were not.

- Given the cradle to gate scope selected for this research, downstream stages such as use, recycling or reclaiming material were not considered.

- In this research, only one extrapolation technique was used during the spatial analysis, limiting in this way its validation. The incorporation of energy on maps is restricted as a deterministic representation of the results, given that no spatial autocorrelations/regressions, which consider the socio-economic or cultural factors have been included.

7.3.4 Further work

Based on the development of this research, findings and discussion and contributions, further work is necessary in the following areas;

7.3.4.1 Research

- Although the capabilities of a spatial life cycle energy analysis has been demonstrated with the study of a single building material, it is suggested that the full potential of this mapping process should be achieved and must be subject of further research in complex systems such as buildings.

- Even though traditionally authors of life cycle energy analysis account only for energy requirements based on fossil fuels, this statement should be more carefully analysed in further studies given that burning biomass on informal manufacturing processes is still a common practice, not only in Mexico but worldwide.

7.3.4.2 Practice

- As identified in the discussion section of Chapter 5, the next step of this study should engage community members (in this case Clay brick producers and local authorities), during the process of establishing energy thresholds and socio-economic values. Thus, the analysis of the study subject (embodied energy in any building materials) will be coordinated by experts, but community members are who will be in charge to validate the entire mapping process. In simple words, a cooperative participatory process should be the aim of further research to truly accomplish the integration of general systems and ecological approaches in life cycle studies.

- In this research, the bioregion case study was analysed as an isolated geographical system. However, variations from one region to another should be considered in further studies in order to have a better picture of building construction related activities.

- Given that the change of land use in bioregions and the number of economic units is a dynamic process, the results of this type of analysis must not be considered definitive, and should be regularly updated. In this research only the case study of clay brick was considered, however, there is a prospective capacity of this type of studies that any building material can be approached.

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Appendix A

This section provides more detailed and precise information of the Input-Output calculation procedures in the derivation of embodied energy coefficients used in this research.

Appendix A-1

The North American Industrial Classification System (NAICS).

NAICS MEXICO 2013 (INEGI, 2013b) consists of five aggregation levels: sector, subsector, industry group, industry and class of economic activity. This code is shared with USA and Canada, however, there is not a tri-national report, and every country has its own version and in it recognizes the trilateral agreement level. The sector is the most general level and The National industry level is the most disaggregated. The sector is divided into subsectors. Each subsector is made by industry groups, which are divided into industries. The National industry, in turn, are disclosures of the sub-branches, as shown in the below graph.

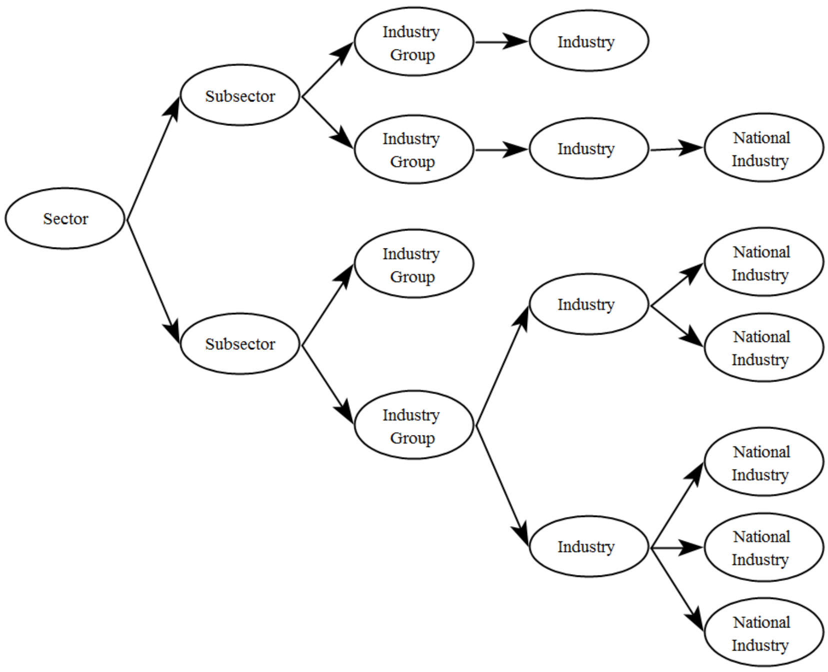

Table AP.A1 Example of NAICS code designation

Level	Code	Categories
Sector (2-digit)	23	Construction
Subsector (3-digit)	236	Construction
Industry group (4-digit)	2361	Residential building construction
Industry (5-digit)	23611	Residential building construction
National industry (6-digit)	236111	Single-family housing construction.

Appendix A-2

Table AP.A2-1 Assumptions and reliability of results in IO according to aggregation levels of commodities

IO (2012)	Commodities aggregation	Level of reliability in IO tables according to aggregation levels. Where 5 is the lowest and 1 is highest	Assumptions taken in IO tables according to aggregation levels
Sector	20	5	Very High
Subsector	94	4	High
Industry group	304	3	Moderated
Industry	617	2	Low
National industry	1074	1	Very Low

Table AP.A2-2 NAICS sector's classification (Mexico)

Traditional grouping	General characteristics	Sector	
Primary Activities	Exploitation of natural resources	11	Agriculture, animal breeding and production, forestry, fishing and hunting
Secondary Activities	Transformation of goods	21	Mining
		22	Utilities
		23	Construction
		31-33	Manufacturing
Tertiary Activities	Distribution of goods	43	Wholesale trade
		46	Retail trade
		48-49	Transportation, postal services and warehousing
	Information operations	51	Mass media information
	Financial activities	52	Financial and insurance services
		53	Real estate services and tangible and intangible goods rental
	Services whose main input is knowledge and experience of staff	54	Professional, scientific and technical services
		55	Head offices
		56	Business support services, waste management and remediation services
		61	Educational services
		62	Health care and social assistance services
	Services related to recreation	71	Cultural and sporting recreation services and other recreational services
		72	Temporary accommodation services and food and beverage preparation services
	Other Services	81	Other services, except government activities
	Government activities	93	Legislative, governmental and justice administration activities, and activities of international and extraterritorial organizations

Appendix A-3

Table AP.A3-1 Primary Energy in petajoules (PJ) of financial year 2012 (Source SENER)

Primary Energy	Coal	Oil	Condensed	Natural Gas	Nuclear energy	Hydro-Energy	Geo-Energy	Solar	Wind power	Bagasse	Firewood	Biogas	Total of primary energy
Production	310.8054	5918.861	87.69245	2029.111	91.317	114.688	133.142	6.672	13.119	95.08	256.7428	1.822	9059.053
From other sources	--	--	--	772.084	--	--	--	--	--	--	--	--	772.084
Residual gas from gas plants	--	--	--	507.917	--	--	--	--	--	--	--	--	507.917
Gas formation used by PEP	--	--	--	264.167	--	--	--	--	--	--	--	--	264.167
Importations	215.3088	0	--	--	--	--	--	--	--	--	--	--	215.309
Inventory variations	24.15412	-21.6894	-3.22933	-17.5381	--	--	--	--	--	--	--	--	-18.303
Total supply	550.2683	5897.171	84.46312	2783.657	91.317	114.688	133.142	6.672	13.119	95.08	256.7428	1.822	10028.14
Exportations	-6.34569	-2946.21	-9.91144	--	--	--	--	--	--	--	--	--	-2962.47
Not utilized	--	-0.35101	0	-53.0796	--	--	--	--	--	-1.05	--	--	-54.477
Manufacturing net exchange	--	0	--	--	--	--	--	--	--	--	--	--	0
Gross domestic supply	543.9226	2950.607	74.55168	2730.577	91.317	114.688	133.142	6.672	13.119	94.03	256.7428	1.822	7011.196
Total transformation	-446.554	-2813.23	-74.5517	-1848.33	-91.317	-114.688	-133.142	-0.24938	-13.12	-52.88	--	-1.822	-5589.64
Coker plants	-81.1031	--	--	--	--	--	--	--	--	--	--	--	-81.103
Refineries and topping plants	--	-2813.23	-3.31769	--	--	--	--	--	--	--	--	--	-2816.55
Gas and petroleum bottling plants	--	--	-71.234	-1848.33	--	--	--	--	--	--	--	--	-1919.57
Public Power stations	-364.122	--	--	--	-91.317	-112.752	-133.142	-0.0072	-0.68	--	--	--	-702.017
PIE Power stations	--	--	--	--	--	--	--	--	-5.6	--	--	--	-5.6
Self-generation power stations	-1.32858	--	--	--	--	-1.936	--	-0.24218	-6.84	-52.88	--	-1.822	-64.8066
Sector own consumption	0	0	0	-270.352	--	--	--	--	--	--	--	--	-270.352
Inter-products transfer	--	--	--	-347.727	--	--	--	--	--	--	--	--	-347.727
Recirculation	--	--	--	-264.167	--	--	--	--	--	--	--	--	-264.167
Statistical difference	1E-06	-108.774	1E-06	-0.00016	0	-1.4E-14	0	--	-0.001	0	0	--	-109.018

Losses (transport, distance and storage)	--	-28.6034	0	0	--	--	--	--	--	--	--	--	-28.603
Total final Consumption	**97.36891**	--	--	--	--	--	--	6.422938	--	41.15	256.7428	--	401.686
Non-energy final consumption	--	--	--	--	--	--	--	--	--	0.16	--	--	0.158
Other economic branches	--	--	--	--	--	--	--	--	--	0.16	--	--	0.158
Energy final consumption	97.36891	--	--	--	--	--	--	6.422938	--	40.99	256.7428	--	401.528
Residential, commercial y public	--	--	--	--	--	--	--	6.124272	--	--	256.7428	--	262.8671
Residential	--	--	--	--	--	--	--	3.659148	--	--	256.7428	--	260.402
Commercial	--	--	--	--	--	--	--	2.465124	--	--	--	--	2.465124
Industrial	97.36891	--	--	--	--	--	--	0.298667	--	40.99	--	--	138.661
Other industries	97.36891	--	--	--	--	--	--	0.298667	--	40.99	--	--	138.6637
Sugar	--	--	--	--	--	--	--	--	--	37.08	--	--	37.076
Cement	5.415868	--	--	--	--	--	--	--	--	--	--	--	5.416
Cellulose y paper	0	--	--	--	--	--	--	--	--	0	--	--	0
Other branches	91.95305	--	--	--	--	--	--	0.298667	--	3.92	--	--	96.17171

Table AP.A3-2 Secondary Energy in petajoules (PJ) of financial year 2012 (Source SENER)

Secondary Energy	Coal Coke	Petroleum Coke	LP Gas	Gasoline and Naphtha	Kerosene	Diesel	Fuel Oil	Non energetic products	Dry Gas	Other self-generated	Electricity	Total of secondary Energy
Production	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
From other sources	0	0	0	0	0	0	0	0	0	--	0	0
Importations	10.36638	103.2159	130.8371	755.482	6.614373	274.7132	103.2859	0	841.3595	--	8.432394	2234.307
Inventory variations	0	-24.4062	-1.57943	0.03605	0.161324	-25.1244	-23.0125	-0.87797	-17.4635	--	--	-92.267
Total supply	10.36638	78.80967	129.2576	755.5181	6.775697	249.5889	80.27338	-0.87797	823.896	--	8.432394	2142.04
Exportations	-0.02964	-22.2844	-0.17325	-130.072	0	0	-161.417	-3.24112	-2.96671	--	-23.6941	-343.878
Not utilized	0	0	0	0	0	0	0	0	0	0	0	0
Manufacturing net exchange	--	--	0	0	0	0	0	0	--	--	--	0
Gross domestic supply	10.33674	56.52529	129.0844	625.4464	6.775697	249.5889	-81.144	-4.11909	820.9293	--	-15.2617	1798.162
Total transformation	**57.446**	**43.49874**	**314.5129**	**919.453**	**114.8765**	**590.4649**	**170.2457**	**169.7561**	**321.3652**	**0**	**1067.878**	**3769.497**
Coker plants	57.446	--	--	--	--	--	--	--	--	3.710535	--	61.15654
Refineries and topping plants	--	81.89317	46.40491	783.8476	114.8765	619.5678	632.9179	82.13256	129.3065	0.096494	--	2490.947
Gas and petroleum bottling plants	--	--	269.0034	135.6054	0	0	0	87.6235	1407.695	--	--	1899.928
Public Power stations	--	--	--	--	--	-25.288	-454.741	--	-444.588	--	644.4781	-280.139
PIE Power Stations	--	--	--	--	--	-0.63574	--	--	-620.329	--	299.59	-321.374
Self-generation power stations	--	-38.3944	-0.89543	--	--	-3.1792	-7.93078	--	-150.72	-3.80703	123.81	-81.1212
Sector own consumption	-3.44674	--	-5.07627	-3.59618	-0.00224	-40.91	-55.5897	0	-541.661	0	-52.3274	-702.61
Inter-products transfer	--	--	--	--	--	--	--	--	347.7266	--	--	347.7266
Recirculation	--	--	--	--	--	--	--	--	-324.473	--	--	-324.473
Statistical difference	-0.00029	0	3E-06	-24.563	-0.11391	4E-06	-1E-06	-6.38541	-0.00038	0	0.000183	-31.0628
Losses (transport, distance and storage)	--	--	--	--	--	--	--	--	--	--	-158.58	-158.58

Total final Consumption	**64.3357**	**100.024**	**438.521**	**1516.74**	**121.5361**	**799.1438**	**33.51203**	**159.2516**	**623.8865**	0	841.7091	-31.0628
Non-energy final consumption	**--**	**0**	**1.620438**	**9.75702**	**0**	**--**	**0**	**159.2516**	**29.25915**	**--**	**--**	**199.8882**
Pemex Petrochemical	--	--	0.006362	7.531921	0	--	--	76.42297	28.5963	--	--	112.5576
Other economic branches	--	0	1.614076	2.225099	0	--	0	82.82859	0.662848	--	--	87.33061
Energy final consumption	**64.3357**	**100.024**	**436.9006**	**1506.983**	**121.5361**	**799.1438**	**33.51203**	**--**	**594.6273**	**--**	**841.7091**	**4498.772**
Residential, commercial and public	**--**	**--**	**339.4958**	**--**	**1.206151**	**4.240413**	**--**	**--**	**42.3448**	**--**	**270.576**	**657.863**
Residential	--	--	274.3765	--	1.206151	--	--	--	32.05964	--	189.9756	497.6179
Commercial	--	--	65.11924	--	--	4.240413	0	--	10.28516	--	50.4036	130.0484
Public	--	--	--	--	--	--	--	--	--	--	30.1968	30.1968
Transport	**--**	**--**	**50.15199**	**1506.573**	**120.3111**	**616.6662**	**0.365248**	**--**	**0.686788**	**--**	**4.068137**	**2298.822**
Air	--	--	--	0.875767	120.3111	--	--	--	--	--	--	121.1869
General freight trucking	--	--	50.15199	1505.697	--	558.1449	--	--	0.686788	--	--	2114.681
Electrical	--	--	--	--	--	--	--	--	--	--	3.908629	3.908629
Rail	--	--	0	0	--	26.21905	--	--	--	--	0.159508	26.37856
Maritime	--	--	--	--	--	32.30221	0.365248	--	--	--	--	32.66746
Agricultural	--	--	6.245377	0	0.018857	113.2455	0	--	--	--	38.9376	158.4474
Industrial	**64.3357**	**100.024**	**41.00748**	**0.410429**	**0**	**64.99171**	**33.14678**	**--**	**551.5957**	**--**	**528.1274**	**1383.229**
Petrochemical Pemex	--	--	--	0.201347	--	0.391825	0.233957	--	101.2789	--	4.783606	106.8896
Other industries	**64.3357**	**100.024**	**41.00748**	**0.209082**	**0**	**64.59988**	**32.91282**	**--**	**450.3169**	**--**	**523.3438**	**1276.541**
Steel	64.3357	2.471719	0.005774	--	0	0.882445	4.510813	--	112.5803	--	23.34899	208.1358
Chemistry	--	1.76396	0.833744	--	--	4.171538	5.153465	--	61.49159	--	17.01174	90.42604
Sugar	--	--	0.00042	--	--	0	3.457389	--	--	--	3.038722	6.496531
Cement	0	90.63582	0.000243	--	--	0.222965	1.477934	--	8.141228	--	33.65861	134.1368
Mining	0	0	6.122185	--	--	12.08515	2.303711	--	9.418575	--	30.88437	60.81399

Cellulose and paper	--	--	0.395624	--	--	1.260859	5.019543	--	28.90089	--	10.03465	45.61156
Glass	--	0.005546	0.151095	--	--	0.156557	3.674998	--	48.21522	--	4.288548	56.49196
Beer and malt	--	--	0.806087	--	--	0.138971	3.168803	--	8.405028	--	3.645391	16.16428
Fertilizers	--	--	--	--	--	0.154711	0	--	0.470594	--	0.486736	1.112041
Automotive	--	--	0.521834	--	--	0.781255	0	--	4.125458	--	7.653523	13.08207
Bottled drink	--	--	1.257988	--	--	3.515768	1.023511	--	1.141581	--	3.032792	9.97164
Construction	--	--	--	--	--	11.41625	--	--	--	--	1.785337	13.20159
Rubber	--	--	0.013593	--	--	1.955944	0.678902	--	5.497819	--	1.659403	9.805661
Aluminium	--	--	N/D	--	N/D	N/D	N/D	--	N/D	--	N/D	N/D
Tobacco	--	--	0	--	--	0	0.008701	--	0.30837	--	0.239364	0.556435
Other Industries	--	5.146984	30.89889	0.209082	0	27.85747	2.435051	--	161.6202	--	382.5756	610.5342

Appendix A-4

Table AP.A4 Distribution of energy requirements within the Mexican economic sectors

SEC	SECTOR	CODE	DEI	IEI_1	IEI_2	IEI_3	IEI_4	IEI_5	IEI_6	IEI_7	IEI_8	IEI_9	IEI_10	IEI_11	IEI_12	TEI
Primary Sector	Oilseed, legume and cereal growing	**1111**	0.00181	0.000278	0.000063	0.000011	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002169**
Primary Sector	Vegetable growing	**1112**	0.00065	0.000376	0.000090	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001136**
Primary Sector	Fruit and tree nut growing	**1113**	0.00032	0.000379	0.000098	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000819**
Primary Sector	Greenhouse and nursery growing, and floriculture	**1114**	0.00127	0.000327	0.000088	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001702**
Primary Sector	Other crop growing	**1119**	0.00317	0.000244	0.000060	0.000011	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003492**
Primary Sector	Cattle raising	**1121**	0.00046	0.001074	0.000177	0.000041	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001760**
Primary Sector	Pig raising	**1122**	0.00013	0.000449	0.000340	0.000076	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001014**
Primary Sector	Poultry raising	**1123**	0.00003	0.000411	0.000355	0.000079	0.000018	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000895**
Primary Sector	Sheep and goat raising	**1124**	0.00013	0.000387	0.000099	0.000023	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000649**
Primary Sector	Aquaculture	**1125**	0.00260	0.000416	0.000282	0.000069	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003391**
Primary Sector	Other animal production	**1129**	0.00619	0.000754	0.000225	0.000048	0.000011	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.007231**
Primary Sector	Silviculture	**1131**	0.00000	0.000490	0.000110	0.000021	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000626**
Primary Sector	Forest nurseries and gathering of forest products	**1132**	0.00005	0.000037	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000103**
Primary Sector	Logging	**1133**	0.00005	0.000472	0.000042	0.000018	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000586**
Primary Sector	Fishing	**1141**	0.01558	0.000557	0.000080	0.000021	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.016246**
Primary Sector	Hunting and trapping	**1142**	0.00104	0.000242	0.000071	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001376**

Primary Sector	Services related to agriculture	**1151**	0.00062	0.000419	0.000056	0.000011	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001112**
Primary Sector	Services related to animal breeding and production	**1152**	0.00104	0.000248	0.000040	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001344**
Primary Sector	Services related to forestry	**1153**	0.00358	0.000172	0.000100	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003873**
Second ary Sector	Oil and gas extraction	**2111**	0.00074	0.000071	0.000024	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000840**
Second ary Sector	Coal mining	**2121**	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Second ary Sector	Metallic ore mining	**2122**	0.00124	0.000242	0.000047	0.000010	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001541**
Second ary Sector	Non-metallic ore mining	**2123**	0.00427	0.000278	0.000043	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004601**
Second ary Sector	Services related to mining	**2131**	0.00055	0.000577	0.000113	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001280**
Second ary Sector	Electric power generation, transmission and distribution	**2211**	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Second ary Sector	Water collection, treatment and supply	**2221**	0.00171	0.000210	0.000053	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001984**
Second ary Sector	Gas supply through mains to final consumers	**2222**	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Second ary Sector	Residential building construction	**2361**	0.00047	0.000594	0.000125	0.000026	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001224**
Second ary Sector	Non-residential building construction	**2362**	0.00114	0.000817	0.000160	0.000036	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002158**
Second ary Sector	Construction works for water, oil, gas, electric power and telecommunications supply	**2371**	0.00161	0.000781	0.000172	0.000042	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002614**

Secondary Sector	Land division and urbanization works	**2372**	0.00106	0.000948	0.000195	0.000045	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002261**
Secondary Sector	Construction of roads, highways and similar works	**2373**	0.00216	0.000555	0.000124	0.000027	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002869**
Secondary Sector	Other civil engineering construction	**2379**	0.00271	0.001243	0.000179	0.000042	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004184**
Secondary Sector	Other specialized construction works	**2381**	0.00245	0.000281	0.000086	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002840**
Secondary Sector	Animal food manufacturing	**2382**	0.00054	0.000889	0.000197	0.000046	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001686**
Secondary Sector	Grain and seed milling, and fats and oils manufacturing	**2383**	0.00090	0.000577	0.000089	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001589**
Secondary Sector	Sugar, chocolate, candies and similar products manufacturing	**2389**	0.00180	0.001131	0.000197	0.000044	0.000010	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003185**
Secondary Sector	Fruits, vegetables and prepared meals preserving	**3111**	0.00064	0.000498	0.000169	0.000040	0.000009	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001360**
Secondary Sector	Dairy products manufacturing	**3112**	0.00110	0.000448	0.000388	0.000093	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002058**
Secondary Sector	Livestock, poultry and other edible animals slaughtering, packaging and processing	**3113**	0.00098	0.000413	0.000340	0.000144	0.000037	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001928**
Secondary Sector	Seafood preparation and packaging	**3114**	0.00242	0.002779	0.000406	0.000070	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.005698**
Secondary Sector	Bakery products and tortilla manufacturing	**3115**	0.00107	0.000530	0.000156	0.000037	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001804**

Secondary Sector	Other food manufacturing	**3116**	0.00096	0.000469	0.000156	0.000042	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001645**
Secondary Sector	Beverage industry	**3117**	0.00123	0.000642	0.000208	0.000049	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002142**
Secondary Sector	Tobacco industry	**3118**	0.00005	0.000079	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000147**
Secondary Sector	Textile fibers preparation and spinning, and thread and yarn manufacturing	**3119**	0.00076	0.000884	0.000149	0.000035	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001835**
Secondary Sector	Fabrics manufacturing	**3121**	0.00129	0.000503	0.000142	0.000031	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001972**
Secondary Sector	Textile products finishing and coated fabrics manufacturing	**3122**	0.00072	0.000350	0.000096	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001190**
Secondary Sector	Rugs, linens and similar products confectioning	**3131**	0.00048	0.000305	0.000087	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000901**
Secondary Sector	Other textile products manufacturing, except apparel	**3132**	0.00034	0.000304	0.000084	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000752**
Secondary Sector	Knitted apparel manufacturing	**3133**	0.00052	0.000466	0.000189	0.000056	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001256**
Secondary Sector	Cut and sew apparel manufacturing	**3141**	0.00039	0.000361	0.000096	0.000023	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000874**
Secondary Sector	Cut and sew apparel accessories and other apparel manufacturing, not elsewhere classified	**3149**	0.00111	0.000370	0.000105	0.000027	0.000008	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001623**
Secondary Sector	Leather and fur tanning and finishing	**3151**	0.00067	0.000676	0.000197	0.000123	0.000050	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001735**

Secondary Sector	Footwear manufacturing	**3152**	0.00034	0.000291	0.000144	0.000040	0.000018	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000845**
Secondary Sector	Manufacturing of other leather, fur and allied materials products	**3159**	0.00071	0.000397	0.000121	0.000049	0.000020	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001300**
Secondary Sector	Wood sawing and preservation	**3161**	0.00523	0.000525	0.000165	0.000023	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.005956**
Secondary Sector	Wood laminates and fiberboard manufacturing	**3162**	0.00169	0.001700	0.000205	0.000060	0.000010	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003671**
Secondary Sector	Other wood products manufacturing	**3169**	0.00128	0.001111	0.000151	0.000041	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002588**
Secondary Sector	Pulp, paper and paperboard manufacturing	**3211**	0.00394	0.000780	0.000173	0.000040	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004947**
Secondary Sector	Paperboard and paper products manufacturing	**3212**	0.00070	0.001017	0.000224	0.000052	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002006**
Secondary Sector	Printing and related industries	**3219**	0.00089	0.000857	0.000204	0.000048	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002015**
Secondary Sector	Manufacturing of products derived from petroleum and coal	**3221**	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Secondary Sector	Basic chemical products manufacturing	**3222**	0.00058	0.000440	0.000082	0.000019	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001123**
Secondary Sector	Synthetic resins and rubbers, and chemical fibers manufacturing	**3231**	0.00096	0.000523	0.000133	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001656**
Secondary Sector	Fertilizers, pesticides and other agrochemical products manufacturing	**3241**	0.00267	0.000856	0.000122	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003681**

Secondary Sector	Pharmaceutical products manufacturing	**3251**	0.00028	0.000241	0.000071	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000618**
Secondary Sector	Paints, coatings, and adhesives manufacturing	**3252**	0.00146	0.000393	0.000108	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001996**
Secondary Sector	Soaps, cleaners and toilet preparations manufacturing	**3253**	0.00055	0.000465	0.000132	0.000031	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001190**
Secondary Sector	Other chemical products manufacturing	**3254**	0.00133	0.000381	0.000104	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001852**
Secondary Sector	Plastic products manufacturing	**3255**	0.00035	0.000412	0.000114	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000912**
Secondary Sector	Rubber products manufacturing	**3256**	0.00119	0.000441	0.000114	0.000028	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001784**
Secondary Sector	Manufacturing of products based on clays and refractory minerals	**3259**	0.00364	0.000552	0.000079	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004296**
Secondary Sector	Glass and glass products manufacturing	**3261**	0.00323	0.000692	0.000141	0.000030	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004105**
Secondary Sector	Cement and concrete products manufacturing	**3262**	0.00596	0.000966	0.000146	0.000025	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.007102**
Secondary Sector	Lime, gypsum and gypsum products manufacturing	**3271**	0.00436	0.001094	0.000165	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.005652**
Secondary Sector	Other nonmetallic mineral products manufacturing	**3272**	0.00111	0.000944	0.000151	0.000028	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002243**
Secondary Sector	Iron and steel basic industry	**3273**	0.00070	0.000407	0.000088	0.000019	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001215**
Secondary Sector	Iron and steel products manufacturing	**3274**	0.00067	0.000465	0.000152	0.000038	0.000009	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001340**
Secondary Sector	Aluminum basic industry	**3279**	0.00031	0.000269	0.000037	0.000008	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000627**

Secondary Sector	Nonferrous metal industry, except aluminum	**3311**	0.00003	0.000714	0.000174	0.000036	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000960**
Secondary Sector	Metal parts molding by casting	**3312**	0.00051	0.000372	0.000118	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001039**
Secondary Sector	Forged and stamped metal products manufacturing	**3313**	0.00048	0.000492	0.000134	0.000044	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001170**
Secondary Sector	Nonpowered hand tools and metal kitchen utensils manufacturing	**3314**	0.00028	0.000405	0.000123	0.000031	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000851**
Secondary Sector	Metal structures and iron works products manufacturing	**3315**	0.00072	0.000335	0.000094	0.000029	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001186**
Secondary Sector	Boilers, tanks and metal containers manufacturing	**3321**	0.00037	0.000513	0.000165	0.000048	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001107**
Secondary Sector	Metal fittings and locks manufacturing	**3322**	0.00001	0.000040	0.000006	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000063**
Secondary Sector	Wire, wire products and springs manufacturing	**3323**	0.00025	0.000506	0.000164	0.000057	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000993**
Secondary Sector	Metal parts machining and screws manufacturing	**3324**	0.00182	0.000480	0.000147	0.000043	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002508**
Secondary Sector	Metal coating and finishings	**3325**	0.00180	0.000573	0.000264	0.000076	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002738**
Secondary Sector	Other metal products manufacturing	**3326**	0.00048	0.000561	0.000142	0.000039	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001234**
Secondary Sector	Agricultural, construction and extractive industry machinery and equipment manufacturing	**3327**	0.00039	0.000590	0.000184	0.000052	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001234**

Second ary Sector	Industrial machinery and equipment manufacturing, except metalworking	**3328**	0.00032	0.000454	0.000100	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000910**
Second ary Sector	Commercial and service industry machinery and equipment manufacturing	**3329**	0.00024	0.000403	0.000056	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000719**
Second ary Sector	Air conditioning, heating, and industrial and commercial refrigeration equipment manufacturing	**3331**	0.00019	0.000505	0.000110	0.000031	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000850**
Second ary Sector	Metalworking industry machinery and equipment manufacturing	**3332**	0.00048	0.000503	0.000095	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001108**
Second ary Sector	Internal combustion engines, turbines and power transmissions manufacturing	**3333**	0.00051	0.000586	0.000125	0.000033	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001262**
Second ary Sector	Other general purpose machinery and equipment manufacturing	**3334**	0.00090	0.000533	0.000095	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001563**
Second ary Sector	Computer and peripheral equipment manufacturing	**3335**	0.00001	0.000031	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000044**
Second ary Sector	Communications equipment manufacturing	**3336**	0.00012	0.000421	0.000038	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000591**
Second ary Sector	Audio and video equipment manufacturing	**3339**	0.00000	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000006**

Secondary Sector	Electronic components manufacturing	**3341**	0.00013	0.000416	0.000043	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000606**
Secondary Sector	Manufacturing of measuring, control, navigation instruments and electronic medical equipment manufacturing	**3342**	0.00010	0.000380	0.000059	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000555**
Secondary Sector	Manufacturing and reproducing magnetic and optical media	**3343**	0.00006	0.000400	0.000097	0.000027	0.000006	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000595**
Secondary Sector	Lighting accessories manufacturing	**3344**	0.00062	0.000442	0.000091	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001179**
Secondary Sector	Household electrical appliances manufacturing	**3345**	0.00014	0.000504	0.000124	0.000032	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000809**
Secondary Sector	Electric power generation and distribution equipment manufacturing	**3346**	0.00013	0.000430	0.000077	0.000019	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000663**
Secondary Sector	Other electrical equipment and accessories manufacturing	**3351**	0.00009	0.000242	0.000127	0.000032	0.000007	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000496**
Secondary Sector	Automobiles and trucks manufacturing	**3352**	0.00002	0.000314	0.000092	0.000023	0.000006	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000463**
Secondary Sector	Motor vehicle bodies and trailers manufacturing	**3353**	0.00029	0.000566	0.000097	0.000025	0.000006	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000982**
Secondary Sector	Motor vehicle parts manufacturing	**3359**	0.00018	0.000484	0.000110	0.000030	0.000008	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000818**
Secondary Sector	Aerospace equipment manufacturing	**3361**	0.00005	0.000402	0.000036	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000499**

Secondary Sector	Railroad equipment manufacturing	**3362**	0.00062	0.000683	0.000126	0.000035	0.000009	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001471**
Secondary Sector	Ship and boat manufacturing	**3363**	0.00016	0.000261	0.000083	0.000023	0.000006	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000533**
Secondary Sector	Other transportation equipment manufacturing	**3364**	0.00022	0.000417	0.000048	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000706**
Secondary Sector	Furniture manufacturing, except office furniture and shelving	**3365**	0.00108	0.000951	0.000174	0.000043	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002257**
Secondary Sector	Office furniture and shelving manufacturing	**3366**	0.00069	0.000686	0.000152	0.000038	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001572**
Secondary Sector	Mattresses, blinds and curtain rods manufacturing	**3369**	0.00121	0.000588	0.000176	0.000046	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002032**
Secondary Sector	Manufacturing of nonelectronic medical, dental and laboratory equipment and disposable material, and ophthalmic goods manufacturing	**3371**	0.00035	0.000735	0.000128	0.000034	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001258**
Secondary Sector	Other manufacturing industries	**3372**	0.00047	0.000415	0.000131	0.000033	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001060**
Secondary Sector	Wholesale trade	**3379**	0.00037	0.000166	0.000048	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000599**
Secondary Sector	Scheduled air transportation	**3391**	0.02806	0.000354	0.000058	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.028488**
Secondary Sector	Nonscheduled air transportation	**3399**	0.01284	0.000599	0.000084	0.000019	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.013544**

Tertiary Sector	Rail transportation	**4311**	0.01182	0.000429	0.000066	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.012337**
Tertiary Sector	Maritime transportation	**4811**	0.00146	0.000400	0.000059	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001934**
Tertiary Sector	Inland water transportation	**4812**	0.00823	0.000110	0.000054	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.008416**
Tertiary Sector	General freight trucking	**4821**	0.01094	0.000173	0.000035	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.011155**
Tertiary Sector	Urban and suburban collective passenger transportation, fixed route	**4831**	0.01555	0.000151	0.000023	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.015733**
Tertiary Sector	Long-distance collective passenger transportation, fixed route	**4832**	0.01772	0.000224	0.000053	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.018013**
Tertiary Sector	Taxi and limousine services	**4841**	0.01819	0.000112	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.018321**
Tertiary Sector	School and employee transportation	**4851**	0.02383	0.000226	0.000037	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.024102**
Tertiary Sector	Bus rental with driver	**4852**	0.00742	0.000157	0.000034	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.007626**
Tertiary Sector	Other passenger transportation by road	**4853**	0.02952	0.000246	0.000039	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.029823**
Tertiary Sector	Pipeline transportation of natural gas	**4854**	0.00385	0.000246	0.000063	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004174**
Tertiary Sector	Pipeline transportation of other products	**4855**	0.00000	0.000060	0.000017	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000085**
Tertiary Sector	Sightseeing transportation by land	**4859**	0.00903	0.000346	0.000068	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.009468**
Tertiary Sector	Sightseeing transportation by water	**4862**	0.01129	0.000266	0.000042	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.011611**
Tertiary Sector	Other sightseeing transportation	**4869**	0.00524	0.000077	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.005334**
Tertiary Sector	Services related to air transportation	**4871**	0.00047	0.000137	0.000033	0.000009	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000649**

Tertiary Sector	Services related to rail transportation	**4872**	0.00166	0.000269	0.000060	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002009**
Tertiary Sector	Services related to water transportation	**4879**	0.00215	0.000229	0.000044	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002441**
Tertiary Sector	Services related to road transportation	**4881**	0.00052	0.000178	0.000034	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000744**
Tertiary Sector	Intermediation services for freight transportation	**4882**	0.00028	0.000202	0.000048	0.000010	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000544**
Tertiary Sector	Other services related to transportation	**4883**	0.00109	0.000240	0.000049	0.000011	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001394**
Tertiary Sector	Postal services	**4884**	0.00163	0.000184	0.000049	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001879**
Tertiary Sector	Long-distance courier and messenger services	**4885**	0.00914	0.000325	0.000066	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.009554**
Tertiary Sector	Warehousing services	**4889**	0.00144	0.000440	0.000124	0.000028	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002044**
Tertiary Sector	Newspaper, magazine, book, software and other materials publishing and integrated publishing/printing of these publications	**4911**	0.00093	0.000387	0.000084	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001428**
Tertiary Sector	Software publishing, and integrated software publishing/reproduction	**4921**	0.00006	0.000079	0.000029	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000175**
Tertiary Sector	Film and video industry	**4931**	0.00016	0.000279	0.000093	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000559**
Tertiary Sector	Sound recording industry	**5111**	0.00046	0.000252	0.000082	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000824**
Tertiary Sector	Radio and television broadcasting	**5112**	0.00026	0.000367	0.000116	0.000027	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000779**
Tertiary Sector	Production of channel programming for	**5121**	0.00069	0.000276	0.000109	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001114**

	cable or satellite television systems															
Tertiary Sector	Wired telecommunications carriers	**5122**	0.00099	0.000229	0.000054	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001291**
Tertiary Sector	Wireless telecommunications carriers, except satellite services	**5151**	0.00007	0.000252	0.000060	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000395**
Tertiary Sector	Satellite telecommunications services	**5152**	0.00001	0.000085	0.000029	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000136**
Tertiary Sector	Other telecommunications services	**5171**	0.00016	0.000269	0.000091	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000554**
Tertiary Sector	Electronic data processing, hosting, and other related services	**5172**	0.00021	0.000260	0.000088	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000584**
Tertiary Sector	Other information services	**5174**	0.00025	0.000352	0.000082	0.000024	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000712**
Tertiary Sector	Central bank	**5179**	0.00000	0.000316	0.000033	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000363**
Tertiary Sector	Multiple banking	**5182**	0.00001	0.000486	0.000079	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000598**
Tertiary Sector	Financial institutions for economic development	**5191**	0.00001	0.000249	0.000073	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000344**
Tertiary Sector	Credit unions and saving institutions	**5211**	0.00070	0.000844	0.000122	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001703**
Tertiary Sector	Other credit and financial intermediation institutions, non-stock exchange	**5221**	0.00015	0.000967	0.000080	0.000019	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001224**
Tertiary Sector	Services related to credit intermediation, non-stock exchange	**5222**	0.00244	0.000532	0.000187	0.000045	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003220**
Tertiary Sector	Brokerage houses, foreign currency exchange houses	**5223**	0.00006	0.001079	0.000066	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001225**

	and exchange offices															
Tertiary Sector	Stock exchange	**5224**	0.00006	0.000354	0.000112	0.000026	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000565**
Tertiary Sector	Investment advice and other services related to stock exchange intermediation	**5225**	0.00017	0.000501	0.000127	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000837**
Tertiary Sector	Insurance and surety institutions	**5231**	0.00000	0.000300	0.000189	0.000042	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000543**
Tertiary Sector	Services related to insurance and surety	**5232**	0.00020	0.000190	0.000039	0.000009	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000440**
Tertiary Sector	Rental of real estate without intermediation	**5239**	0.00075	0.000040	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000803**
Tertiary Sector	Real estate agencies and brokers	**5241**	0.00028	0.000278	0.000145	0.000034	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000745**
Tertiary Sector	Services related to real estate	**5242**	0.00042	0.000455	0.000180	0.000049	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001123**
Tertiary Sector	Rental of automobiles, trucks and other road transportation vehicles	**5311**	0.00651	0.000411	0.000075	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.007016**
Tertiary Sector	Rental of household and personal goods	**5312**	0.00146	0.000291	0.000103	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001885**
Tertiary Sector	General rental centers	**5313**	0.00359	0.000253	0.000109	0.000028	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003988**
Tertiary Sector	Rental of agricultural, fishing, industrial, commercial and services machinery and equipment	**5321**	0.00349	0.000287	0.000075	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003874**
Tertiary Sector	Rental services of trademarks, patents and franchises	**5322**	0.00047	0.000128	0.000040	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000653**
Tertiary Sector	Legal services	**5323**	0.00110	0.000330	0.000060	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001505**

Tertiary Sector	Accounting, auditing and related services	**5324**	0.00077	0.000404	0.000061	0.000011	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001248**
Tertiary Sector	Architecture, engineering and related activities services	**5331**	0.00035	0.000128	0.000089	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000593**
Tertiary Sector	Specialized design	**5411**	0.00039	0.000172	0.000058	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000639**
Tertiary Sector	Computer systems design and related services	**5412**	0.00003	0.000208	0.000069	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000324**
Tertiary Sector	Management, scientific and technical consulting services	**5413**	0.00034	0.000132	0.000047	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000530**
Tertiary Sector	Scientific research and development services	**5414**	0.00100	0.000465	0.000073	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001557**
Tertiary Sector	Advertising services and related activities	**5415**	0.00055	0.000246	0.000083	0.000021	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000905**
Tertiary Sector	Other professional, scientific and technical services	**5416**	0.00058	0.000126	0.000043	0.000009	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000765**
Tertiary Sector	Head offices	**5417**	0.00077	0.000168	0.000044	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000992**
Tertiary Sector	Business administration services	**5418**	0.00005	0.000552	0.000095	0.000023	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000730**
Tertiary Sector	Facilities support services	**5419**	0.00098	0.000342	0.000086	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001432**
Tertiary Sector	Employment services	**5511**	0.00008	0.000052	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000154**
Tertiary Sector	Secretarial support, photocopying, collection, credit investigation and similar services	**5611**	0.00082	0.000391	0.000084	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001318**
Tertiary Sector	Travel agencies and reservation services	**5612**	0.00063	0.000329	0.000131	0.000032	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001128**

Tertiary Sector	Investigation, protection and security services	**5613**	0.00142	0.000133	0.000036	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001604**
Tertiary Sector	Cleaning services	**5614**	0.00075	0.000278	0.000081	0.000019	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001136**
Tertiary Sector	Other business support services	**5615**	0.00047	0.000307	0.000095	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000906**
Tertiary Sector	Waste management and remediation services	**5616**	0.00301	0.000404	0.000072	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003507**
Tertiary Sector	Basic, middle and special needs education schools	**5617**	0.00014	0.000096	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000258**
Tertiary Sector	Higher technical education schools	**5619**	0.00099	0.000306	0.000093	0.000019	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001410**
Tertiary Sector	Higher education schools	**5621**	0.00028	0.000194	0.000039	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000531**
Tertiary Sector	Business, computer and management training schools	**6111**	0.00040	0.000269	0.000074	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000762**
Tertiary Sector	Trade schools	**6112**	0.00140	0.000567	0.000151	0.000033	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002159**
Tertiary Sector	Other educational services	**6113**	0.00096	0.000445	0.000067	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001497**
Tertiary Sector	Educational support services	**6114**	0.00027	0.000209	0.000072	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000587**
Tertiary Sector	Medical doctors offices	**6115**	0.00098	0.000367	0.000057	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001423**
Tertiary Sector	Dental offices	**6116**	0.00039	0.000148	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000567**
Tertiary Sector	Other health care offices	**6117**	0.00067	0.000294	0.000065	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001048**
Tertiary Sector	Outpatient care centers	**6211**	0.00059	0.000195	0.000064	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000866**
Tertiary Sector	Medical and diagnostic laboratories	**6212**	0.00059	0.000327	0.000081	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001018**
Tertiary Sector	Home nursing services	**6213**	0.00084	0.000124	0.000049	0.000010	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001028**
Tertiary Sector	Ambulance services, organ banks and other	**6214**	0.00368	0.000286	0.000067	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004058**

	medical treatment ancillary services															
Tertiary Sector	General hospitals	**6215**	0.00105	0.000397	0.000072	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001539**
Tertiary Sector	Psychiatric and addiction hospitals	**6216**	0.00084	0.000273	0.000067	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001204**
Tertiary Sector	Other medical specialties hospitals	**6219**	0.00098	0.000434	0.000078	0.000019	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001522**
Tertiary Sector	Residential facilities with nursing care for convalescent, in rehabilitation, incurable and terminal patients	**6221**	0.00168	0.000305	0.000078	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002089**
Tertiary Sector	Residential care facilities for persons with mental retardation, mental disorder and addictions	**6222**	0.00063	0.000188	0.000049	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000879**
Tertiary Sector	Homes and other residential care facilities for the elderly	**6223**	0.00169	0.000296	0.000077	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002082**
Tertiary Sector	Orphanages and other social assistance residential care facilities	**6231**	0.00072	0.000253	0.000137	0.000041	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001167**
Tertiary Sector	Guidance and social work services	**6232**	0.00160	0.000591	0.000103	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002327**
Tertiary Sector	Community food, housing and emergency services	**6233**	0.00310	0.000253	0.000075	0.000019	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003451**
Tertiary Sector	Job training services for unemployed, underemployed or disabled persons	**6239**	0.00053	0.000176	0.000039	0.000009	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000752**
Tertiary Sector	Nurseries	**6241**	0.00071	0.000579	0.000109	0.000028	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001437**
Tertiary Sector	Performing arts companies and groups	**6242**	0.00022	0.000185	0.000055	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000477**

Tertiary Sector	Professional athletes and sports teams	**6243**	0.00383	0.000225	0.000089	0.000023	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004174**
Tertiary Sector	Promoters of performing arts, sports and similar events	**6244**	0.00049	0.000476	0.000094	0.000023	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001094**
Tertiary Sector	Agents and managers for artists, athletes and similar figures	**7111**	0.00071	0.000546	0.000067	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001342**
Tertiary Sector	Independent artists, writers and technicians	**7112**	0.00006	0.000007	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000067**
Tertiary Sector	Museums, historical sites, zoos and similar institutions	**7113**	0.00079	0.000662	0.000080	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001562**
Tertiary Sector	Parks with recreational facilities and amusement arcades	**7114**	0.00037	0.000265	0.000107	0.000031	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000786**
Tertiary Sector	Casinos, lotteries and other gambling services	**7115**	0.00053	0.000196	0.000065	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000813**
Tertiary Sector	Other recreational services	**7121**	0.00169	0.000452	0.000091	0.000022	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002265**
Tertiary Sector	Hotels, motels and similar facilities	**7131**	0.00113	0.000188	0.000054	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001395**
Tertiary Sector	Recreational camps and lodgings	**7132**	0.00254	0.000232	0.000065	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002860**
Tertiary Sector	Rooming and boarding houses, and furnished apartments and houses with maid services	**7139**	0.00063	0.000362	0.000091	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001110**
Tertiary Sector	Full service restaurants	**7211**	0.00072	0.000315	0.000118	0.000031	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001195**
Tertiary Sector	Self-service, take-out and other limited service restaurants	**7212**	0.00119	0.000238	0.000100	0.000048	0.000017	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001599**

Tertiary Sector	Food catering services	**7213**	0.00027	0.000196	0.000047	0.000012	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000532**
Tertiary Sector	Nightclubs, bars and similar drinking places	**7221**	0.00041	0.000299	0.000113	0.000032	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000860**
Tertiary Sector	Repair and maintenance of automobiles and trucks	**7222**	0.00249	0.000247	0.000053	0.000013	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002807**
Tertiary Sector	Electronic and precision equipment repair and maintenance	**7223**	0.00068	0.000319	0.000072	0.000019	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001100**
Tertiary Sector	Agricultural, industrial, commercial and services machinery and equipment repair and maintenance	**7224**	0.00178	0.000317	0.000091	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002218**
Tertiary Sector	Household and personal goods repair and maintenance	**8111**	0.00229	0.000214	0.000069	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002590**
Tertiary Sector	Beauty salons and clinics, public baths and washrooms, and shoeshine shops	**8112**	0.00051	0.000246	0.000083	0.000023	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000872**
Tertiary Sector	Laundries and dry-cleaning shops	**8113**	0.00342	0.000334	0.000093	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003883**
Tertiary Sector	Funeral services and cemetery management	**8114**	0.00075	0.000399	0.000124	0.000029	0.000007	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001308**
Tertiary Sector	Parking lots and garages for motor vehicle	**8121**	0.00025	0.000313	0.000077	0.000021	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000669**
Tertiary Sector	Photograph developing and printing and other personal services	**8122**	0.00007	0.000020	0.000005	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000096**
Tertiary Sector	Commercial, labor, professional and	**8123**	0.00792	0.000529	0.000112	0.000025	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.008597**

	recreational associations and organizations															
Tertiary Sector	Religious, political and civic associations and organizations	**8124**	0.00047	0.000667	0.000070	0.000016	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001227**
Tertiary Sector	Private households employing domestic personnel	**8129**	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Tertiary Sector	Legislative bodies	**8131**	0.00091	0.000471	0.000056	0.000015	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001458**
Tertiary Sector	General public administration	**8132**	0.00251	0.000423	0.000118	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003080**
Tertiary Sector	Regulation and promotion of economic development	**8141**	0.00220	0.001254	0.000106	0.000024	0.000006	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.003594**
Tertiary Sector	Justice administration and security and public order preservation	**9311**	0.00493	0.000358	0.000057	0.000015	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.005366**
Tertiary Sector	Regulation and promotion of environmental improvement and preservation activities	**9312**	0.00144	0.000445	0.000069	0.000018	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001974**
Tertiary Sector	Administrative activities of social welfare institutions	**9313**	0.00059	0.000312	0.000055	0.000014	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000976**
Tertiary Sector	Foreign affairs	**9314**	0.00018	0.000281	0.000228	0.000044	0.000011	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000746**
Tertiary Sector	National security activities	**9315**	0.00410	0.000138	0.000030	0.000008	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004282**
Tertiary Sector	Extraterritorial and international organizations	**9316**	0.00616	0.001701	0.000186	0.000045	0.000010	0.000002	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.008107**

Appendix A-5

Table AP.A5 Comparison of total energy intensities derived using Leontief inverse matrix and Power series approxximation

SECTOR	ID	Code	Leontief inverse matrix (A)	Power series of approximation (B)	Comparison (A/B)
Oilseed, legume and cereal growing	1	1111	0.002169	0.002169	100.00%
Vegetable growing	2	1112	0.001136	0.001136	100.00%
Fruit and tree nut growing	3	1113	0.000819	0.000819	100.00%
Greenhouse and nursery growing, and floriculture	4	1114	0.001702	0.001702	100.00%
Other crop growing	5	1119	0.003492	0.003492	100.00%
Cattle raising	6	1121	0.001760	0.001760	100.00%
Pig raising	7	1122	0.001014	0.001014	100.00%
Poultry raising	8	1123	0.000895	0.000895	100.00%
Sheep and goat raising	9	1124	0.000649	0.000649	100.00%
Aquaculture	10	1125	0.003391	0.003391	100.00%
Other animal production	11	1129	0.007231	0.007231	100.00%
Silviculture	12	1131	0.000626	0.000626	100.00%
Forest nurseries and gathering of forest products	13	1132	0.000103	0.000103	100.00%
Logging	14	1133	0.000586	0.000586	100.00%
Fishing	15	1141	0.016246	0.016246	100.00%
Hunting and trapping	16	1142	0.001376	0.001376	100.00%
Services related to agriculture	17	1151	0.001112	0.001112	100.00%
Services related to animal breeding and production	18	1152	0.001344	0.001344	100.00%
Services related to forestry	19	1153	0.003873	0.003873	100.00%
Oil and gas extraction	20	2111	0.000840	0.000840	100.00%
Metallic ore mining	22	2122	0.001541	0.001541	100.00%
Nonmetallic ore mining	23	2123	0.004601	0.004601	100.00%
Services related to mining	24	2131	0.001280	0.001280	100.00%
Water collection, treatment and supply	26	2221	0.001984	0.001984	100.00%
Residential building construction	28	2361	0.001224	0.001224	100.00%
Nonresidential building construction	29	2362	0.002158	0.002158	100.00%
Construction works for water, oil, gas, electric power and telecommunications supply	30	2371	0.002614	0.002614	100.00%
Land division and urbanization works	31	2372	0.002261	0.002261	100.00%
Construction of roads, highways and similar works	32	2373	0.002869	0.002869	100.00%
Other civil engineering construction	33	2379	0.004184	0.004184	100.00%
Other specialized construction works	34	2389	0.002840	0.002840	100.00%
Animal food manufacturing	35	3111	0.001686	0.001686	100.00%
Grain and seed milling, and fats and oils manufacturing	36	3112	0.001589	0.001589	100.00%
Sugar, chocolate, candies and similar products manufacturing	37	3113	0.003185	0.003185	100.00%
Fruits, vegetables and prepared meals preserving	38	3114	0.001360	0.001360	100.00%
Dairy products manufacturing	39	3115	0.002058	0.002058	100.00%
Livestock, poultry and other edible animals slaughtering, packaging and processing	40	3116	0.001928	0.001928	100.00%

Seafood preparation and packaging	41	3117	0.005698	0.005698	100.00%
Bakery products and tortilla manufacturing	42	3118	0.001804	0.001804	100.00%
Other food manufacturing	43	3119	0.001645	0.001645	100.00%
Beverage industry	44	3121	0.002142	0.002142	100.00%
Tobacco industry	45	3122	0.000147	0.000147	100.00%
Textile fibers preparation and spinning, and thread and yarn manufacturing	46	3131	0.001835	0.001835	100.00%
Fabrics manufacturing	47	3132	0.001972	0.001972	100.00%
Textile products finishing and coated fabrics manufacturing	48	3133	0.001190	0.001190	100.00%
Rugs, linens and similar products confectioning	49	3141	0.000901	0.000901	100.00%
Other textile products manufacturing, except apparel	50	3149	0.000752	0.000752	100.00%
Knitted apparel manufacturing	51	3151	0.001256	0.001256	100.00%
Cut and sew apparel manufacturing	52	3152	0.000874	0.000874	100.00%
Cut and sew apparel accessories and other apparel manufacturing, not elsewhere classified	53	3159	0.001623	0.001623	100.00%
Leather and fur tanning and finishing	54	3161	0.001735	0.001735	100.00%
Footwear manufacturing	55	3162	0.000845	0.000845	100.00%
Manufacturing of other leather, fur and allied materials products	56	3169	0.001300	0.001300	100.00%
Wood sawing and preservation	57	3211	0.005956	0.005956	100.00%
Wood laminates and fiberboard manufacturing	58	3212	0.003671	0.003671	100.00%
Other wood products manufacturing	59	3219	0.002588	0.002588	100.00%
Pulp, paper and paperboard manufacturing	60	3221	0.004947	0.004947	100.00%
Paperboard and paper products manufacturing	61	3222	0.002006	0.002006	100.00%
Printing and related industries	62	3231	0.002015	0.002015	100.00%
Basic chemical products manufacturing	64	3251	0.001123	0.001123	100.00%
Synthetic resins and rubbers, and chemical fibers manufacturing	65	3252	0.001656	0.001656	100.00%
Fertilizers, pesticides and other agrochemical products manufacturing	66	3253	0.003681	0.003681	100.00%
Pharmaceutical products manufacturing	67	3254	0.000618	0.000618	100.00%
Paints, coatings, and adhesives manufacturing	68	3255	0.001996	0.001996	100.00%
Soaps, cleaners and toilet preparations manufacturing	69	3256	0.001190	0.001190	100.00%
Other chemical products manufacturing	70	3259	0.001852	0.001852	100.00%
Plastic products manufacturing	71	3261	0.000912	0.000912	100.00%
Rubber products manufacturing	72	3262	0.001784	0.001784	100.00%
Manufacturing of products based on clays and refractory minerals	73	3271	0.004296	0.004296	100.00%
Glass and glass products manufacturing	74	3272	0.004105	0.004105	100.00%
Cement and concrete products manufacturing	75	3273	0.007102	0.007102	100.00%
Lime, gypsum and gypsum products manufacturing	76	3274	0.005652	0.005652	100.00%
Other nonmetallic mineral products manufacturing	77	3279	0.002243	0.002243	100.00%
Iron and steel basic industry	78	3311	0.001215	0.001215	100.00%
Iron and steel products manufacturing	79	3312	0.001340	0.001340	100.00%
Aluminum basic industry	80	3313	0.000627	0.000627	100.00%
Nonferrous metal industry, except aluminum	81	3314	0.000960	0.000960	100.00%
Metal parts molding by casting	82	3315	0.001039	0.001039	100.00%
Forged and stamped metal products manufacturing	83	3321	0.001170	0.001170	100.00%

Nonpowered hand tools and metal kitchen utensils manufacturing	84	3322	0.000851	0.000851	100.00%
Metal structures and iron works products manufacturing	85	3323	0.001186	0.001186	100.00%
Boilers, tanks and metal containers manufacturing	86	3324	0.001107	0.001107	100.00%
Metal fittings and locks manufacturing	87	3325	0.000063	0.000063	100.00%
Wire, wire products and springs manufacturing	88	3326	0.000993	0.000993	100.00%
Metal parts machining and screws manufacturing	89	3327	0.002508	0.002508	100.00%
Metal coating and finishings	90	3328	0.002738	0.002738	100.00%
Other metal products manufacturing	91	3329	0.001234	0.001234	100.00%
Agricultural, construction and extractive industry machinery and equipment manufacturing	92	3331	0.001234	0.001234	100.00%
Industrial machinery and equipment manufacturing, except metalworking	93	3332	0.000910	0.000910	100.00%
Commercial and service industry machinery and equipment manufacturing	94	3333	0.000719	0.000719	100.00%
Air conditioning, heating, and industrial and commercial refrigeration equipment manufacturing	95	3334	0.000850	0.000850	100.00%
Metalworking industry machinery and equipment manufacturing	96	3335	0.001108	0.001108	100.00%
Internal combustion engines, turbines and power transmissions manufacturing	97	3336	0.001262	0.001262	100.00%
Other general purpose machinery and equipment manufacturing	98	3339	0.001563	0.001563	100.00%
Computer and peripheral equipment manufacturing	99	3341	0.000044	0.000044	100.00%
Communications equipment manufacturing	100	3342	0.000591	0.000591	100.00%
Audio and video equipment manufacturing	101	3343	0.000006	0.000006	100.00%
Electronic components manufacturing	102	3344	0.000606	0.000606	100.00%
Manufacturing of measuring, control, navigation instruments and electronic medical equipment manufacturing	103	3345	0.000555	0.000555	100.00%
Manufacturing and reproducing magnetic and optical media	104	3346	0.000595	0.000595	100.00%
Lighting accessories manufacturing	105	3351	0.001179	0.001179	100.00%
Household electrical appliances manufacturing	106	3352	0.000809	0.000809	100.00%
Electric power generation and distribution equipment manufacturing	107	3353	0.000663	0.000663	100.00%
Other electrical equipment and accessories manufacturing	108	3359	0.000496	0.000496	100.00%
Automobiles and trucks manufacturing	109	3361	0.000463	0.000463	100.00%
Motor vehicle bodies and trailers manufacturing	110	3362	0.000982	0.000982	100.00%
Motor vehicle parts manufacturing	111	3363	0.000818	0.000818	100.00%
Aerospace equipment manufacturing	112	3364	0.000499	0.000499	100.00%
Railroad equipment manufacturing	113	3365	0.001471	0.001471	100.00%
Ship and boat manufacturing	114	3366	0.000533	0.000533	100.00%
Other transportation equipment manufacturing	115	3369	0.000706	0.000706	100.00%
Furniture manufacturing, except office furniture and shelving	116	3371	0.002257	0.002257	100.00%
Office furniture and shelving manufacturing	117	3372	0.001572	0.001572	100.00%
Mattresses, blinds and curtain rods manufacturing	118	3379	0.002032	0.002032	100.00%
Manufacturing of nonelectronic medical, dental and laboratory equipment and disposable material, and ophthalmic goods manufacturing	119	3391	0.001258	0.001258	100.00%
Other manufacturing industries	120	3399	0.001060	0.001060	100.00%
Wholesale trade	121	4311	0.000599	0.000599	100.00%
Scheduled air transportation	122	4811	0.028488	0.028488	100.00%

Nonscheduled air transportation	123	4812	0.013544	0.013544	100.00%
Rail transportation	124	4821	0.012337	0.012337	100.00%
Maritime transportation	125	4831	0.001934	0.001934	100.00%
Inland water transportation	126	4832	0.008416	0.008416	100.00%
General freight trucking	127	4841	0.011155	0.011155	100.00%
Urban and suburban collective passenger transportation, fixed route	128	4851	0.015733	0.015733	100.00%
Long-distance collective passenger transportation, fixed route	129	4852	0.018013	0.018013	100.00%
Taxi and limousine services	130	4853	0.018321	0.018321	100.00%
School and employee transportation	131	4854	0.024102	0.024102	100.00%
Bus rental with driver	132	4855	0.007626	0.007626	100.00%
Other passenger transportation by road	133	4859	0.029823	0.029823	100.00%
Pipeline transportation of natural gas	134	4862	0.004174	0.004174	100.00%
Pipeline transportation of other products	135	4869	0.000085	0.000085	100.00%
Sightseeing transportation by land	136	4871	0.009468	0.009468	100.00%
Sightseeing transportation by water	137	4872	0.011611	0.011611	100.00%
Other sightseeing transportation	138	4879	0.005334	0.005334	100.00%
Services related to air transportation	139	4881	0.000649	0.000649	100.00%
Services related to rail transportation	140	4882	0.002009	0.002009	100.00%
Services related to water transportation	141	4883	0.002441	0.002441	100.00%
Services related to road transportation	142	4884	0.000744	0.000744	100.00%
Intermediation services for freight transportation	143	4885	0.000544	0.000544	100.00%
Other services related to transportation	144	4889	0.001394	0.001394	100.00%
Postal services	145	4911	0.001879	0.001879	100.00%
Long-distance courier and messenger services	146	4921	0.009554	0.009554	100.00%
Warehousing services	147	4931	0.002044	0.002044	100.00%
Newspaper, magazine, book, software and other materials publishing and integrated publishing/printing of these publications	148	5111	0.001428	0.001428	100.00%
Software publishing, and integrated software publishing/reproduction	149	5112	0.000175	0.000175	100.00%
Film and video industry	150	5121	0.000559	0.000559	100.00%
Sound recording industry	151	5122	0.000824	0.000824	100.00%
Radio and television broadcasting	152	5151	0.000779	0.000779	100.00%
Production of channel programming for cable or satellite television systems	153	5152	0.001114	0.001114	100.00%
Wired telecommunications carriers	154	5171	0.001291	0.001291	100.00%
Wireless telecommunications carriers, except satellite services	155	5172	0.000395	0.000395	100.00%
Satellite telecommunications services	156	5174	0.000136	0.000136	100.00%
Other telecommunications services	157	5179	0.000554	0.000554	100.00%
Electronic data processing, hosting, and other related services	158	5182	0.000584	0.000584	100.00%
Other information services	159	5191	0.000712	0.000712	100.00%
Central bank	160	5211	0.000363	0.000363	100.00%
Multiple banking	161	5221	0.000598	0.000598	100.00%
Financial institutions for economic development	162	5222	0.000344	0.000344	100.00%
Credit unions and saving institutions	163	5223	0.001703	0.001703	100.00%
Other credit and financial intermediation institutions, non-stock exchange	164	5224	0.001224	0.001224	100.00%

Services related to credit intermediation, non-stock exchange	165	5225	0.003220	0.003220	100.00%
Brokerage houses, foreign currency exchange houses and exchange offices	166	5231	0.001225	0.001225	100.00%
Stock exchange	167	5232	0.000565	0.000565	100.00%
Investment advice and other services related to stock exchange intermediation	168	5239	0.000837	0.000837	100.00%
Insurance and surety institutions	169	5241	0.000543	0.000543	100.00%
Services related to insurance and surety	170	5242	0.000440	0.000440	100.00%
Rental of real estate without intermediation	171	5311	0.000803	0.000803	100.00%
Real estate agencies and brokers	172	5312	0.000745	0.000745	100.00%
Services related to real estate	173	5313	0.001123	0.001123	100.00%
Rental of automobiles, trucks and other road transportation vehicles	174	5321	0.007016	0.007016	100.00%
Rental of household and personal goods	175	5322	0.001885	0.001885	100.00%
General rental centers	176	5323	0.003988	0.003988	100.00%
Rental of agricultural, fishing, industrial, commercial and services machinery and equipment	177	5324	0.003874	0.003874	100.00%
Rental services of trademarks, patents and franchises	178	5331	0.000653	0.000653	100.00%
Legal services	179	5411	0.001505	0.001505	100.00%
Accounting, auditing and related services	180	5412	0.001248	0.001248	100.00%
Architecture, engineering and related activities services	181	5413	0.000593	0.000593	100.00%
Specialized design	182	5414	0.000639	0.000639	100.00%
Computer systems design and related services	183	5415	0.000324	0.000324	100.00%
Management, scientific and technical consulting services	184	5416	0.000530	0.000530	100.00%
Scientific research and development services	185	5417	0.001557	0.001557	100.00%
Advertising services and related activities	186	5418	0.000905	0.000905	100.00%
Other professional, scientific and technical services	187	5419	0.000765	0.000765	100.00%
Head offices	188	5511	0.000992	0.000992	100.00%
Business administration services	189	5611	0.000730	0.000730	100.00%
Facilities support services	190	5612	0.001432	0.001432	100.00%
Employment services	191	5613	0.000154	0.000154	100.00%
Secretarial support, photocopying, collection, credit investigation and similar services	192	5614	0.001318	0.001318	100.00%
Travel agencies and reservation services	193	5615	0.001128	0.001128	100.00%
Investigation, protection and security services	194	5616	0.001604	0.001604	100.00%
Cleaning services	195	5617	0.001136	0.001136	100.00%
Other business support services	196	5619	0.000906	0.000906	100.00%
Waste management and remediation services	197	5621	0.003507	0.003507	100.00%
Basic, middle and special needs education schools	198	6111	0.000258	0.000258	100.00%
Higher technical education schools	199	6112	0.001410	0.001410	100.00%
Higher education schools	200	6113	0.000531	0.000531	100.00%
Business, computer and management training schools	201	6114	0.000762	0.000762	100.00%
Trade schools	202	6115	0.002159	0.002159	100.00%
Other educational services	203	6116	0.001497	0.001497	100.00%
Educational support services	204	6117	0.000587	0.000587	100.00%
Medical doctors offices	205	6211	0.001423	0.001423	100.00%
Dental offices	206	6212	0.000567	0.000567	100.00%

Other health care offices	207	6213	0.001048	0.001048	100.00%
Outpatient care centers	208	6214	0.000866	0.000866	100.00%
Medical and diagnostic laboratories	209	6215	0.001018	0.001018	100.00%
Home nursing services	210	6216	0.001028	0.001028	100.00%
Ambulance services, organ banks and other medical treatment ancillary services	211	6219	0.004058	0.004058	100.00%
General hospitals	212	6221	0.001539	0.001539	100.00%
Psychiatric and addiction hospitals	213	6222	0.001204	0.001204	100.00%
Other medical specialties hospitals	214	6223	0.001522	0.001522	100.00%
Residential facilities with nursing care for convalescent, in rehabilitation, incurable and terminal patients	215	6231	0.002089	0.002089	100.00%
Residential care facilities for persons with mental retardation, mental disorder and addictions	216	6232	0.000879	0.000879	100.00%
Homes and other residential care facilities for the elderly	217	6233	0.002082	0.002082	100.00%
Orphanages and other social assistance residential care facilities	218	6239	0.001167	0.001167	100.00%
Guidance and social work services	219	6241	0.002327	0.002327	100.00%
Community food, housing and emergency services	220	6242	0.003451	0.003451	100.00%
Job training services for unemployed, underemployed or disabled persons	221	6243	0.000752	0.000752	100.00%
Nurseries	222	6244	0.001437	0.001437	100.00%
Performing arts companies and groups	223	7111	0.000477	0.000477	100.00%
Professional athletes and sports teams	224	7112	0.004174	0.004174	100.00%
Promoters of performing arts, sports and similar events	225	7113	0.001094	0.001094	100.00%
Agents and managers for artists, athletes and similar figures	226	7114	0.001342	0.001342	100.00%
Independent artists, writers and technicians	227	7115	0.000067	0.000067	100.00%
Museums, historical sites, zoos and similar institutions	228	7121	0.001562	0.001562	100.00%
Parks with recreational facilities and amusement arcades	229	7131	0.000786	0.000786	100.00%
Casinos, lotteries and other gambling services	230	7132	0.000813	0.000813	100.00%
Other recreational services	231	7139	0.002265	0.002265	100.00%
Hotels, motels and similar facilities	232	7211	0.001395	0.001395	100.00%
Recreational camps and lodgings	233	7212	0.002860	0.002860	100.00%
Rooming and boarding houses, and furnished apartments and houses with maid services	234	7213	0.001110	0.001110	100.00%
Full service restaurants	235	7221	0.001195	0.001195	100.00%
Self-service, take-out and other limited service restaurants	236	7222	0.001599	0.001599	100.00%
Food catering services	237	7223	0.000532	0.000532	100.00%
Nightclubs, bars and similar drinking places	238	7224	0.000860	0.000860	100.00%
Repair and maintenance of automobiles and trucks	239	8111	0.002807	0.002807	100.00%
Electronic and precision equipment repair and maintenance	240	8112	0.001100	0.001100	100.00%
Agricultural, industrial, commercial and services machinery and equipment repair and maintenance	241	8113	0.002218	0.002218	100.00%
Household and personal goods repair and maintenance	242	8114	0.002590	0.002590	100.00%
Beauty salons and clinics, public baths and washrooms, and shoeshine shops	243	8121	0.000872	0.000872	100.00%
Laundries and dry-cleaning shops	244	8122	0.003883	0.003883	100.00%
Funeral services and cemetery management	245	8123	0.001308	0.001308	100.00%

Parking lots and garages for motor vehicle	246	8124	0.000669	0.000669	100.00%
Photograph developing and printing and other personal services	247	8129	0.000096	0.000096	100.00%
Commercial, labor, professional and recreational associations and organizations	248	8131	0.008597	0.008597	100.00%
Religious, political and civic associations and organizations	249	8132	0.001227	0.001227	100.00%
Private households employing domestic personnel	250	8141	0.000000	0.000000	#DIV/0!
Legislative bodies	251	9311	0.001458	0.001458	100.00%
General public administration	252	9312	0.003080	0.003080	100.00%
Regulation and promotion of economic development	253	9313	0.003594	0.003594	100.00%
Justice administration and security and public order preservation	254	9314	0.005366	0.005366	100.00%
Regulation and promotion of environmental improvement and preservation activities	255	9315	0.001974	0.001974	100.00%
Administrative activities of social welfare institutions	256	9316	0.000976	0.000976	100.00%
Foreign affairs	257	9317	0.000746	0.000746	100.00%
National security activities	258	9318	0.004282	0.004282	100.00%
Extraterritorial and international organizations	259	9321	0.008107	0.008107	100.00%

Appendix A-6

Table AP.A6 Total and highlighted energy paths of the Mexican residential building construction sector (2361)

SECTORS	T SECT	DEI	Stage1	Stage2	Stage3	Stage4	Stage5	Stage6	Stage7	Stage8	Stage9	Stage10	Stage11	Stage12	TEI	%
Residential building construction	**2361**	**0.00047093**	**0.00059385**	**0.00012500**	**0.00002636**	**0.00000588**	**0.00000136**	**0.00000032**	**0.00000008**	**0.00000002**	**0.00000000**	**0.00000000**	**0.00000000**	**0.00000000**	**0.00122379**	**100.00%**
Residential building construction	**2361**	0.00047093	0.00000281	0.00000355	0.00000075	0.00000016	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00047823	39.08%
Cement and concrete products manufacturing	3273		0.00020154	0.00003267	0.00000494	0.00000085	0.00000017	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00024022	19.63%
Other specialized construction works	2389		0.00010643	0.00001221	0.00000375	0.00000088	0.00000022	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00012355	10.10%
General freight trucking	4841		0.00006428	0.00000102	0.00000021	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00006557	5.36%
Manufacturing of products based on clays and refractory minerals	3271		0.00003662	0.00000555	0.00000079	0.00000016	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00004317	3.53%
Nonmetallic ore mining	2123		0.00003825	0.00000249	0.00000039	0.00000010	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00004126	3.37%
Iron and steel basic industry	3311		0.00001564	0.00000913	0.00000197	0.00000042	0.00000009	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00002728	2.23%
Wholesale trade	4311		0.00001361	0.00000615	0.00000178	0.00000047	0.00000012	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00002216	1.81%
Lime, gypsum and gypsum products manufacturing	3274		0.00001434	0.00000360	0.00000054	0.00000010	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00001861	1.52%
Wood sawing and preservation	3211		0.00001007	0.00000101	0.00000032	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00001146	0.94%
Rental of agricultural, fishing,	5324		0.00000955	0.00000078	0.00000021	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00001060	0.87%

industrial, commercial and services machinery and equipment																
Iron and steel products manufacturing	3312		0.00000492	0.00000339	0.00000111	0.00000028	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000978	0.80 %
Glass and glass products manufacturing	3272		0.00000700	0.00000150	0.00000031	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000889	0.73 %
Other nonmetallic mineral products manufacturing	3279		0.00000426	0.00000362	0.00000058	0.00000011	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000860	0.70 %
Plastic products manufacturing	3261		0.00000286	0.00000336	0.00000093	0.00000023	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000745	0.61 %
Metal structures and iron works products manufacturing	3323		0.00000435	0.00000203	0.00000057	0.00000018	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000719	0.59 %
Rubber products manufacturing	3262		0.00000446	0.00000165	0.00000043	0.00000010	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000667	0.55 %
Other wood products manufacturing	3219		0.00000316	0.00000275	0.00000037	0.00000010	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000640	0.52 %
Furniture manufacturing , except office furniture and shelving	3371		0.00000284	0.00000250	0.00000046	0.00000011	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000594	0.49 %
Long-distance collective passenger transportation, fixed route	4852		0.00000544	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000553	0.45 %
Paints, coatings, and adhesives manufacturing	3255		0.00000381	0.00000102	0.00000028	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000520	0.42 %
Wood laminates and fiberboard manufacturing	3212		0.00000238	0.00000239	0.00000029	0.00000008	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000516	0.42 %

Fertilizers, pesticides and other agrochemical products manufacturing	3253		0.00000365	0.00000117	0.00000017	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000503	0.41%
Accounting, auditing and related services	5412		0.00000295	0.00000155	0.00000023	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000479	0.39%
Repair and maintenance of automobiles and trucks	8111		0.00000369	0.00000037	0.00000008	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000416	0.34%
Wired telecommunications carriers	5171		0.00000286	0.00000066	0.00000016	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000372	0.30%
Rail transportation	4821		0.00000348	0.00000013	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000363	0.30%
Multiple banking	5221		0.00000006	0.00000254	0.00000041	0.00000009	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000313	0.26%
Architecture, engineering and related activities services	5413		0.00000185	0.00000067	0.00000046	0.00000009	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000311	0.25%
Brokerage houses, foreign currency exchange houses and exchange offices	5231		0.00000015	0.00000262	0.00000016	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000297	0.24%
Soaps, cleaners and toilet preparations manufacturing	3256		0.00000137	0.00000115	0.00000033	0.00000008	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000295	0.24%
Other electrical equipment and accessories manufacturing	3359		0.00000042	0.00000117	0.00000061	0.00000015	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000239	0.20%
Metal parts molding by casting	3315		0.00000101	0.00000074	0.00000023	0.00000006	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000206	0.17%

Metal coating and finishings	3328		0.00000124	0.00000039	0.00000018	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000189	0.15%
Hotels, motels and similar facilities	7211		0.00000138	0.00000023	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000170	0.14%
Financial institutions for economic development	5222		0.00000002	0.00000122	0.00000036	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000168	0.14%
Other credit and financial intermediation institutions, non-stock exchange	5224		0.00000018	0.00000114	0.00000009	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000145	0.12%
Forged and stamped metal products manufacturing	3321		0.00000060	0.00000061	0.00000016	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000144	0.12%
Employment services	5613		0.00000072	0.00000045	0.00000013	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000134	0.11%
Scheduled air transportation	4811		0.00000119	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000121	0.10%
Agricultural, industrial, commercial and services machinery and equipment repair and maintenance	8113		0.00000096	0.00000017	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000120	0.10%
Rental of real estate without intermediation	5311		0.00000105	0.00000006	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000112	0.09%
Pulp, paper and paperboard manufacturing	3221		0.00000086	0.00000017	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000107	0.09%
Other metal products manufacturing	3329		0.00000041	0.00000048	0.00000012	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000105	0.09%
Agricultural, construction and extractive industry machinery and equipment manufacturing	3331		0.00000031	0.00000047	0.00000015	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000099	0.08%

Wire, wire products and springs manufacturing	3326		0.00000024	0.00000049	0.00000016	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000096	0.08 %
Wireless telecommunications carriers, except satellite services	5172		0.00000016	0.00000060	0.00000014	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000094	0.08 %
Commercial, labor, professional and recreational associations and organizations	8131		0.00000077	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000084	0.07 %
Boilers, tanks and metal containers manufacturing	3324		0.00000025	0.00000035	0.00000011	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000075	0.06 %
Nonferrous metal industry, except aluminum	3314		0.00000002	0.00000050	0.00000012	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000067	0.05 %
Investment advice and other services related to stock exchange intermediation	5239		0.00000012	0.00000036	0.00000009	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000061	0.05 %
Lighting accessories manufacturing	3351		0.00000029	0.00000021	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000055	0.04 %
Water collection, treatment and supply	2221		0.00000038	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000044	0.04 %
Basic chemical products manufacturing	3251		0.00000021	0.00000016	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000041	0.03 %
Aluminum basic industry	3313		0.00000020	0.00000017	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000040	0.03 %

Pipeline transportation of natural gas	4862		0.00000034	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000036	0.03%
Paperboard and paper products manufacturing	3222		0.00000011	0.00000015	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000030	0.02%
Other chemical products manufacturing	3259		0.00000022	0.00000006	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000030	0.02%
Maritime transportation	4831		0.00000020	0.00000006	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000027	0.02%
Rugs, linens and similar products confectioning	3141		0.00000011	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000021	0.02%
Metal parts machining and screws manufacturing	3327		0.00000015	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000020	0.02%
Insurance and surety institutions	5241		0.00000000	0.00000011	0.00000007	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000020	0.02%
Nonscheduled air transportation	4812		0.00000016	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000017	0.01%
Other manufacturing industries	3399		0.00000008	0.00000007	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000017	0.01%
Motor vehicle parts manufacturing	3363		0.00000004	0.00000009	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000016	0.01%
Intermediation services for freight transportation	4885		0.00000008	0.00000006	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000016	0.01%
Electric power generation and distribution equipment manufacturing	3353		0.00000003	0.00000010	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000016	0.01%
Other general purpose machinery and equipment manufacturing	3339		0.00000008	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000013	0.01%

Printing and related industries	3231		0.00000005	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000012	0.01%
Communications equipment manufacturing	3342		0.00000002	0.00000008	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000012	0.01%
Synthetic resins and rubbers, and chemical fibers manufacturing	3252		0.00000006	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000011	0.01%
Services related to water transportation	4883		0.00000010	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000011	0.01%
Services related to real estate	5313		0.00000004	0.00000004	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000010	0.01%
Nonpowered hand tools and metal kitchen utensils manufacturing	3322		0.00000003	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000009	0.01%
Manufacturing of nonelectronic medical, dental and laboratory equipment and disposable material, and ophthalmic goods manufacturing	3391		0.00000002	0.00000005	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000009	0.01%
Manufacturing and reproducing magnetic and optical media	3346		0.00000001	0.00000006	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000008	0.01%
Other crop growing	1119		0.00000007	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000008	0.01%
Footwear manufacturing	3162		0.00000003	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000007	0.01%
Services related to insurance and surety	5242		0.00000003	0.00000003	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000007	0.01%

Household electrical appliances manufacturing	3352		0.00000001	0.00000004	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000007	0.01%
Beverage industry	3121		0.00000004	0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000006	0.01%
Mattresses, blinds and curtain rods manufacturing	3379		0.00000003	0.00000002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000006	0.00%
Manufacturing of other leather, fur and allied materials products	3169		0.00000002	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000004	0.00%
Cut and sew apparel manufacturing	3152		0.00000001	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000003	0.00%
Manufacturing of measuring, control, navigation instruments and electronic medical equipment manufacturing	3345		0.00000000	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000002	0.00%
Other textile products manufacturing, except apparel	3149		0.00000001	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000002	0.00%
Credit unions and saving institutions	5223		0.00000001	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000002	0.00%
Greenhouse and nursery growing, and floriculture	1114		0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000001	0.00%
Internal combustion engines, turbines and power transmissions manufacturing	3336		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000001	0.00%
Services related to	5225		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

credit intermediation, non-stock exchange															
Other passenger transportation by road	4859		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Pipeline transportation of other products	4869		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Metal fittings and locks manufacturing	3325		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Air conditioning, heating, and industrial and commercial refrigeration equipment manufacturing	3334		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Sightseeing transportation by land	4871		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Inland water transportation	4832		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Services related to road transportation	4884		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Fabrics manufacturing	3132		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Sightseeing transportation by water	4872		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Rental services of trademarks, patents and franchises	5331		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Computer and peripheral equipment manufacturing	3341		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Bus rental with driver	4855		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

Electronic components manufacturing	3344		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Office furniture and shelving manufacturing	3372		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Forest nurseries and gathering of forest products	1132		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Textile fibers preparation and spinning, and thread and yarn manufacturing	3131		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Oilseed, legume and cereal growing	1111		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Vegetable growing	1112		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Fruit and tree nut growing	1113		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Cattle raising	1121		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Pig raising	1122		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Poultry raising	1123		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Sheep and goat raising	1124		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Aquaculture	1125		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other animal production	1129		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Silviculture	1131		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Logging	1133		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Fishing	1141		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

Hunting and trapping	1142		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Services related to agriculture	1151		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Services related to animal breeding and production	1152		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Services related to forestry	1153		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Oil and gas extraction	2111		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Coal mining	2121		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Metallic ore mining	2122		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Services related to mining	2131		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Electric power generation, transmission and distribution	2211		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Gas supply through mains to final consumers	2222		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Nonresidential building construction	2362		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Construction works for water, oil, gas, electric power and telecommunications supply	2371		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Land division and urbanization works	2372		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Construction of roads,	2373		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %

highways and similar works																
Other civil engineering construction	2379		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Animal food manufacturing	3111		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Grain and seed milling, and fats and oils manufacturing	3112		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Sugar, chocolate, candies and similar products manufacturing	3113		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Fruits, vegetables and prepared meals preserving	3114		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Dairy products manufacturing	3115		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Livestock, poultry and other edible animals slaughtering, packaging and processing	3116		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Seafood preparation and packaging	3117		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Bakery products and tortilla manufacturing	3118		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other food manufacturing	3119		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Tobacco industry	3122		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Textile products finishing and coated fabrics manufacturing	3133		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

Knitted apparel manufacturing	3151		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Cut and sew apparel accessories and other apparel manufacturing, not elsewhere classified	3159		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Leather and fur tanning and finishing	3161		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Manufacturing of products derived from petroleum and coal	3241		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Pharmaceutical products manufacturing	3254		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Industrial machinery and equipment manufacturing, except metalworking	3332		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Commercial and service industry machinery and equipment manufacturing	3333		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Metalworking industry machinery and equipment manufacturing	3335		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Audio and video equipment manufacturing	3343		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Automobiles and trucks manufacturing	3361		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Motor vehicle bodies and	3362		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

trailers manufacturing																
Aerospace equipment manufacturing	3364		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Railroad equipment manufacturing	3365		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Ship and boat manufacturing	3366		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other transportation equipment manufacturing	3369		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Urban and suburban collective passenger transportation, fixed route	4851		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Taxi and limousine services	4853		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
School and employee transportation	4854		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other sightseeing transportation	4879		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Services related to air transportation	4881		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Services related to rail transportation	4882		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other services related to transportation	4889		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Postal services	4911		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Long-distance courier and messenger services	4921		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Warehousing services	4931		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Newspaper, magazine,	5111		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

book, software and other materials publishing and integrated publishing/printing of these publications																
Software publishing, and integrated software publishing/reproduction	5112		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Film and video industry	5121		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Sound recording industry	5122		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Radio and television broadcasting	5151		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Production of channel programming for cable or satellite television systems	5152		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Satellite telecommunications services	5174		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Other telecommunications services	5179		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Electronic data processing, hosting, and other related services	5182		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Other information services	5191		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %
Central bank	5211		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00 %

Stock exchange	5232		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Real estate agencies and brokers	5312		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Rental of automobiles, trucks and other road transportation vehicles	5321		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Rental of household and personal goods	5322		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
General rental centers	5323		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Legal services	5411		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Specialized design	5414		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Computer systems design and related services	5415		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Management, scientific and technical consulting services	5416		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Scientific research and development services	5417		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Advertising services and related activities	5418		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other professional, scientific and technical services	5419		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Head offices	5511		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

Business administration services	5611		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Facilities support services	5612		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Secretarial support, photocopying, collection, credit investigation and similar services	5614		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Travel agencies and reservation services	5615		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Investigation, protection and security services	5616		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Cleaning services	5617		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other business support services	5619		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Waste management and remediation services	5621		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Basic, middle and special needs education schools	6111		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Higher technical education schools	6112		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Higher education schools	6113		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Business, computer and management	6114		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

training schools																
Trade schools	6115		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other educational services	6116		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Educational support services	6117		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Medical doctors offices	6211		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Dental offices	6212		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other health care offices	6213		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Outpatient care centers	6214		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Medical and diagnostic laboratories	6215		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Home nursing services	6216		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Ambulance services, organ banks and other medical treatment ancillary services	6219		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
General hospitals	6221		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Psychiatric and addiction hospitals	6222		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other medical specialties hospitals	6223		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Residential facilities with nursing care for convalescent, in rehabilitation,	6231		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

incurable and terminal patients																
Residential care facilities for persons with mental retardation, mental disorder and addictions	6232		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Homes and other residential care facilities for the elderly	6233		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Orphanages and other social assistance residential care facilities	6239		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Guidance and social work services	6241		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Community food, housing and emergency services	6242		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Job training services for unemployed, underemployed or disabled persons	6243		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Nurseries	6244		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Performing arts companies and groups	7111		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Professional athletes and sports teams	7112		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Promoters of performing arts, sports	7113		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

and similar events																
Agents and managers for artists, athletes and similar figures	7114		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Independent artists, writers and technicians	7115		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Museums, historical sites, zoos and similar institutions	7121		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Parks with recreational facilities and amusement arcades	7131		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Casinos, lotteries and other gambling services	7132		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Other recreational services	7139		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Recreational camps and lodgings	7212		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Rooming and boarding houses, and furnished apartments and houses with maid services	7213		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Full service restaurants	7221		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Self-service, take-out and other limited service restaurants	7222		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Food catering services	7223		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

Nightclubs, bars and similar drinking places	7224		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Electronic and precision equipment repair and maintenance	8112		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Household and personal goods repair and maintenance	8114		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Beauty salons and clinics, public baths and washrooms, and shoeshine shops	8121		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Laundries and dry-cleaning shops	8122		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Funeral services and cemetery management	8123		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Parking lots and garages for motor vehicle	8124		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Photograph developing and printing and other personal services	8129		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Religious, political and civic associations and organizations	8132		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Private households employing domestic personnel	8141		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%

Legislative bodies	9311		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
General public administration	9312		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Regulation and promotion of economic development	9313		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Justice administration and security and public order preservation	9314		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Regulation and promotion of environmental improvement and preservation activities	9315		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Administrative activities of social welfare institutions	9316		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Foreign affairs	9317		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
National security activities	9318		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
Extraterritorial and international organizations	9321		0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00%
		38.52%	**48.50%**	**10.20%**	**2.15%**	**0.48%**	**0.11%**	**0.03%**	**0.01%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**		
THRESHOLD VALUE	0.0000100	1	39	24	7	1	0	0	0	0	0	0	0	0		
	SECTORS	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12		

	255	1	257	66049	16974593	4362470401	1121154893057	28813680751564 9	74051159531521 800	19031147999601 100000	48910050358974 8000000 0	############## #####	############## #####	############## #####

Appendix B

Appendix B-1

Table AP.B1 Bioregional Built environment Inventory

NAICS CODE	ACTIVITY NAME	NUMBER OF ECONOMIC UNITS
212299	Other metallic ore mining	1
212319	Other dimensioned stones mining	1
212321	Construction sand and gravel mining	22
212322	Tezontle and tepetate mining	3
212329	Other clay and refractory minerals mining	1
213119	Other services related to mining	1
221110	Electric power generation, transmission and distribution	14
222111	Water collection, treatment and supply	42
222112	Water collection, treatment and supply, public sector	2
236111	Single-family housing construction	43
236112	Multifamily housing construction	4
236211	Industrial plants and buildings construction, except construction supervision	3
236221	Commercial and service building construction, except construction supervision	60
237111	Construction works for water treatment, distribution and supply, and drainage	13
237112	Agricultural irrigation systems construction	6
237131	Construction works for electric power generation and transmission	8
237132	Telecommunications construction works	2
237211	Land division	1
237212	Urbanization works	24
237213	Supervision of land division and urbanization construction works	1
237311	Installation of roadwork signs and protection	1
237312	Construction of highways, bridges and similar works	31
237999	Other civil engineering construction	5
238110	Foundation works	1
238122	Prefabricated steel structures assembly	1
238130	Masonry works	6
238190	Other exterior construction works	1
238210	Building electrical installations	14
238221	Sanitary and gas installations	14

238222	Central air conditioning and heating system installations	3
238290	Other building installations and equipment	9
238311	Drywall installation and insulation work	2
238320	Painting and other wall covering works	5
238330	Resilient and wood floor installation	1
238340	Ceramic floor and glazed tile installation	1
238390	Other building finishing works	5
238910	Construction site preparation	2
238990	Other specialized construction works	2
313111	Natural hard fibres preparation and spinning	4
313112	Natural soft fibres preparation and spinning	1
313240	Knitted fabrics manufacturing	3
313310	Textile products finishing	4
314120	Cut and sew curtains, linen and similar products manufacturing	11
314911	Cut and sew sacks manufacturing	6
314912	Cut and sew coated textile and allied materials products manufacturing	3
321112	Boards and planks sawing	1
321210	Wood laminates and fibreboard manufacturing	1
321910	Manufacturing of wood products for construction	250
321920	Wood containers and packaging products manufacturing	14
321991	Manufacturing of planting materials products, except palm	57
321992	Wood household goods and utensils manufacturing	19
321993	Manufacturing of wood products for industrial use	4
321999	Other wood products manufacturing	2
322122	Paper manufacturing from pulp	3
322132	Paperboard manufacturing from pulp	2
322210	Paperboard containers manufacturing	4
325180	Other basic inorganic chemical products manufacturing	1
325190	Other basic organic chemical products manufacturing	4
325211	Synthetic resins manufacturing	2
325310	Fertilizers manufacturing	1
325510	Paints and coatings manufacturing	6
325610	Soaps, cleaners and dentifrices manufacturing	8
325991	Matches manufacturing	1
325993	Resins of recycled plastics manufacturing	5
326110	Flexible plastic bags and films manufacturing	17
326120	Manufacturing of pipes, pipe fitting and packaging tubes manufacturing	3
326140	Polystyrene foam and polystyrene products manufacturing	3

326160	Plastic bottles manufacturing	1
326191	Reinforced and non-reinforced household plastic products manufacturing	1
326193	Manufacturing of reinforced and non-reinforced plastic containers for packaging	5
326194	Manufacturing of other non-reinforced plastic products for industrial use	1
326198	Other reinforced plastic products manufacturing	1
326199	Other non-reinforced plastic products manufacturing	5
326211	Tires and inner tubes manufacturing	1
326220	Rubber and plastic bands and hoses manufacturing	3
327121	Non-refractory bricks manufacturing	102
327123	Refractory products manufacturing	1
327215	Household glass goods manufacturing	2
327219	Other glass products manufacturing	10
327320	Concrete manufacturing	5
327330	Manufacturing of cement and concrete pipes and blocks	47
327399	Other cement and concrete products manufacturing	17
327410	Lime manufacturing	1
327420	Gypsum and gypsum products manufacturing	11
327991	Manufacturing of products based on quarry stone	49
327999	Other non-metallic mineral products manufacturing	1
331310	Aluminium basic industry	1
331510	Iron and steel parts moulding by casting	1
332110	Forged and stamped metal products manufacturing	1
332211	Non-powered metal hand tools manufacturing	6
332212	Metal kitchen utensils manufacturing	2
332310	Metal structures manufacturing	8
332320	Iron works products manufacturing	758
332410	Industrial boilers manufacturing	1
332420	Heavy gauge metal tanks manufacturing	1
332510	Metal fittings and locks manufacturing	2
332610	Wire, wire products and springs manufacturing	10
332710	Metal parts machining for general purpose machinery and equipment	53
332810	Metal coating and finishings	2
332999	Other metal products manufacturing	11
333111	Farming machinery and equipment manufacturing	1
333610	Internal combustion engines, turbines and power transmissions manufacturing	1
333993	Scales and balances manufacturing	1
333999	Other general purpose machinery and equipment manufacturing	1
335220	Major household manufacturing	2
335311	Electric motors and generators manufacturing	1

335312	Electric power distribution equipment and appliances manufacturing	1
335910	Accumulators and batteries manufacturing	1
336210	Motor vehicle bodies and trailers manufacturing	10
336390	Other automotive vehicle parts manufacturing	3
336610	Ship and boat manufacturing	1
337110	Integral kitchens and bathroom modular furniture manufacturing	53
337120	Furniture manufacturing, except integral kitchens, bathroom modular furniture, office furniture and shelvings	569
337210	Office furniture and shelving manufacturing	17
337920	Blinds and curtain rods manufacturing	6
433420	Wholesale trade of books	1
434211	Wholesale trade of cement, brick and gravel	195
434219	Wholesale trade of other construction materials, except wood and metallic materials	20
434221	Wholesale trade of metallic materials for construction and manufacturing	57
434224	Wholesale trade of wood for construction and manufacturing	76
434225	Wholesale trade of electric equipment and material	55
434227	Wholesale trade of glass and mirrors	5
434229	Wholesale trade of other raw materials for other industries	9
434230	Wholesale trade of fuel for industrial use	8
434311	Wholesale trade of metallic waste	66
434312	Wholesale trade of paper and paperboard waste	15
434313	Wholesale trade of glass waste	1
434314	Wholesale trade of plastic waste	22
434319	Wholesale trade of other waste materials	5
435210	Wholesale trade of construction and mining machinery and equipment	7
435220	Wholesale trade of manufacturing machinery and equipment	16
435419	Wholesale trade of other general purpose machinery and equipment	47
465911	Retail trade of pets	10
466111	Retail trade of household furniture	305
466112	Retail trade of small and major household appliances	90
466113	Retail trade of outdoor home furniture	1
466311	Retail trade of carpets, curtains, tapestries and similar products	32
466314	Retail trade of ornamental lamps and chandeliers	6
466410	Retail trade of used goods	29
467111	Retail trade of hardware	585

467112	Retail trade of ceramic floors and coverings	77
467113	Retail trade of paint	190
467114	Retail trade of glass and mirrors	204
467116	Retail trade of construction materials in specialized self-service shops	9
467117	Retail trade of pool equipment and accessories, and other articles	7
468411	Retail trade of gasoline and diesel	84
468412	Retail trade of LP gas in cylinders and for stationary tanks	16
468413	Retail trade of LP gas in gas filling stations	2
468419	Retail trade of other fuels	32
482110	Rail transportation	1
484129	Other general freight trucking, long-distance	34
484221	Construction materials trucking, local	4
484222	Hazardous material and waste trucking, local	4
484231	Construction materials trucking, long-distance	3
484232	Hazardous material and waste trucking, long-distance	1
484239	Other specialized freight trucking, long-distance	2
487110	Sightseeing transportation by land	1
488410	Motor vehicle towing services	7
488519	Other intermediation services for freight transportation	2
493119	Other general warehousing services in non-specialized facilities	7
531112	Rental of unfurnished dwellings without intermediation	11
531119	Rental of other real estate without intermediation	5
531210	Real estate agencies and brokers	71
531311	Real estate management services	18
531319	Other services related to real estate	17
532310	General rental centres	3
532411	Rental of construction, mining and forestry machinery and equipment	42
532492	Rental of materials handling machinery and equipment	9
541310	Architecture services	49
541330	Engineering services	22
543340	Drafting services	11
541350	Building inspection services	1
541380	Testing laboratories	7
541410	Interior design and decorating	10
541620	Environmental consulting services	9
541870	Advertising material distribution	1
541990	Other professional, scientific and technical services	2
551111	Head offices	3

931210	General public administration	18
931310	Regulation and promotion of economic development	2
931510	Regulation and promotion of environmental improvement and preservation activities	6
931610	Administrative activities of social welfare institutions	1

Appendix C

Appendix C-1

The follow table summarizes energy paths of NAICS sector 3271 Manufacturing of products based on clays and refractory minerals. The total inclusion of this table, which contains indirect energy coefficients from upstream stages 1 to 12 have not been included given the unpractical size to visualize its data. However, the importance to show the proportion of indirect flows to the manufacturing of clay bricks is expressed in percentage in last column, where 84.88% is the proportion of direct energy in this sector, the rest rows show the influence of the other sectors. In traditional process analysis (PA), these energy flows cannot be perceived.

SECTORS	NAICS	DEI	TEI	%
Manufacturing of products based on clays and refractory minerals	**3271**	**0.0036433722**	**0.0042955304**	**100.00 %**
Manufacturing of products based on clays and refractory minerals	3271	0.0036433722	0.0036458943	84.88%
Nonmetallic ore mining	2123	0.0000000000	0.0002890293	6.73%
General freight trucking	4841	0.0000000000	0.0000814861	1.90%
Paints, coatings, and adhesives manufacturing	3255	0.0000000000	0.0000641327	1.49%
Cement and concrete products manufacturing	3273	0.0000000000	0.0000312226	0.73%
Scheduled air transportation	4811	0.0000000000	0.0000293053	0.68%
Wholesale trade	4311	0.0000000000	0.0000270130	0.63%
Lime, gypsum and gypsum products manufacturing	3274	0.0000000000	0.0000220887	0.51%
Basic chemical products manufacturing	3251	0.0000000000	0.0000191606	0.45%
Paperboard and paper products manufacturing	3222	0.0000000000	0.0000070975	0.17%
Wood sawing and preservation	3211	0.0000000000	0.0000060879	0.14%
Rail transportation	4821	0.0000000000	0.0000046701	0.11%
Other wood products manufacturing	3219	0.0000000000	0.0000046582	0.11%
Agricultural, industrial, commercial and services machinery and equipment repair and maintenance	8113	0.0000000000	0.0000041183	0.10%
Rental of agricultural, fishing, industrial, commercial and services machinery and equipment	5324	0.0000000000	0.0000040255	0.09%
Employment services	5613	0.0000000000	0.0000038804	0.09%
Water collection, treatment and supply	2221	0.0000000000	0.0000033733	0.08%

Rental of automobiles, trucks and other road transportation vehicles	5321	0.0000000000	0.0000033522	0.08%
Repair and maintenance of automobiles and trucks	8111	0.0000000000	0.0000033510	0.08%
Accounting, auditing and related services	5412	0.0000000000	0.0000032825	0.08%
School and employee transportation	4854	0.0000000000	0.0000032642	0.08%
Commercial, labor, professional and recreational associations and organizations	8131	0.0000000000	0.0000027177	0.06%
Rental of real estate without intermediation	5311	0.0000000000	0.0000022954	0.05%
Brokerage houses, foreign currency exchange houses and exchange offices	5231	0.0000000000	0.0000021049	0.05%
Long-distance courier and messenger services	4921	0.0000000000	0.0000019377	0.05%
Multiple banking	5221	0.0000000000	0.0000017593	0.04%
Other credit and financial intermediation institutions, non-stock exchange	5224	0.0000000000	0.0000017424	0.04%
Business administration services	5611	0.0000000000	0.0000017169	0.04%
Nonferrous metal industry, except aluminum	3314	0.0000000000	0.0000016593	0.04%
Urban and suburban collective passenger transportation, fixed route	4851	0.0000000000	0.0000014052	0.03%
Investigation, protection and security services	5616	0.0000000000	0.0000012644	0.03%
Other chemical products manufacturing	3259	0.0000000000	0.0000011189	0.03%
Rubber products manufacturing	3262	0.0000000000	0.0000009751	0.02%
Warehousing services	4931	0.0000000000	0.0000007197	0.02%
Pulp, paper and paperboard manufacturing	3221	0.0000000000	0.0000006104	0.01%
Hotels, motels and similar facilities	7211	0.0000000000	0.0000005929	0.01%
Wired telecommunications carriers	5171	0.0000000000	0.0000005534	0.01%
Credit unions and saving institutions	5223	0.0000000000	0.0000005485	0.01%
Insurance and surety institutions	5241	0.0000000000	0.0000005273	0.01%
Cleaning services	5617	0.0000000000	0.0000005189	0.01%
Printing and related industries	3231	0.0000000000	0.0000005140	0.01%
Full service restaurants	7221	0.0000000000	0.0000005086	0.01%
Aluminum basic industry	3313	0.0000000000	0.0000004981	0.01%
Head offices	5511	0.0000000000	0.0000004978	0.01%
Pipeline transportation of natural gas	4862	0.0000000000	0.0000004677	0.01%
Other nonmetallic mineral products manufacturing	3279	0.0000000000	0.0000004561	0.01%
Other metal products manufacturing	3329	0.0000000000	0.0000004426	0.01%
Investment advice and other services related to stock exchange intermediation	5239	0.0000000000	0.0000004296	0.01%
Other manufacturing industries	3399	0.0000000000	0.0000004231	0.01%
Nonpowered hand tools and metal kitchen utensils manufacturing	3322	0.0000000000	0.0000003721	0.01%

Legal services	5411	0.0000000000	0.0000003659	0.01%
Services related to real estate	5313	0.0000000000	0.0000003618	0.01%
Maritime transportation	4831	0.0000000000	0.0000003441	0.01%
Glass and glass products manufacturing	3272	0.0000000000	0.0000003247	0.01%
Services related to water transportation	4883	0.0000000000	0.0000002813	0.01%
Newspaper, magazine, book, software and other materials publishing and integrated publishing/printing of these publications	5111	0.0000000000	0.0000002735	0.01%
Motor vehicle parts manufacturing	3363	0.0000000000	0.0000002539	0.01%
Grain and seed milling, and fats and oils manufacturing	3112	0.0000000000	0.0000002428	0.01%
Other general purpose machinery and equipment manufacturing	3339	0.0000000000	0.0000002380	0.01%
Other business support services	5619	0.0000000000	0.0000002303	0.01%
Plastic products manufacturing	3261	0.0000000000	0.0000002253	0.01%
Synthetic resins and rubbers, and chemical fibers manufacturing	3252	0.0000000000	0.0000002243	0.01%
Nonscheduled air transportation	4812	0.0000000000	0.0000002236	0.01%
Advertising services and related activities	5418	0.0000000000	0.0000002210	0.01%
Intermediation services for freight transportation	4885	0.0000000000	0.0000002024	0.00%
Footwear manufacturing	3162	0.0000000000	0.0000001899	0.00%
Architecture, engineering and related activities services	5413	0.0000000000	0.0000001672	0.00%
Financial institutions for economic development	5222	0.0000000000	0.0000001619	0.00%
Services related to credit intermediation, non-stock exchange	5225	0.0000000000	0.0000001531	0.00%
Wireless telecommunications carriers, except satellite services	5172	0.0000000000	0.0000001015	0.00%
Other specialized construction works	2389	0.0000000000	0.0000000955	0.00%
Services related to insurance and surety	5242	0.0000000000	0.0000000952	0.00%
Other professional, scientific and technical services	5419	0.0000000000	0.0000000946	0.00%
Cut and sew apparel manufacturing	3152	0.0000000000	0.0000000744	0.00%
Management, scientific and technical consulting services	5416	0.0000000000	0.0000000714	0.00%
Taxi and limousine services	4853	0.0000000000	0.0000000593	0.00%
Manufacturing of other leather, fur and allied materials products	3169	0.0000000000	0.0000000517	0.00%
Soaps, cleaners and toilet preparations manufacturing	3256	0.0000000000	0.0000000515	0.00%
Services related to air transportation	4881	0.0000000000	0.0000000324	0.00%
Electronic data processing, hosting, and other related services	5182	0.0000000000	0.0000000319	0.00%
Metal parts machining and screws manufacturing	3327	0.0000000000	0.0000000240	0.00%
Iron and steel basic industry	3311	0.0000000000	0.0000000205	0.00%

Metallic ore mining	2122	0.0000000000	0.0000000203	0.00%
Computer systems design and related services	5415	0.0000000000	0.0000000202	0.00%
Manufacturing of measuring, control, navigation instruments and electronic medical equipment manufacturing	3345	0.0000000000	0.0000000168	0.00%
Electronic and precision equipment repair and maintenance	8112	0.0000000000	0.0000000122	0.00%
Manufacturing of nonelectronic medical, dental and laboratory equipment and disposable material, and ophthalmic goods manufacturing	3391	0.0000000000	0.0000000120	0.00%
Business, computer and management training schools	6114	0.0000000000	0.0000000103	0.00%
Facilities support services	5612	0.0000000000	0.0000000100	0.00%
Electronic components manufacturing	3344	0.0000000000	0.0000000094	0.00%
Other passenger transportation by road	4859	0.0000000000	0.0000000068	0.00%
Industrial machinery and equipment manufacturing, except metalworking	3332	0.0000000000	0.0000000059	0.00%
Other telecommunications services	5179	0.0000000000	0.0000000058	0.00%
Textile fibers preparation and spinning, and thread and yarn manufacturing	3131	0.0000000000	0.0000000053	0.00%
Long-distance collective passenger transportation, fixed route	4852	0.0000000000	0.0000000043	0.00%
Pipeline transportation of other products	4869	0.0000000000	0.0000000038	0.00%
Secretarial support, photocopying, collection, credit investigation and similar services	5614	0.0000000000	0.0000000036	0.00%
Self-service, take-out and other limited service restaurants	7222	0.0000000000	0.0000000034	0.00%
Sightseeing transportation by land	4871	0.0000000000	0.0000000025	0.00%
Dairy products manufacturing	3115	0.0000000000	0.0000000020	0.00%
Iron and steel products manufacturing	3312	0.0000000000	0.0000000018	0.00%
Inland water transportation	4832	0.0000000000	0.0000000017	0.00%
Other textile products manufacturing, except apparel	3149	0.0000000000	0.0000000015	0.00%
Metal fittings and locks manufacturing	3325	0.0000000000	0.0000000013	0.00%
Rental services of trademarks, patents and franchises	5331	0.0000000000	0.0000000013	0.00%
Sugar, chocolate, candies and similar products manufacturing	3113	0.0000000000	0.0000000010	0.00%
Services related to road transportation	4884	0.0000000000	0.0000000010	0.00%
Sightseeing transportation by water	4872	0.0000000000	0.0000000009	0.00%
Communications equipment manufacturing	3342	0.0000000000	0.0000000009	0.00%
Other electrical equipment and accessories manufacturing	3359	0.0000000000	0.0000000009	0.00%
Food catering services	7223	0.0000000000	0.0000000006	0.00%
Cattle raising	1121	0.0000000000	0.0000000006	0.00%

Electric power generation and distribution equipment manufacturing	3353	0.0000000000	0.0000000004	0.00%
Waste management and remediation services	5621	0.0000000000	0.0000000002	0.00%
Bus rental with driver	4855	0.0000000000	0.0000000002	0.00%
Wire, wire products and springs manufacturing	3326	0.0000000000	0.0000000002	0.00%
Internal combustion engines, turbines and power transmissions manufacturing	3336	0.0000000000	0.0000000002	0.00%
Knitted apparel manufacturing	3151	0.0000000000	0.0000000002	0.00%
Household electrical appliances manufacturing	3352	0.0000000000	0.0000000001	0.00%
Fabrics manufacturing	3132	0.0000000000	0.0000000001	0.00%
Wood laminates and fiberboard manufacturing	3212	0.0000000000	0.0000000001	0.00%
Postal services	4911	0.0000000000	0.0000000001	0.00%
Forest nurseries and gathering of forest products	1132	0.0000000000	0.0000000001	0.00%
Air conditioning, heating, and industrial and commercial refrigeration equipment manufacturing	3334	0.0000000000	0.0000000000	0.00%
Metal parts molding by casting	3315	0.0000000000	0.0000000000	0.00%
Computer and peripheral equipment manufacturing	3341	0.0000000000	0.0000000000	0.00%
Oilseed, legume and cereal growing	1111	0.0000000000	0.0000000000	0.00%
Vegetable growing	1112	0.0000000000	0.0000000000	0.00%
Fruit and tree nut growing	1113	0.0000000000	0.0000000000	0.00%
Greenhouse and nursery growing, and floriculture	1114	0.0000000000	0.0000000000	0.00%
Other crop growing	1119	0.0000000000	0.0000000000	0.00%
Pig raising	1122	0.0000000000	0.0000000000	0.00%
Poultry raising	1123	0.0000000000	0.0000000000	0.00%
Sheep and goat raising	1124	0.0000000000	0.0000000000	0.00%
Aquaculture	1125	0.0000000000	0.0000000000	0.00%
Other animal production	1129	0.0000000000	0.0000000000	0.00%
Silviculture	1131	0.0000000000	0.0000000000	0.00%
Logging	1133	0.0000000000	0.0000000000	0.00%
Fishing	1141	0.0000000000	0.0000000000	0.00%
Hunting and trapping	1142	0.0000000000	0.0000000000	0.00%
Services related to agriculture	1151	0.0000000000	0.0000000000	0.00%
Services related to animal breeding and production	1152	0.0000000000	0.0000000000	0.00%
Services related to forestry	1153	0.0000000000	0.0000000000	0.00%
Oil and gas extraction	2111	0.0000000000	0.0000000000	0.00%
Coal mining	2121	0.0000000000	0.0000000000	0.00%
Services related to mining	2131	0.0000000000	0.0000000000	0.00%
Electric power generation, transmission and distribution	2211	0.0000000000	0.0000000000	0.00%

Gas supply through mains to final consumers	2222	0.0000000000	0.0000000000	0.00%
Residential building construction	2361	0.0000000000	0.0000000000	0.00%
Nonresidential building construction	2362	0.0000000000	0.0000000000	0.00%
Construction works for water, oil, gas, electric power and telecommunications supply	2371	0.0000000000	0.0000000000	0.00%
Land division and urbanization works	2372	0.0000000000	0.0000000000	0.00%
Construction of roads, highways and similar works	2373	0.0000000000	0.0000000000	0.00%
Other civil engineering construction	2379	0.0000000000	0.0000000000	0.00%
Animal food manufacturing	3111	0.0000000000	0.0000000000	0.00%
Fruits, vegetables and prepared meals preserving	3114	0.0000000000	0.0000000000	0.00%
Livestock, poultry and other edible animals slaughtering, packaging and processing	3116	0.0000000000	0.0000000000	0.00%
Seafood preparation and packaging	3117	0.0000000000	0.0000000000	0.00%
Bakery products and tortilla manufacturing	3118	0.0000000000	0.0000000000	0.00%
Other food manufacturing	3119	0.0000000000	0.0000000000	0.00%
Beverage industry	3121	0.0000000000	0.0000000000	0.00%
Tobacco industry	3122	0.0000000000	0.0000000000	0.00%
Textile products finishing and coated fabrics manufacturing	3133	0.0000000000	0.0000000000	0.00%
Rugs, linens and similar products confectioning	3141	0.0000000000	0.0000000000	0.00%
Cut and sew apparel accessories and other apparel manufacturing, not elsewhere classified	3159	0.0000000000	0.0000000000	0.00%
Leather and fur tanning and finishing	3161	0.0000000000	0.0000000000	0.00%
Manufacturing of products derived from petroleum and coal	3241	0.0000000000	0.0000000000	0.00%
Fertilizers, pesticides and other agrochemical products manufacturing	3253	0.0000000000	0.0000000000	0.00%
Pharmaceutical products manufacturing	3254	0.0000000000	0.0000000000	0.00%
Forged and stamped metal products manufacturing	3321	0.0000000000	0.0000000000	0.00%
Metal structures and iron works products manufacturing	3323	0.0000000000	0.0000000000	0.00%
Boilers, tanks and metal containers manufacturing	3324	0.0000000000	0.0000000000	0.00%
Metal coating and finishings	3328	0.0000000000	0.0000000000	0.00%
Agricultural, construction and extractive industry machinery and equipment manufacturing	3331	0.0000000000	0.0000000000	0.00%
Commercial and service industry machinery and equipment manufacturing	3333	0.0000000000	0.0000000000	0.00%
Metalworking industry machinery and equipment manufacturing	3335	0.0000000000	0.0000000000	0.00%
Audio and video equipment manufacturing	3343	0.0000000000	0.0000000000	0.00%

Manufacturing and reproducing magnetic and optical media	3346	0.0000000000	0.0000000000	0.00%
Lighting accessories manufacturing	3351	0.0000000000	0.0000000000	0.00%
Automobiles and trucks manufacturing	3361	0.0000000000	0.0000000000	0.00%
Motor vehicle bodies and trailers manufacturing	3362	0.0000000000	0.0000000000	0.00%
Aerospace equipment manufacturing	3364	0.0000000000	0.0000000000	0.00%
Railroad equipment manufacturing	3365	0.0000000000	0.0000000000	0.00%
Ship and boat manufacturing	3366	0.0000000000	0.0000000000	0.00%
Other transportation equipment manufacturing	3369	0.0000000000	0.0000000000	0.00%
Furniture manufacturing, except office furniture and shelving	3371	0.0000000000	0.0000000000	0.00%
Office furniture and shelving manufacturing	3372	0.0000000000	0.0000000000	0.00%
Mattresses, blinds and curtain rods manufacturing	3379	0.0000000000	0.0000000000	0.00%
Other sightseeing transportation	4879	0.0000000000	0.0000000000	0.00%
Services related to rail transportation	4882	0.0000000000	0.0000000000	0.00%
Other services related to transportation	4889	0.0000000000	0.0000000000	0.00%
Software publishing, and integrated software publishing/reproduction	5112	0.0000000000	0.0000000000	0.00%
Film and video industry	5121	0.0000000000	0.0000000000	0.00%
Sound recording industry	5122	0.0000000000	0.0000000000	0.00%
Radio and television broadcasting	5151	0.0000000000	0.0000000000	0.00%
Production of channel programming for cable or satellite television systems	5152	0.0000000000	0.0000000000	0.00%
Satellite telecommunications services	5174	0.0000000000	0.0000000000	0.00%
Other information services	5191	0.0000000000	0.0000000000	0.00%
Central bank	5211	0.0000000000	0.0000000000	0.00%
Stock exchange	5232	0.0000000000	0.0000000000	0.00%
Real estate agencies and brokers	5312	0.0000000000	0.0000000000	0.00%
Rental of household and personal goods	5322	0.0000000000	0.0000000000	0.00%
General rental centers	5323	0.0000000000	0.0000000000	0.00%
Specialized design	5414	0.0000000000	0.0000000000	0.00%
Scientific research and development services	5417	0.0000000000	0.0000000000	0.00%
Travel agencies and reservation services	5615	0.0000000000	0.0000000000	0.00%
Basic, middle and special needs education schools	6111	0.0000000000	0.0000000000	0.00%
Higher technical education schools	6112	0.0000000000	0.0000000000	0.00%
Higher education schools	6113	0.0000000000	0.0000000000	0.00%
Trade schools	6115	0.0000000000	0.0000000000	0.00%
Other educational services	6116	0.0000000000	0.0000000000	0.00%
Educational support services	6117	0.0000000000	0.0000000000	0.00%
Medical doctors offices	6211	0.0000000000	0.0000000000	0.00%

Dental offices	6212	0.0000000000	0.0000000000	0.00%
Other health care offices	6213	0.0000000000	0.0000000000	0.00%
Outpatient care centers	6214	0.0000000000	0.0000000000	0.00%
Medical and diagnostic laboratories	6215	0.0000000000	0.0000000000	0.00%
Home nursing services	6216	0.0000000000	0.0000000000	0.00%
Ambulance services, organ banks and other medical treatment ancillary services	6219	0.0000000000	0.0000000000	0.00%
General hospitals	6221	0.0000000000	0.0000000000	0.00%
Psychiatric and addiction hospitals	6222	0.0000000000	0.0000000000	0.00%
Other medical specialties hospitals	6223	0.0000000000	0.0000000000	0.00%
Residential facilities with nursing care for convalescent, in rehabilitation, incurable and terminal patients	6231	0.0000000000	0.0000000000	0.00%
Residential care facilities for persons with mental retardation, mental disorder and addictions	6232	0.0000000000	0.0000000000	0.00%
Homes and other residential care facilities for the elderly	6233	0.0000000000	0.0000000000	0.00%
Orphanages and other social assistance residential care facilities	6239	0.0000000000	0.0000000000	0.00%
Guidance and social work services	6241	0.0000000000	0.0000000000	0.00%
Community food, housing and emergency services	6242	0.0000000000	0.0000000000	0.00%
Job training services for unemployed, underemployed or disabled persons	6243	0.0000000000	0.0000000000	0.00%
Nurseries	6244	0.0000000000	0.0000000000	0.00%
Performing arts companies and groups	7111	0.0000000000	0.0000000000	0.00%
Professional athletes and sports teams	7112	0.0000000000	0.0000000000	0.00%
Promoters of performing arts, sports and similar events	7113	0.0000000000	0.0000000000	0.00%
Agents and managers for artists, athletes and similar figures	7114	0.0000000000	0.0000000000	0.00%
Independent artists, writers and technicians	7115	0.0000000000	0.0000000000	0.00%
Museums, historical sites, zoos and similar institutions	7121	0.0000000000	0.0000000000	0.00%
Parks with recreational facilities and amusement arcades	7131	0.0000000000	0.0000000000	0.00%
Casinos, lotteries and other gambling services	7132	0.0000000000	0.0000000000	0.00%
Other recreational services	7139	0.0000000000	0.0000000000	0.00%
Recreational camps and lodgings	7212	0.0000000000	0.0000000000	0.00%
Rooming and boarding houses, and furnished apartments and houses with maid services	7213	0.0000000000	0.0000000000	0.00%
Nightclubs, bars and similar drinking places	7224	0.0000000000	0.0000000000	0.00%
Household and personal goods repair and maintenance	8114	0.0000000000	0.0000000000	0.00%
Beauty salons and clinics, public baths and washrooms, and shoeshine shops	8121	0.0000000000	0.0000000000	0.00%

Laundries and dry-cleaning shops	8122	0.0000000000	0.0000000000	0.00%
Funeral services and cemetery management	8123	0.0000000000	0.0000000000	0.00%
Parking lots and garages for motor vehicle	8124	0.0000000000	0.0000000000	0.00%
Photograph developing and printing and other personal services	8129	0.0000000000	0.0000000000	0.00%
Religious, political and civic associations and organizations	8132	0.0000000000	0.0000000000	0.00%
Private households employing domestic personnel	8141	0.0000000000	0.0000000000	0.00%
Legislative bodies	9311	0.0000000000	0.0000000000	0.00%
General public administration	9312	0.0000000000	0.0000000000	0.00%
Regulation and promotion of economic development	9313	0.0000000000	0.0000000000	0.00%
Justice administration and security and public order preservation	9314	0.0000000000	0.0000000000	0.00%
Regulation and promotion of environmental improvement and preservation activities	9315	0.0000000000	0.0000000000	0.00%
Administrative activities of social welfare institutions	9316	0.0000000000	0.0000000000	0.00%
Foreign affairs	9317	0.0000000000	0.0000000000	0.00%
National security activities	9318	0.0000000000	0.0000000000	0.00%
Extraterritorial and international organizations	9321	0.0000000000	0.0000000000	0.00%

Appendix C-2

Table Embodied Energy results per Brickwork site Cuitzeo Bioregion

code	fid	Location	Latitud	Longitud	PricePiece	EE MJ/Kg	HMJ/Brick	HGJ/Burn	GJ/Year	GJ/Year2
327121	1	Tenencia Morelos	19.63771	-101.23994	$ 0.90	5.30	11.58	173.74	521.23	521.23
327121	2	Tenencia Morelos	19.63821	-101.23776	$ 1.00	2.83	7.89	118.38	1420.56	1420.56
327121	3	Tenencia Morelos	19.63741	-101.23701	$ 1.35	1.42	4.28	106.89	961.99	961.99
327121	4	Tenencia Morelos	19.6372	-101.22729	$ 0.90	1.86	5.98	89.74	1076.90	1076.90
327121	5	Tenencia Morelos	19.63643	-101.22699	$ 1.10	1.42	3.76	105.16	841.31	841.31
327121	6	Indaparapeo	19.79325	-100.94588	$ 0.80	2.41	5.94	118.80	594.02	594.02
327121	7	Indaparapeo	19.78784	-100.94851	$ 0.75	6.31	15.58	155.80	934.82	934.82
327121	8	Indaparapeo	19.78832	-100.94739	$ 0.75	5.27	9.65	86.87	608.10	608.10
327121	9	San Lucas Pio	19.79469	-100.93375	$ 1.10	2.73	6.69	60.21	602.11	602.11
327121	10	Zinapecuaro	19.86864	-100.81586	$ 1.50	3.59	12.47	174.62	4190.84	4190.84
327121	11	Zinapecuaro	19.86847	-100.81528	$ 1.50	6.43	22.52	202.66	2431.91	2431.91
327121	12	Zinapecuaro	19.84526	-100.81785	$ 2.00	7.46	26.48	397.23	3575.03	3575.03
327121	13	Zinapecuaro	19.87839	-100.81142	$ 1.50	3.32	12.64	25.28	75.83	75.83
327121	14	Bocaneo	19.83277	-100.81823	$ 1.30	8.64	28.37	212.76	638.28	638.28
327121	15	Jesus del monte	19.66386	-101.15969	$ 1.50	3.86	11.98	95.81	1341.35	1341.35
327121	16	Jesus del monte	19.66167	-101.16009	$ 1.20	3.19	11.71	117.10	819.73	819.73

327121	17	Jesus del monte	19.65337	-101.15952	$	1.50	3.38	11.84	118.38	1183.80	1183.80
327121	18	Jesus del monte	19.64559	-101.15692	$	1.70	2.16	7.72	61.78	1482.82	1482.82
327121	19	Indaparapeo	19.78753	-100.9811	$	0.85	1.07	2.60	130.08	650.38	650.38
327121	20	Indaparapeo	19.78758	-100.98174	$	0.80	2.27	4.65	60.42	725.08	725.08
327121	21	Indaparapeo	19.78708	-100.98148	$	0.80	4.46	9.67	58.04	696.50	696.50
327121	22	San Lucas Pio	19.7933	-100.93514	$	1.20	2.45	4.71	94.21	94.21	94.21
327121	23	Indaparapeo	19.78686	-100.98301	$	0.95	1.58	4.14	62.06	1117.09	1117.09
327121	24	Indaparapeo	19.78581	-100.98064	$	0.85	2.26	5.03	60.34	724.06	724.06
327121	25	Indaparapeo	19.78552	-100.97996	$	0.80	2.77	6.02	60.16	481.24	481.24
327121	26	San Lucas Pio	19.79403	-100.93577	$	0.80	2.03	4.09	61.36	736.32	736.32
327121	27	Tenencia Morelos	19.63758	-101.22645	$	1.40	1.48	4.00	135.93	679.66	679.66
327121	28	Tenencia Morelos	19.6369	-101.22575	$	0.90	2.50	6.30	94.54	756.33	756.33
327121	29	Tenencia Morelos	19.63762	-101.22566	$	1.00	4.73	10.52	136.73	546.92	546.92
327121	30	Tenencia Morelos	19.63822	-101.22598	$	1.40	1.61	4.38	100.77	2015.34	2015.34
327121	31	Tenencia Morelos	19.63825	-101.22707	$	1.05	2.32	5.70	91.15	546.87	546.87
327121	32	Acuitzio del Canje	19.50541	-101.34256	$	2.50	1.97	9.20	18.39	183.91	183.91
327121	33	Acuitzio del Canje	19.50506	-101.34277	$	2.50	2.23	9.52	47.59	571.10	571.10
327121	34	Acuitzio del Canje	19.50563	-101.34176	$	2.20	2.50	9.70	48.48	581.79	581.79
327121	35	Acuitzio del Canje	19.50508	-101.34227	$	2.10	4.45	17.14	34.29	342.88	342.88
327121	36	Acuitzio del Canje	19.50459	-101.34323	$	2.50	5.58	23.02	92.09	552.56	552.56
327121	37	Acuitzio del Canje	19.50391	-101.33983	$	2.50	5.33	22.06	88.25	529.52	529.52
327121	38	Santa Ana Maya	20.01088	-101.00991	$	2.00	1.39	5.37	48.33	290.00	290.00
327121	39	Santa Ana Maya	20.01065	-101.00952	$	2.00	1.35	5.37	48.33	386.67	386.67

327121	40	Santa Ana Maya	20.00938	-101.00933	$	1.80	1.68	5.97	47.79	191.17	191.17
327121	41	Santa Ana Maya	20.00869	-101.01163	$	2.00	1.33	4.99	49.87	199.47	199.47
327121	42	Santa Ana Maya	20.00369	-101.00501	$	2.00	1.50	6.18	71.06	568.44	568.44
327121	43	Santa Ana Maya	20.00484	-101.00593	$	1.80	1.36	5.33	47.97	191.87	191.87
327121	44	Santiago Undameo	19.58581	-101.29464	$	1.10	2.64	5.87	61.68	308.40	308.40
327121	45	Santiago Undameo	19.58434	-101.29584	$	1.00	1.50	4.48	62.71	313.55	313.55
327121	46	Santiago Undameo	19.58288	-101.29689	$	1.00	4.76	10.18	117.02	1404.23	1404.23
327121	47	Santiago Undameo	19.60264	-101.27259	$	1.00	3.63	11.68	58.38	700.59	700.59
327121	48	Santiago Undameo	19.60195	-101.27321	$	1.00	1.92	5.09	6.11	61.10	61.10
					$	1.38	**3.09**	**9.38**	**94.07**	**842.66**	**842.66**

Appendix C-3

The University Of Sheffield.

School Of Architecture.

Rafael M. Eufrasio Espinosa
PhD Candidate
School of Architecture
The University of Sheffield

Room 9.04
The Arts Tower,
Western Bank
Sheffield, S10 2TN
Phone: +44 (0) 7707020021
Email: arp11re@sheffield.ac.uk

Date:

INVITATION LETTER / MANUFACTURING INDUSTRY

Dear Sir or Madam,

My name is Rafael M. Eufrasio, I'm a Mexican PhD student at the Architecture department of the University of Sheffield in the UK where I am conducting research supported by CONACYT. I would like to invite you to take part in a research project. Before you decide to take part it is important for you to understand why this research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether you wish to take part or not. Thank you for reading this.

This study aims to develop scientific information based on clay bricks materials used in the Morelia housing sector in order to minimise its carbon emissions. The purpose of the collected data is to calculate the total energy used in the production process of clay bricks based on their life cycle energy analysis (LCEA).

It is up to you to decide whether or not to take part in this research. If you do decide to take part you have this information sheet and are asked to sign the consent form (attached) to keep. You can still withdraw from this study at any time, without having to give a reason. The data required to carry out the analysis is explained below. You and the researcher will fill out a form (LCI DATA COLLECTION FORM) by interview. These data is necessary not only to reflect local manufacturing practices but also to validate energy calculation and simulation models developed in this research.

During the interview, you will be asked several questions about the type of raw materials used in their origin, technology and manufacturing processes, amount and use of energy sources, delivered transportation and product price. Your response during the interview will be noted. The information will be used only for analysis and no one outside of the project team will be allowed to have access to them. Likewise you will be requested for pictures of your facilities. All of the information that I collect about you during the course of the research will be kept strictly confidential, anonymity is guaranteed according to the University policy on data storage. You will not be able to be identified in any reports or publication. Thank you very much for your participation.

Regards,
Rafael M. Eufrasio
Please do not hesitate to contact to Professor Fionn Stevenson who is the academic supervisor if you which to discuss my research or conduct.

Professor Fionn Stevenson Head of School
Sheffield School of Architecture, The University of Sheffield
The Arts Tower, Western Bank, Sheffield S10 2TN, UK
Email: f.stevenson@sheffield.ac.uk
Telephone: ++44 (0)114 222 0301
Website: http://www.sheffield.ac.uk/architecture/people/stevenson_f
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Appendix C-4

Participant Consent Form for

Title of Research Project: Spatial Life Cycle Energy Model of dwellings within a bioregional context (SLCEM)

Name of Researcher: Rafael M. Eufrasio Espinosa

Participant Identification Number for this project: **Please initial box**

1. I confirm that I have read and understand the information sheet explaining the above research project and I have had the opportunity to ask questions about the project [dd / mm / yyyy]. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐
3. I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐
4. I agree for the data collected from me to be used in future research. ☐
5. I agree to take part in the above research project. I also allow the investigator to take pictures of my products. ☐

Name of Participant	Date	Signature
Lead Researcher	Date	Signature

Copies:

Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/pre-written script/information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be placed in the project's main record (e.g. a site file), which must be kept in a secure location.

Appendix C-5

LCI Data Collection Form (Section A)

ESTIMATED EMBODIED ENERGY PER KG: 2.13 MJ

INVENTORY DATE: 25/04/2014

FID:	14	PRODUCT PRICE (MILLAR)	$1,500.00		Interviewer RMEE
SECTOR:	327121	DIMENSIONS IN cms	HIGH 25	LARGE 4	THICKNESS 6
LOCATION:	Acultzio del Canje	WEIGHT (KG):	2.5		
		APPARENT QUALITY:	GOOD X	FAIR	POOR

INPUTS/ add raw materials from below list or add a new one

Abono | Arcilla | Grava | Madera | Tepetate | (blank)

Item #	INPUTS/ Raw Materials	QUANTITY/ Amount	UNITS/ Kgs,Lts,M3,etc2	PERIOD/ Y,M,W,D	Purchase price/unit	Purchase Total	Origin Purchased/ Location	Aprox Distance/ Kms2	Transport type/ Observed by the buyer	First hand data?
1	Arcilla				$ -	$ -				
2	Grava				$ -	$ -				
3	Abono				$ -	$ -				
4	Grava				$ -	$ -				
5	Madera				$ -	$ -				
6	Tepetate				$ -	$ -				
7	Arcilla				$ -	$ -				
8	Abono				$ -	$ -				
9	Grava				$ -	$ -				
10					$ -	$ -				
11					$ -	$ -				
TOTALS	INVENTORY ITEMS: 9					$ -				

FUEL TYPES/ add fuel type from below list or add a new one

Asserin | Basura Ind. (ll... | Diesel | Electricidad | Gas LP | Gas Natural | Gasolina | Leña | Madera | Querosenos | (blank)

Item #	INPUTS/ Fuels	QUANTITY/ Amount	UNITS/ Kgs,Lts,M3,etc2	PERIOD/ Y,M,W,D	Purchase price/unit	Purchase Total	Origin Purchased/ Location	Aprox Distance/ Kms2	Transport type/ Observed by the buyer	First hand data?
1	Asserin				$ -	$ -				
2	Leña				$ -	$ -				
3	Madera				$ -	$ -				
4	Diesel				$ -	$ -				
5	Gasolina				$ -	$ -				
6	Querosenos				$ -	$ -				
7	Gas LP				$ -	$ -				
8	Gas Natural				$ -	$ -				
9	Basura Ind. (llantas)				$ -	$ -				
10					$ -	$ -				
11	Electricidad				$ -	$ -				
TOTALS	FUEL TYPES: 10					$ -				

Steps by Burning process

Cocción | Extracción | Mezclado ó | Moldeo | Preparación | Raspado de t | Recolección | Secado | (blank)

Item #	Process/ Type	Equipment/ use	Time Process/ Hours,	Equipment/ type	Equipment/ capacity	Fuel/ Type	Fuel Quantity/ Kgs,Lts,M3,etc2	Oven/ Temperature 'C2	Waste per Process/ Units	Note:
1	Extracción									
2	Recolección									
3	Preparación de pastas									
4	Mezclado ó batido									
5	Moldeo									
6	Secado									
7	Raspado de tabique									
8	Cocción									
9	Secado									
10										

PRODUCTION AND DELIVERY

AQ1 PRODUCTION: How many burns do you do monthly? [4]

AQ2 PRODUCTION: Do you produce other products? [NO]

	Product	Monthly quantity
If yes		

AQ3 PRODUCT DELIVERY: How your sales are distributed in percentaje?

Intermediates	Direct to consumer	Housing developers
%	%	%

AQ4 PRODUCT DELIVERY: How your product is delivery?

AQ5 PRODUCT DELIVERY: Main destiny of your product?

Destiny 1:	Destiny 2:	Destiny 3:

AQ6 ENERGY: Why do you use these fuels in your manufacturing process?

It is cheap	It is available	By tradition
		X

	YES	NO	I do not know
PQ7 MATERIALS: Do you use recycled or reclaimed materials?			
PQ8 ENERGY: Do you think that your manufacturing process is polluting?			
PQ9 ENERGY: Would you willing to change for a cleaner energy fuel?			

PQ10 OWN DELIVERY TRANSPORT

Type	Year	Fuel/type	Transport tank capacity	Load capacity

LCI (Section B)

SOCIO-ECONOMIC

Q1 IS THIS A PROFITABLE BUSINESS? YES [ ] NO [ ]

If yes/no why?

Q2 DO YOU HAVE SOME TYPE OF ECONOMIC SUPPORT? YES [ ] NO [ ]

If yes/ what type of support do you receive?

Q3 DO YOU HAVE PLANS TO INVEST IN NEW TECHNOLOGY? YES [ ] NO [ ]

If yes/no why? and what kind of technology would you willing to pay for ?

Q4 ARE YOU THE OWNER OF THIS PARCEL OR ARE YOU PAYING RENT FOR LAND USE? YES, I'm the owner [ ] NO, I'm paying rent [ ]

If NO, IS THE OWNER OF THE PARCEL LIVING IN YOUR COMMUNITY ? YES [ ] NO [ ]

Q5 HOW MANY PEOPLE ARE WORKING IN THIS PLACE? [ ]

Q6 ARE THERE PEOPLE UNDER 15 WORKING IN THIS PLACE? YES [ ] NO [ ]

If YES, how many people? [ ]

Q7 HOW MANY DAYS PER WEEK AND HOW MANY HOURS PER DAY DO YOU WORK?

Days per week [ ]

Hours per day [ ]

Q8 IN YOUR OPINION, WHAT ARE THE ECONOMIC PROSPECTS FOR YOUR BUSINESS? Good [ ] Bad [ ] It will remain the same [ ]

If bad or the same, what are you going to do about it?

Q9 PLEASE STATE WHICH CATEGORY BEST DESCRIBES YOUR JOB

Very satisfactory [ ] Satisfactory [ ] Neutral [ ] Barely satisfactory [ ] No satisfactory at all [ ]

LCI (Section C)

?	CULTURAL			
Q1	HOW MANY YEARS HAVE YOU BEEN DOING THIS ACTIVITY?			
		YES	NO	
Q2	DO YOU HAVE A FAMILY MEMBER THAT WORK OR HAVE WORKED IN THIS ACTIVITY?			
	If YES, for how long?			
		YES	NO	I do not know
Q3	DO YOU CONSIDER THIS AS FAMILY BUSINESS?			
	If YES/NO, why?			
		YES	NO	I do not know
Q4	IF YOU HAD THE OPPORTUNITY TO DO OR MOVE TO ANOTHER JOB, WOULD YOU DO IT ?			
	If YES/NO, why?			
		YES	NO	I do not know
Q5	DO YOU THINK THAT CLAY BRICK IS THE MOST REPRESENTATIVE MATERIAL IN YOUR REGION OR COMMUNITY?			
	If YES/NO, why?			
		YES	NO	I do not know
Q6	DO YOU THINK THAT CLAY BRICK HAS A LONG TRADITION YOUR REGION OR COMMUNITY?			
	If YES/NO, why?			

Comments: