Utrecht University

Master's Thesis - MSc Sustainable Development

Exploring household energy consumption patterns and inequalities in sustainability transitions

Evidence from residential energy consumption in Beijing

Student name: Giulia Viero
Student number: 5791901
E-mail address: g.viero@students.uu.nl

Track: Earth System Governance
Course code: GEO4-2321 (45 ECTS)
Date: January 31st , 2017

Supervisor: Dr. Bettina Bluemling
Email address:b.bluemling@uu.nl

Second reader: Professor Frank Biermann
Email address:f.biermann@uu.nl

Summary

It is broadly recognised that demographic changes and human economic activities substantially contribute to global environmental issues, such as climate change and air pollution, with negative health externalities. Among total energy consumption, energy use in residential buildings is a large contributor to carbon emissions. Moreover, significant inequalities exist in energy use-related emissions among household groups along the energy ladder. Governments are seeking to adopt alternative energy solutions to phase out fossil fuels, both at the household- and residential sector-level. Among all countries, China figures the highest solar energy installed capacity and critical technical potential to cost-effectively improve buildings energy efficiency. The adoption of sustainable alternatives in residential buildings can help reducing carbon emissions, and addressing inequality, as the ability to access technology and/or infrastructure across urbanised and rural areas. It is thus necessary to understand the conditions under which such measures can be applied locally, without exacerbating contextual inequalities. The overarching question is: *To what extent and owing to what factors can households climb up on top of the energy ladder towards the adoption of solar energy and energy efficiency technologies in Beijing? And can sustainability transitions encompass a diversity of household groups?*. To answer this question, a literature review was performed to design the present framework on two analytical levels. The energy ladder model was first employed at the household-level, whilst notions from the Needs-Opportunities-Abilities model and contextual equity were employed for the residential sustainability transition analysis. A qualitative-based approach was used for the analysis of household surveys, (participatory) observations in urban, suburban and rural sampled areas in Beijing, policy interventions and expert interviews that helped triangulating previous results. Theoretical factors influencing energy consumption were employed to guide the empirical data collection. After coding interviews and processing primary data, findings were integrated. Results showed that techno-infrastructural and institutional factors constrain the opportunity to climb the ladder for all household groups, but to different extents. Rural and suburban residents presented larger opportunity to climb up towards solar energy than their urban counterparts. Urbanised areas has techno-infratructural advantage and policy regulations support to adop energy efficiecny improvements. However, revised policy interventions were found lacking of an understanding of households' contextual inequalities. Also, opportunities were identified for each household group and related energy use. This research revealed that socio-technical-level factors are interrelated to energy consumption patterns and more empirical evidence from local contexts is necessary to deeper understand this dynamic field.

Keywords: household energy consumption; energy ladder; solar energy; energy efficiency; contextual equity; sustainability transitions

Acknowledgements

I am deeply grateful to my supervisor, Dr. Bettina Bluemling. Thank you for your guidance and useful comments when I needed to clearly and concisely express my puzzled ideas. I would also like to acknowledge the funding and support from Climate-KIC in carrying out this research in Beijing. Climate-KIC is supported by the European Institute of Innovation and Technology, a body of the European Union.

In addition, I wish to thank Professor Tu and Dr. Lin from the hosting Beijing Normal University, for welcoming me and supporting my research during my stay. I am also thankful to Ann Peng for her unbelievably supportive role during the field research.

In conclusion, my warmest thanks and appreciation to my family and friends, who constantly supported me throughout the course of this project, and continue to do so in every aspect of my life. Thank you.

Giulia Viero,

Utrecht, January 2018

List of Abbreviations

°C	degree Celsius
BNU	Beijing Normal University
CHP	Combined heating and power generation plant
CO_2	Carbon dioxide
ELM	Energy ladder model
FYP	Five Year Plan
GHG	Greenhouse gases
GW	Gigawatt
IEA	International Energy Agency
IMF	International Monetary Fund
IoT	Internet of Things
IPCC	Intergovernmental Panel of Climate Change
IRENA	International Renewable Energy Agency
m^2	Square metres
NEA	National Energy Administration
NOA	Needs-Opportunities-Abilities
NUH	Northern urban heating
OECD	Organisation for Economic Co-operation and Development
PV	Solar photovoltaic
REN21	Renewable Energy Policy Network for the 21st Century
SDG-7	Sustainable Development Goal number 7
SE4All	Sustainable Energy for All
SWH	Solar water heaters
TU	Tsinghua University
TU BERC	Tsinghua University Building Energy Center
UN	United Nations
WEO	World Economic Outlook
WHO	World Health Organisation

List of Figure

List of Tables

Table of contents

1.Introduction

Over the past 20 years, the world population has grown by more than 1.5 billion people and total economic output has nearly tripled (Intergovernmental Panel of Climate Change [IPCC], 2014). Several studies proved that such sheer demographic changes and human economic activities substantially contribute to global environmental issues, such as climate change and air pollution (Gielen, Saygin, Wagner, Petrichenko & Tsakiris, 2015; Urban, Geall & Wang, 2016). Impeding pressures on the Earth ecosystems include, for instance increased air pollutants in the atmosphere, where greenhouse gases (GHG) already rose by 70% from 1970 to 2004 (Organisation for Economic Co-operation and Development [OECD], 2008). Other climate-related effects reported by the OECD (2008) comprise more erratic and intense climate events as well as global average temperature rise. To put this into perspective, by building on solid emission baseline scenarios, the 2014 *IPCC Fifth Assessment* report estimated an increase in global average temperature from 3.7 degree Celsius (°C) to 4.8°C by 2100, with catastrophic consequences for the planet (IPCC, 2014).

In this context, the residential sub-sector final energy consumption in 2014 accounted for 406 million tons oil equivalent (Mtoe), 20.4% of total final energy consumption (Zhang, Yu, Cai & Wei, 2017). The energy use in residential buildings is a large contributor to total energy consumption and to carbon dioxide (CO_2) emissions from fuels combustion, which reached 343.9 million tons in 2014 (Zhang et al., 2017). In addition, in 2016, the Tsinghua University Building Energy Center (TU BERC) reported that China's residential floor area has progressively increased since 2000 and it is expected to continue expanding over the next two decades. This originates from the impending necessity to accommodate the energy needs of an upsurging population, which particularly concentrates in urbanised areas (Gross, 2015; TU BERC, 2016).

Notably, Zhang and colleagues' study (2017) assessed the linkage between household[1] consumption and CO_2 emissions, focusing on differences across urban-rural and rich-poor groups. Their key findings demonstrated the significant inequality in energy consumption-related emissions between social groups. For instance, in 2012, the CO_2 emissions of urban residents were 1.8 times that of rural residents and urban highest-income residents emitted 3.8 times more CO_2 than the poorest households (Zhang et al., 2017). These findings reveal the need to take inequality across a diversity of household groups into consideration, when looking at sectoral carbon emissions in the residential sector.

Growing concerns in this context of daunting global- and local-environmental pressures and energy consumption inequalities were globally addressed in the 2012 *Sustainable Energy for All* (SE4All) initiative, in line with the Sustainable Development

[1] This thesis applies the definition of household by Schlör,Fischer and Hake (2013, p. 1496), as a private "individual living alone or a group of related or linked (not necessarily family-related) persons, who belong together in terms of income and consumption".

Goal number 7 (SDG-7) (United Nations [UN], 2017). Seemingly to the SDG-7 targets, the SE4All mission is rooted on three interconnected goals for 2030 (based on 2010 levels): ensuring universal access to modern energy services, doubling the global rate of energy efficiency improvements, and doubling the shares of renewable energy within the global energy mix (Gielen et al., 2015, p. 4).

Arguably, the adoption of renewable energy and energy efficiency technologies is high on the policy agenda of numerous countries, as governments seek to phase out fossil fuels in several sectors, including residential energy use (Renewable Energy Policy Network for the 21st Century [REN21], 2016). As a matter of fact, sustainable energy alternatives enable structural and necessary changes, and help mitigating the effects of climate change and air pollution, with future positive spillovers on the environment and personal health (Gielen et al., 2015).

Furthermore, the SE4All initiative integrates among its overarching sustainability objectives the notion of ensuring energy accessibility to all (Gielen et al., 2015). This is explained in the next section, whilst explaining in greater detail the sustainable energy alternatives addressed within the scope of this research project.

1.1 Sustainable energy alternatives

Solar energy

Several studies asserted the great potential of solar as an exploitable renewable resource, using well-established technologies, such as solar thermal hot water systems or solar water heaters (SWH) and solar photovoltaic (PV) (International Energy Agency [IEA], 2017b; Urban et al., 2016). SWH herein relate to small scale technologies that produce heat for hot water needs (IEA, 2017b). Instead, modern solar PV systems convert solar energy directly into electricity, and are not limited anymore to flat or square panels, but present significant flexibility as they can be modelled to adapt to the building design (IEA, 2017b).

The extent to which policy strategies and measures have been effective in taking advantage of these technologies and in realising carbon emission reductions is different across countries. Among all, China shifted from 8 GW (Gigawatt) of installed solar capacity in 2012 to alone featuring 12 GW of solar power (IEA, 2011). Moreover, the country has figured the highest solar installed capacity since 2015 (REN21, 2016) (Figure 1).

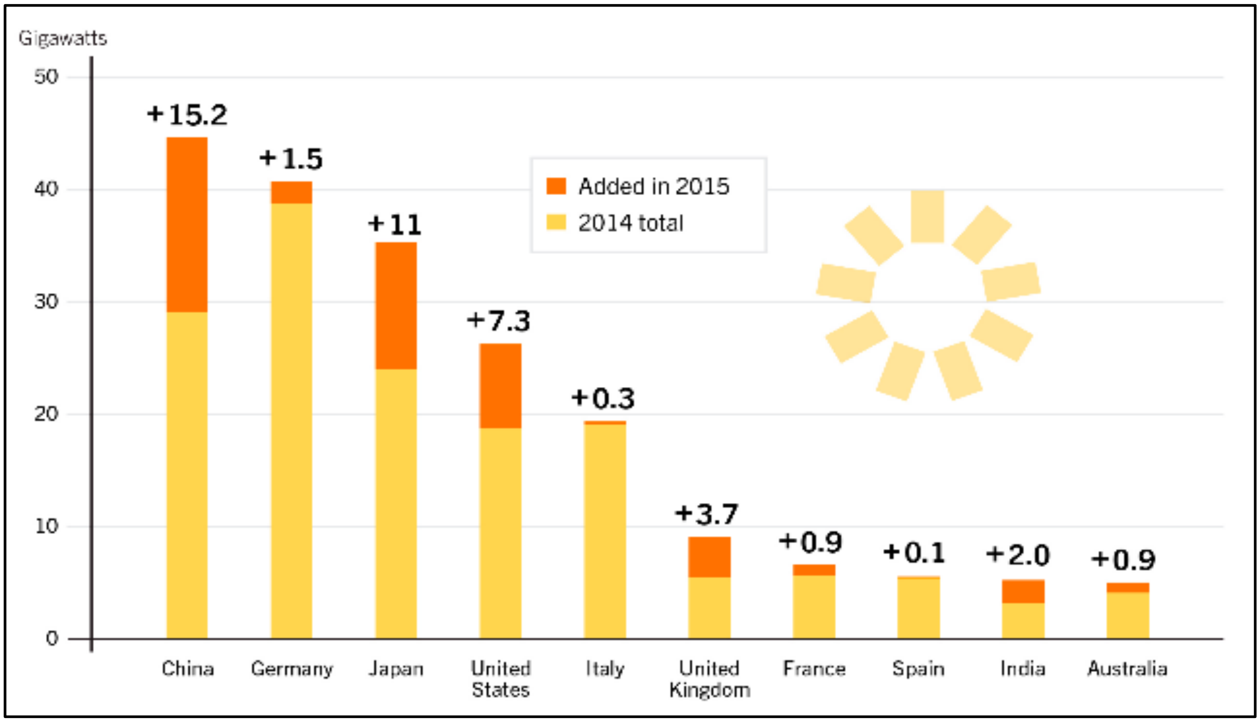


Figure 1. Solar PV capacity and additions, top 10 countries (2014-2015).

China's efforts in this field were enhanced in the *13th Solar Energy Development Five Year Plan* (FYP) (2016-2020), disclosed in December 2016 by China's National Energy Administration (NEA) (REN21, 2016). Accordingly, minimum solar development targets by 2020 were set at 105 GW for solar PV and 800 million square meters (m^2) of installations for solar thermal (NEA, 2017). In this context, the solar radiation in Beijing is moderate-high and there is potential for more exploitation of solar energy in the residential building sector (Ma, Song, Smardon & Chen, 2014). This allows for lower costs of SWHs utilization than in other locations (Ma et al., 2014).

Nevertheless, further advancements are necessary to increase the economic viability and cost-effectiveness of solar energy technologies installations to lower-income and/or off-grid households (Hauff et al., 2014; REN21, 2016). This is also argued in light of rural residents being predominantly dependent on biomass and direct fuel consumption for cooking and space heating services, generating harmful air pollutants (Pachauri et al., 2012; World Health Organisation [WHO], 2016).

While there is wide recognition of the technical and economic potential of providing cleaner energy sources and technologies to substitute fossil fuel use, it is also important to regard the equal provision of technically available technologies (Hiemstra-van der Horst & Hovorka, 2008). These not only encompass solar energy, but also energy efficiency improvements in buildings.

Energy efficiency

The 2012 World Energy Outlook (WEO) report conveyed that energy efficiency improvements could reduce the rise in global energy demand by 50% (IEA, 2012, cited in Bartiaux, Schmidt, Horta & Correira, 2015). Likewise, the International Renewable Energy Agency (IRENA) calculated the 2030 energy reduction potential from the adoption of energy efficiency technologies in industry, transport and buildings (based on 2010 levels), in four regions: the United States, the European Union, India and China (Gielen et al., 2015). The report showed that the building sector scored the highest percentage in fossil fuel consumption reduction, especially in relation to coal. For instance, 34% of coal use could be reduced in China from adopting energy efficiency technologies (Gielen et al., 2015, p. 24).

Seemingly, figure 2 shows that, for reducing GHG emissions, the technical potential of buildings energy efficiency is clearly higher and comes at lower (or zero) costs compared to any other sector in the graph (Urge-Vorsatz & Novikova, 2008).

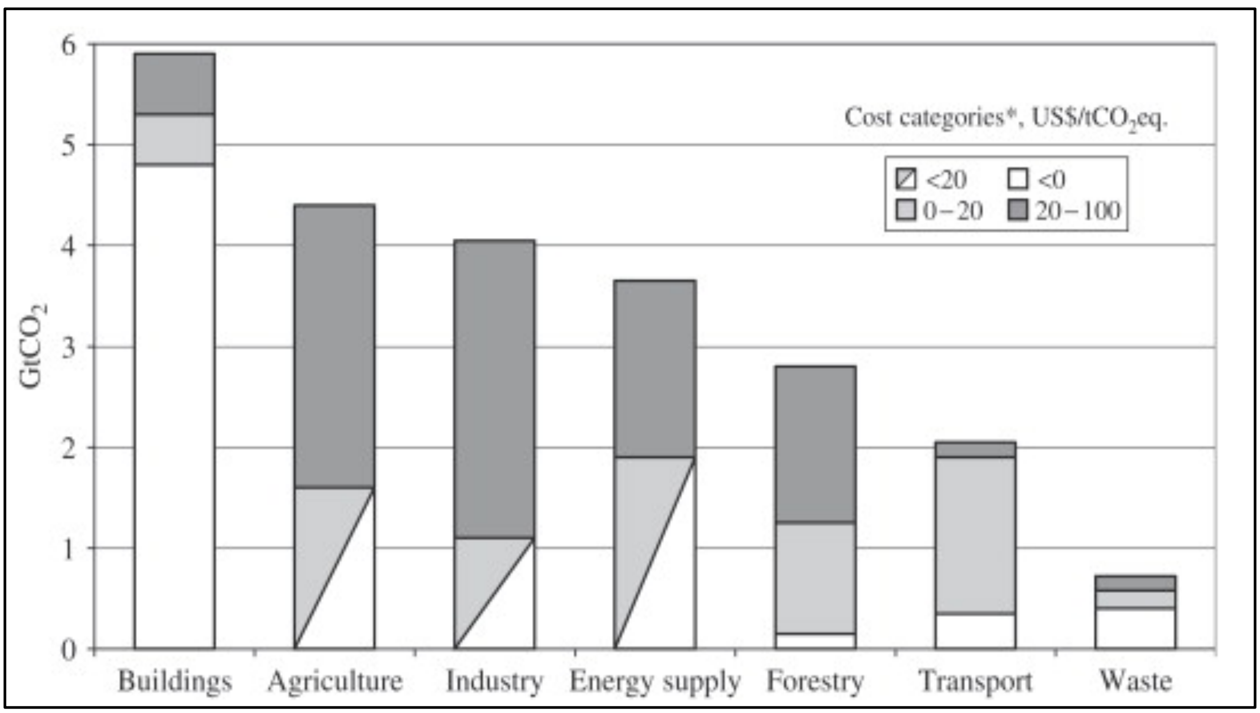


Figure 2. Estimated potential for GHG mitigation at a sectoral level in 2030 in different cost categories.

Examples of energy efficiency measures in the building sector that could reduce GHG emissions from energy consumption include: passive housing and advanced building envelopes as well as installations of solar PV and SWHs to exploit the incidence of sunlight (Diamond et al., 2013; REN21, 2016).

Clearly, based on these findings, energy efficiency improvements in residential buildings are technically feasible low- or even zero-cost energy saving measures (Urge-Vorsatz & Novikova, 2008). Nevertheless, with socio-economic development and changes in lifestyles, increased energy consumption may paradoxically counterbalance advancements in energy efficiency, which is defined as rebound effect (Wang, Han & Lu, 2016). Synergies hence underly energy efficiency improvements and the expected sectoral increase in the purchases of energy-consuming appliances (TU BERC, 2016).

Thus, there is the need to deepen the current understanding of the conditions under which such measures can be applied locally, taking into account context-related energy consumption asymmetries in the energy technology accessibility across diverse household groups (McDermott, Mahanty & Schreckenberg, 2013). To put this into perspective, Zhang and colleagues (2017) shed light on the differences in energy consumption-related CO_2 emissions between urban-rural household groups, and reported that such disparities often originated from inequalities in the ability to access technology and/or infrastructure (e.g. power infrastructure networks) across urban and rural areas.

Additionally, Bartiaux et al.’s study (2015, p. 413) revealed that energy policy instruments may exacerbate existing across social groups or “classes”, while seeking to warrant the adoption of low-carbon solutions. The key findings of their study are particularly interesting in this instance, as they suggest that policy interventions need to target higher energy consumers as they are also higher emitters of CO_2, in order to be effective (Bartiaux et al., 2015). In another study, Schlör, Fischer and Hake (2013) asserted that energy-efficient practices and social equalities are both fundamental in the pursuit of sustainable development, as also claimed in the report *Our Common Future* (Brundtland et al., 1987).

A better understanding is critical with regards to which policy instruments that could address one aspect without neglecting the other (Schlör et al., 2013). For instance, the authors reported policies targeting sustainability issues and social inequalities, which were addressed in the reform of fossil fuel prices, based on the internalisation of negative social and environmental externalities.

Prior to addressing policy instruments however, there exist the need to deepen the current understanding of factor influencing the energy consumption of different households groups (Bartiaux et al., 2015), outlined in the next section.

1.2 Household energy consumption

Traditionally, Chinese rural households are dependable on (direct combustion of) polluting and low-efficient fuels, seemingly to other developing countries[2] (TU BERC, 2016). For example Smith, Apte, Yuqing, Wongsekiarttirat and Kulkarni (1994) partly attributed severe air pollution issues in Beijing to the utilisation of coal-stoves for cooking, water heating and space heating, with negative externalities for personal health. Accordingly, the WHO (2016) related more than 4 million premature households deaths to illness caused by household exposure to polluting solid fuels combustion for cooking. Moreover, rural areas were found to utilise the kang bed[3] for heating the sleeping room (Wang, Shan, Xionga, & Yanga, 2014). The authors reported that it features very low thermal efficiency and high risks for users of skin burns.

Additionally, traditional rural single-family houses are characterised by low heating thermal insulation, hence efficiency (TU BERC, 2016). Notably, the same publication reported substantial inefficiencies in the heating systems of urban high-storey multi-family residential complexes. To put this into perspective, Lo (2014) reported space heating in northern China's residential buildings to be 100% to 200% more energy-consuming than in developed countries having identical latitude.

In addition to techno-infrastructural factors, the progressive socio-economic development, new lifestyles and increased comfort requirements in residential buildings are having large impacts on fossil fuels demand for space heating, home appliances and other energy-consuming electronics (TU BERC, 2016, Wang et al., 2014). According to recent research studies, this is not only reflected in urbanised areas, but also in rural areas (TU BERC, 2016). For instance Increased accessibility to modern energy (e.g. LPG and electricity) was reported to substantially decrease biomass use by rural households (TU BERC, 2016).

Furthermore, several studies indicated that part of the changes that occur over time in households' energy consumption patterns are due to government policies (Elias & Victor, 2005; Schlör et al., 2013). These seek to achieve economic growth and societal stability in various sectors, however often failing to take into account local influencing factors on household energy consumption patterns (Elias & Victor, 2005).

The quantity of factors addressed in this section is non exhaustive, therefore below an overview is presented of the core concepts enabling a deeper understanding of households' energy consumption patterns and inequalities in regards with sustainable energy alternatives. These are then treated in greater detail in chapter 2.

---

[2] There exist contradictory sources for considering China a developing country. This thesis applies the definition of emerging and developing economies by the 2015 World Economic Outlook (WEO) database (International Monetary Fund [IMF], 2015).

[3] The kang is a traditional structure made of bricks or similar material, adjacent to a coal stove and a chimney, from which fumes are channeled to the sleeping room (Wang et al., 2014).

1.3 The energy ladder and equity

In an attempt to better explain context-related inequalities in relation to energy use, the energy ladder model (ELM) is utilised in this thesis (Hosier & Dowd, 1987; Leach, 1992). The basic notion of this model asserts that, as income rises, households tend to climb upwards along an invisible energy ladder (Leach, 1992), and while climbing upwards, they move away from polluting and low-quality traditional fuels (e.g. firewood, charcoal) placed on the lowest rungs of the ladder, towards cleaner and more efficient modern energy sources (e.g. electricity, natural gas) on top of the ladder (Hosier, 2004; Hosier & Dowd, 1987).

Climbing upwards along the ladder may be difficult for some household groups (van der Kroon et al., 2013; Sovacool, 2017). Accordingly, the ELM was selected since it could help to deepen the understanding of what local opportunities and constraints may influence different household groups when climbing up along the ladder. Accordingly, the present research takes interest in process of climbing upwards the ladder at the household-level, but also considers asymmetries across diverse households the level of sectoral sustainability transitions.

1.4 Sustainability transitions and equity

Whilst in the past human needs from changing lifestyles could be satisfied with larger energy consumption, this is no longer sustainable under the environmental constraints that were aforementioned in this chapter (IPCC, 2014). Hence, addressing household energy consumption could also be part of sectoral policy interventions that seek to mitigate climate change and reduce carbon emissions, by cutting household fossil fuel inefficient consumption (Campbell, Vermeulen, e & Mabugu, 2003).

As previously mentioned, household groups feature highly diverse energy consumption patterns. Therefore, when researching residential energy use, it is important to consider energy equity among a diversity of household groups, and to explore factors that influence how widespread certain technologies are or can be, on a higher level of analysis.

This analysis therefore comprises of two levels: the individual household-level and the higher sectoral level of residential energy use. Conventional theoretical models on the household-level were found to fall short in satisfactorily incorporating the sustainability dimension. A framework that theoretically and empirically supports the analysis of energy consumption along the energy ladder is important to identify policy implications to overcome inequalities and address sustainability in residential energy use (van der Kroon et al., 2013).

1.5 Research scope, objective and questions

The scope of this research encompasses households in urban, suburban and rural areas in Beijing Municipality. In this instance, household energy consumption is disaggregated into four energy services: space heating/cooling, water heating, lighting and cooking (TU BERC, 2016). This research analyses energy consumption during the operating phase of residential buildings in Beijing.

The first objective of this thesis is to explore how household may shift their energy consumption over time in response to changes in some influencing factors, by exploring these in their particular local context.

A second objective relates to identify differences in energy consumption among different household groups in different localities, namely urban, suburban and rural areas, further taking a sectoral approach that seeks to deepen the current understanding of energy-related policy interventions on the adoption of cleaner and more efficient technologies. This research is conducted according to the following overarching research questions:

To what extent and owing to what factors can households climb up on top of the energy ladder towards the adoption of solar energy and energy efficiency technologies in Beijing? And can sustainability transitions encompass a diversity of household groups?

Given the above overarching question, four sub-questions are articulated as follows:

1.1 What are the major factors explaining households climbing up on top of the energy ladder, which can be found in the literature?

1.2 To what extent can a diversity of household groups climb up on top of the energy ladder to enable sustainability transition in the residential sector?

1.3 Owing to what factors can households adopt solar energy and energy efficiency technologies, based on empirical evidence?

1.4 To what extent climbing up the energy ladder depends on diverse households' connection to a sustainability transition?

Sub-questions 1.1 and 1.2 are concerned with the theory, the first being related to the energy ladder and contextual accessibility to energy types, while the second one relating to sustainability transitions. This is reflected in the empirical part of this research project, referring to sub-questions 1.3 and 1.4.

1.6 Scientific and societal relevance

The scientific knowledge provided in this thesis attempts to offer a better understanding of the factors underlying energy consumption patterns at the household-level. It does so by employing the theoretical lenses of the energy ladder to the field of household energy consumption of cleaner and more efficient energy sources, i.e. solar energy and energy efficiency. This research has not been conducted yet, to the best of my knowledge, hence a gap was identified in the existing scientific knowledge, which this thesis aims to address. The allocation of solar energy and energy efficiency on top of the energy ladder can hence be regarded as an innovative application of the ladder conceptualisation.

Further, Zheng et al. (2014) reported that there is a limited number of studies focusing on rural and urban household energy consumption differences, whilst the majority of studies surveyed one of the two groups at once. This thesis therefore aims to bridge this knowledge gap and focus on three groups (rural, suburban and urban).

On the higher level of analysis, the institutional factor dimension is employed in this framework. This is done to support the explanation of the progress of the residential sector towards sustainability across diverse household groups. These feature different living standards, lifestyles and context-related opportunities to access cleaner and more energy-efficient technologies.

Finally, this research attempts to contribute to the existing knowledge by supporting the identification of inequalities across diverse household groups in the context of sustainability transitions.

In terms of societal and practical relevance, the results of this research may contribute to identify policy implications to support equal sustainability transitions. Accordingly, Pachuari et al. (2012) asserted that inequalities have often been addressed in term income gaps or other asymmetries in monetary measures. Hence, this research attempts to offers policy-makers a deeper understanding of which factors inhibit or stimulate inequalities. This is done in regards to the accessibility to energy sources/technologies, thus services, among household groups.

A new approach that looks at environmental challenges by considering the social dimension of energy systems is appropriate in this research project, as it reflects the current context, which demand a rapid and drastic but strategically well-planned transition in energy use, that also lead to future benefits for people’s quality of life.

1.7 Research outline

The remainder of this thesis is organised as follows: chapter 2 illustrates and explains the multi-dimensional framework used in this research. The framework is applied according to the above problem definition and research objectives, and it is designed in regards to sub-questions 1.1 and 1.2. Chapter 2 also contains the analytical framework guiding the data collection and analysis. Chapter 3 explains the research approach, the case study methodology, and related data collection methods in light of the scope and objectives of this research. Ethics issues are also addressed. Chapter 4 analyses the results in consideration of sub-questions 1.3 and 1.4, and of the two levels of analysis underlying this research. Finally, chapter 5 discusses key findings, the research contributions to the theory and some practical policy implications. This is done in relation to the research scientific and societal relevance outlined in section 1.4. The chapter is also comprises of limitations of the framework and research methods. Finally, concluding remarks and the answer to the overarching research question follow.

2. Theoretical Framework

As aforementioned in the introductory chapter, the present research aims to contribute to the existing scientific knowledge by taking an innovative approach in regards to the integration of two different levels of analysis and different theories and models into a single theoretical framework. An intense literature review precedes the proposed framework. On the basis of more recent literature, four critiques of the ELM are provided in sub-section 2.1.1. After critically revising the model in light of new sustainability challenges and opportunities outlined in chapter 1, fundamental concepts are also defined in regards with contextual equity (2.1.2) and institutions in sustainability transitions, discussing theoretical insights from the Needs-Opportunities-Abilities (NOA) model (2.1.3).

Section 2.2 then illustrates the conceptual framework and highlights the relevance of the reviewed literature for this research project. Based on the literature discussion, the analytical framework is illustrated in section 2.3.

2.1 Literature Review

The energy ladder model

The literature on energy household energy choice and behaviour has widely applied the ELM in developing countries since the 1980s (Hosier, 2004; Hosier & Dowd, 1987, Nansaior, Patanothai, Rambo & Simaraks, 2011; van der Kroon et al., 2013). According to the literature, the underlying notion of this model is that households deal with a range of energy supply choices, which can be ordered from the least to the most technologically modern and clean (Hosier, 2004; Leach, 1992). The model is generally employed to conceptualised the process of climbing the energy ladder by different households. This can be defined as a linear shift (usually upwards) as part of socio-economic development (Hosier, 2004).

Several scholars agree on the fact that the abstract idea of an *energy ladder* is representative of the household energy consumption trends and budgetary decisions within a specific context and at a given point in time (Hosier, 2004; Reddy & Reddy, 1994). Most empirical studies indeed assessed the relationship between income and fuel choice in the domestic context of developing countries in Asia, Latin America and Africa, given the crucial role of energy in economic development and societal wellbeing (Gupta & Köhlin, 2006; Hosier & Dowd, 1987).

Despite finding some empirical evidence in the existing literature of the basic notion embedded in this model (a switch from traditional to modern fuels occurs as income rises), more recent literature provided evidence of even low-income households accessing modern fuels, e.g. LPG (Campbell et al., 2003; Heltberg, 2004; van der Kroon et al., 2013). For instance, Heltberg (2004) assessed that household expenditure did not have significant impact on fuel switching choices, contrary to what the ELM would hypothesise. This suggests that other factors may arise locally over time, and they may influence household energy consumption patterns beyond income (Heltberg, 2004; Hiemstra-van der Horst & Hovorka, 2008; Masera, Saatkamp & Kammen, 2000).

2.1.1 Conceptual revisitation of the energy ladder

Generally, the ELM claimed that socio-economic development would eventually lead to a decrease in traditional fuels, e.g. biomass, from being largely used for multiple purposes and by a large proportion of the population to being used for fewer purposes and by fewer households; eventually, electricity would be exclusively used on top of the ladder (Campbell et al., 2003). When the substitution from one energy source to another is perfect, fuel switching is observed (van der Kroon et al., 2013, p. 505).

On the contrary, several scholars argued that a linear energy switch from one inferior to a superior energy type is impractical over time, for four main reasons (Hosier, 2004; Nissing & von Blottnitz, 2010; van der Kroon et al., 2013).

First, households may directly switch from primitive to advanced fuels without consuming transitional fuels (located on the middle rung) (Hosier, 2004). This behaviour does not conform with the ladder conceptualisation, for which energy end-users “stand on one step at a time” and generally climb upwards (Heltberg, 2004, p. 871).

Hosier (2004) offered an explanation for this simplistic view and pre-defined, progressive (upward) movement along the ladder with economic development. The author indeed argued that the core precepts of the ladder are grounded on energy consumption trends of developed countries, falling short in mirroring other more complex empirical realities of developing countries (Hosier, 2004).

Secondly, Masera and colleagues (2000), among all (Nansaior et al., 2011; Nissing & von Blottnitz, 2010; van der Kroon et al., 2013), argued that households tend to use a combination of energy sources over time, rather than perfectly switching from one fuel to another. When referring to the use of multiple energy sources by households, this thesis applies the definition of “energy stacking” by van der Kroon and colleagues (2013, p. 505) (right side, Figure 3). Energy stacking denotes a partial - instead of perfect - switch from one energy source to another, leading to a diversification of the household energy portfolio.

Notably, the formulation of the overarching research questions in section 1.4 in terms of *to what extent* refers to the type of household energy switch (partial or perfect). When partial, this thesis applies the notion of energy stacking that comprises of a wider combination of energy types, i.e. solar energy and energy efficiency.

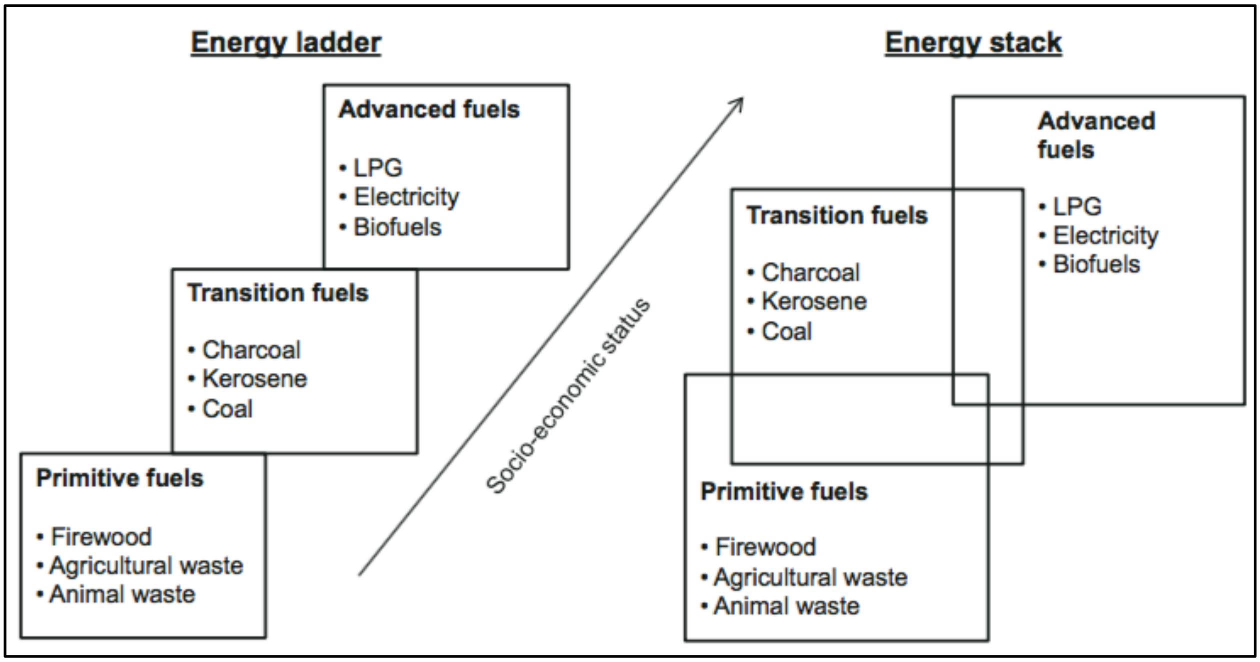


Figure 3. The traditional ELM (left) and the energy stacking re-conceptualisation (right).

In a study on reassessing the energy ladder in Maun (Botswana), Hiemstra-van der Horst and Hovorka (2008) observed that household energy use was driven by the tendency of accumulating different types of fuels and diversifying the consumption among several energy carriers. Additionally, Masera and colleagues (2000) reported evidence from other several countries that energy stack (Figure 3, right side) may be the rule and not the exception for energy consumption patterns of developing countries.

A third critique relates to the traditional ELM emphasizing higher scale (economic) factors, such energy prices, for understanding households' energy consumption choices, neglecting significant local factors, e.g. fuel/energy preferences (Hiemstra-van der Horst & Hovorka, 2008; Mekonnen & Kohlin, 2008). Accordingly, other studies conceptualised an energy ladder that ranked multiple fuels according to consumers' preferences, e.g. cleanliness, convenience and efficiency (Hiemstra-van der Horst & Hovorka, 2008; Smith et al., 1994).

For instance, Nansaior and colleagues (2011) reported that urbanising Thai communities preferred to keep using firewood or charcoal for cooking glutinous rice, although having access to modern fuels, i.e. electricity and LPG (Nansaior et al., 2011).

The case of Thai household biomass use featured evidence of a decline in biomass consumption as rural areas become more urbanised. However, shares of biomass continued to be present in households' energy portfolio, linked to traditional cooking practices.

In addition to household preferences, other studies asserted that energy use may be determined by a coordination between demand and supply (Nissing & von Blottnitz, 2010; van der Kroon et al., 2013). This is relevant for the holistic approach of this framework aspires to. By exploring the extent to which diverse households may shift their energy consumption over time in response to changes in some contextual factors.

Fourth and last, the view of a homogenous societal energy transition in the residential energy use may still be unrealistic (Campbell et al., 2003). The authors reported empirical evidence from longitudinal studies Sub-Saharan African local communities, where household groups were not equally climbing along the ladder. Over time, a "dichotomy" was increasingly emerging between higher-income households having access to modern fuels and lower-income households obliged to use less efficient and more polluting fuel alternatives (Campbell et al., 2003, p.554). In view of that, Zhang et al. (2017) claimed that energy consumption patterns among households in diverse locations may mirror or even enhance existing inequalities, in relation to context-related accessibility to energy technologies (McDermott et al., 2013).

To put this into perspective, the next paragraph explains the theoretical notion of contextual equity, clarifying how it is integrated into the proposed framework.

2.1.2 Contextual equity

A large body of literature has contributed to conceptualise what forms equity, however the definition still remains debated and elusive (McDermott et al., 2013). Bearing in mind that a comprehensive review of the literature on this concept is beyond the scope of this study, the notion of equity is herein utilised based on the framework by McDermott and colleagues (2013).

Contextual equity relates to the "equity in access" defined it as the "ability to derive benefit from things", or "contextual disposition of access" defined as the distribution of resources that depends on context-specific factors (McDermott et al., 2013, pp. 420-423). In this research project, it relates to the benefits from the utilisation of solar energy and energy efficiency technologies.These are likely to facilitate and/or constrain the capabilities of households to access technologies.

In line with the scope of this thesis, contextual equity is first explored at the local household-level in Beijing, and it is a valuable addition to the present framework as it allows to reach further when analysing the existing technological/infrastructural conditions that influence the process of climbing the energy ladder.

Subsequently, asymmetries with regards to energy-related *contextual disposition of access* are considered at the higher level of analysis, by exploring the influences of institutional factors, e.g. sectoral policies, on the abilities of diverse household groups in rural, suburban and urban areas to benefit from the adoption of more sustainable energy alternatives.

The above literature discussion is grounded on the energy ladder literature, hence the household-level of analysis. Contextual equity is bridging the two level of analysis in this framework. The next section moves to a higher analytical level, in relation to sectoral sustainability transitions (Brizga & Līce, 2013).

2.1.3 Sectoral sustainability transitions

This section is concerned with a set of factors that impose themselves upon the behaviour of consumers (Figure 4), and it bring into the theoretical discussion the dimension of *Institutions.* This was conceptualised within the NOA model on consumer choice and behaviour (Gatersleben & Vleek, 1998).

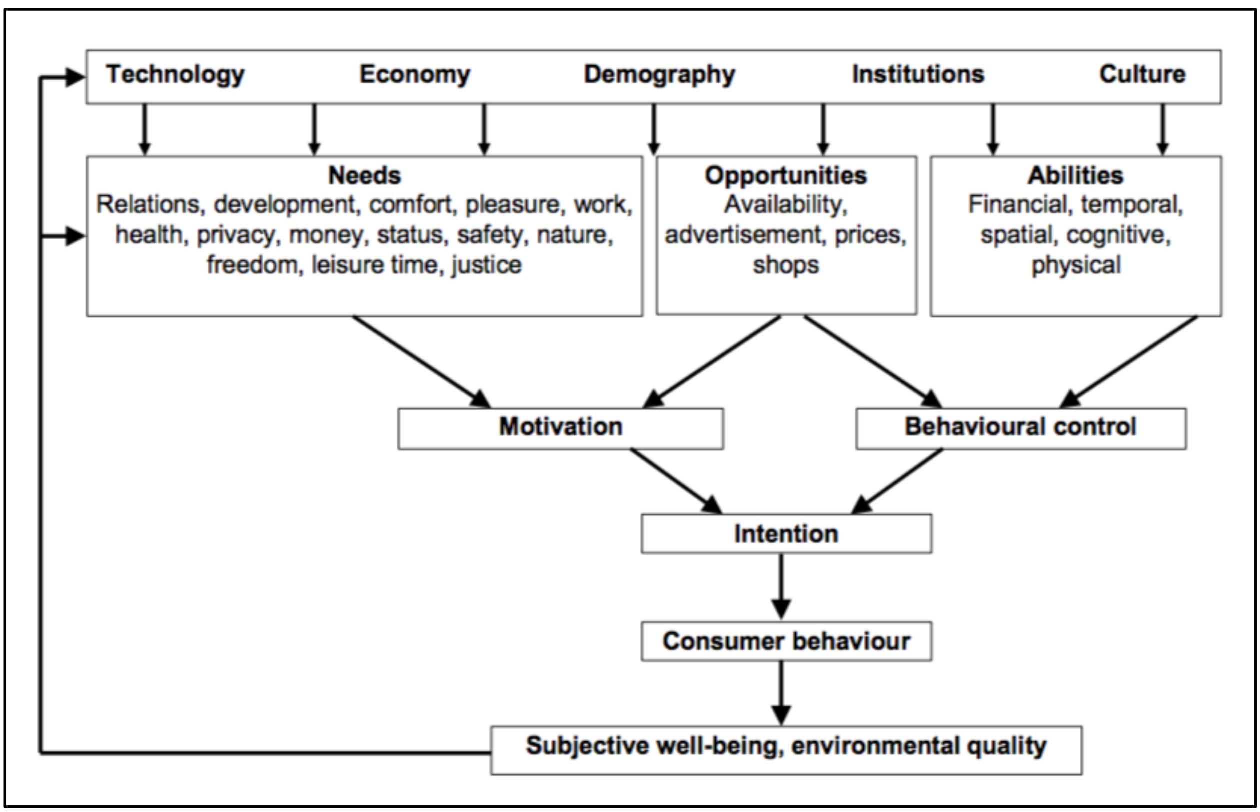


Figure 4. The Needs-Opportunities-Abilities model (adopted from Gatersleben and Vleek, 1998).

Notably, Lucas, Brooks, Darnton and Jones (2008) described the NOA model as a circular model, which streams from institutions (in the top corner of Figure 4) to opportunities influencing the consumption behaviour and, finally, “subjective well-being” as well as “environmental quality” (Lucas et al., 2008, p. 458). These then feedback to the set of external factor dimensions, e.g. institutions. Opportunities can be seen as individual households’ abilities to satisfy energy-related needs, e.g. physical accessibility to resources, technologies and services or financial accessibility to credit (Brizga & Līce, 2013). The feedback loop within this model clearly implies that the right institutional context has great influence on steering the consumption behaviour towards sustainability, which could in turn affect the higher institutional context itself (Lucas et al., 2008).

It was previously mentioned that the literature on the ELM explains technology accessibility to households mainly based on economic factors (Reddy & Reddy, 1994). In light of this, there is value in the integration of the NOA model, in the sense that it expands the focus on the proposed framework on policy and political forces, that are crucial in influencing residential energy use (Lucas et al., 2008). This explains why not all the features of this model are looked at, but only the notion that was not prominently addressed in the ELM, i.e. institutions.

Based on the two levels of analysis outlined in this chapter, the conceptual framework is illustrated in the next section.

2.2 Conceptual Framework

The concepts and linkages discussed above are graphically represented in figure 5.

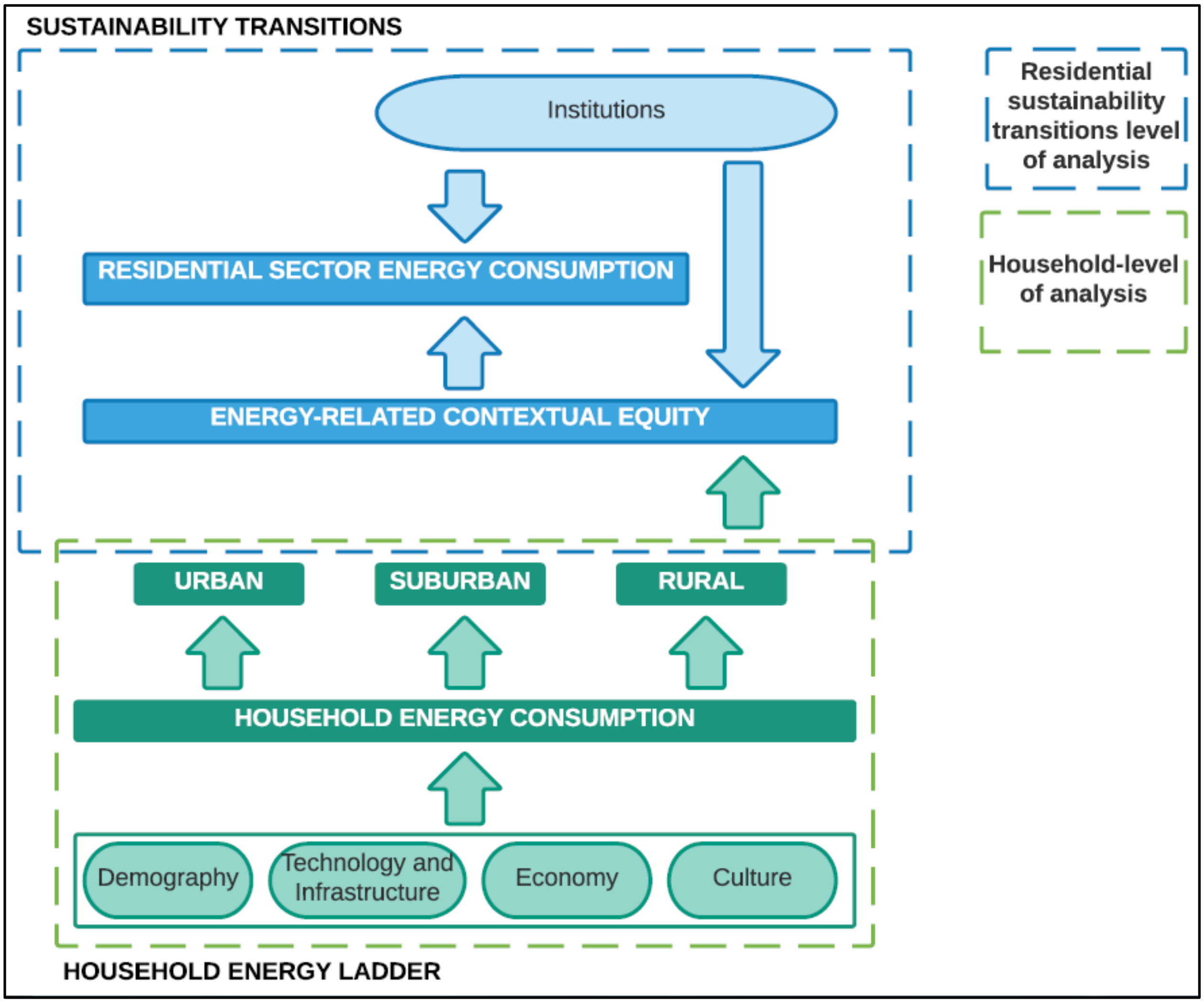


Figure 5. Conceptual framework representing two analytical levels of research.

2.2.1 Factors influencing energy consumption patterns

The literature presents several factors that attempt to explain the complexity of household energy stacking patterns.

Household energy ladder

Demography

Hosier and Dowd (1987) claimed that urban households tend to use modern energy sources, such as electricity, than their rural counterparts. Seemingly, van der Kroon and colleagues (2013) indicated "urban locality" as a key factor influencing household energy consumption (p. 511). This is confirmed also in Mekonnen and Kohlin's study (2008), who found that populous and large cities in Ethiopia are more likely to enable the progressive switch from solid fuels (e.g. fuelwood) to non-solid fuels (e.g. kerosene, natural gas). Hence, households in rural areas may be limited in their accessibility to technologies.

Technology and infrastructure

This factors dimensions comprises infrastructural lock-ins, residential building characteristics and reliability. Lock-in situations - where energy network infrastructure and/or building inefficiencies inhibit structural adjustments to adopt cleaner and more efficient energy sources - need to be considered in this framework (Unruh, 2000; 2002). As a matter of fact, households may be limited in their use of more sustainable energy options due to inefficiencies in the dominant regime of buildings infrastructure (Unruh, 2002). Moreover, Elias and Victor (2005) suggest that total dependence on commercial energy, e.g. electricity grid network, may in some cases increase the vulnerability of households to the unreliability of the energy supply, such as unexpected electricity outages (Elias & Victor, 2005). In this instance, the reliability of the energy infrastructure to end-users is a critical factor for the adoption and continued use of a specific energy source (Nissing & von Blottnitz, 2010; van der Kroon et al., 2013). The above factors referred to contextual pre-conditions that may be present when exploring household energy consumption in its locality. The next paragraph presents factors that may arise during urbanisation.

One could argue that increased availability and accessibility of energy technology and infrastructure with rising urbanisation may help explaining why urban households shift from lower-quality and more polluting fuels to cleaner and more efficient energy sources (Hiemstra-van der Horst & Hovorka, 2008; van der Kroon et al., 2013). Nonetheless, the study by Hiemstra-van der Horst and Hovorka (2008) reported that transition barriers may appear throughout the urbanisation process.

For instance, the perfect or partial switch to cleaner sources may be undermined in case household groups have limited or no accessibility to modern technologies, even when modern energy sources are available. This is defined as "stove barrier" (Hiemstra-van der Horst & Hovorka, 2008, p. 3335). Also van der Kroon and colleagues (2013) pointed at the synergy between available and accessible energy sources and technologies as key to better understand the potential adoption of cleaner and more energy-efficient options. The literature on the ELM provides explanations for limited or no technology accessibility that depend on economic factors.

Economy

The economy dimension encompasses household income rise, income variability and cost competitiveness of energy sources/technologies. First, Hosier (2004) defines climbing the ladder as an upward movement from traditional to modern fuels as income increases. Second, Van der Kroon et al. (2013) redefines the classical ELM by reporting that energy stacking behaviour may be associated with irregular households' income flows. Informed by Reddy & Reddy (1994), regular income from salaries and wages is assumed to positively affect the adoption of cleaner and more efficient energy sources. The difficulty in determining the magnitude of erratic income sources - due to informal goods sales and/or agricultural activities - in rural household groups was reported to undermine the linear relationship between income and fuel choice (van der Kroon et al., 2013). Again, the urban/rural divide was found to help to explain energy consumption inequalities in the residential sector.

Finally, access to energy sources/technologies due to "high monetary costs" was found in the literature to be an important economic determinant of household energy consumption patterns, for which the cost competitiveness of certain energy types over others is critical (van der Kroon et al., 2013, p. 511).

Socio-cultural habits and preferences

Van der Kroon and colleagues (2013) report household energy stacking behaviour to be related to cultural resistance to change, owing to households' socio-cultural habits and preferences.

On the one hand, in 1992, Leach (p.118) argued for the existence of a ladder of household "fuel preference" in developing countries from biomass to electricity. In defining renewable energy for sustainable urban development, Nissing and von Blottnitz (2010, p. 2180) indicated "cultural acceptability" as one of the major enablers of the adoption of renewables. Thus, one can assume that household preferences may lead to opt for energy stacking, rather than total fuel switching to modern energy sources, and households may continue to use low-efficiency and polluting fuels accordingly to local traditional practices, despite the availability of modern energy sources.

Alternatively, another explanation for cultural acceptability is given by Masera and colleagues (2000), arguing that households tend to identify energy technologies with socio-economic status. This implies that energy users tend to climb upwards along the ladder not only as they prefer to utilise less polluting sources, but also to display a higher socio-economic status.

Institutions in sustainability transitions

Within the context sustainability transitions, institutions comprises of government policy interventions and business actors, which may influence the technology quality, maintenance and *contextual disposition of access.*

a. Government policy interventions

As mentioned above, existing studies do not emphasise the influential role of policy interventions on households energy use, which van der Kroon and colleagues (2013) indicate as a flaw in the energy ladder literature. Policies could have either a positive or a negative impact on the adoption of cleaner and more-efficient energy sources, depending on their targets and policy instruments directed to the targeted population (Campbell et al., 2003). For instance, Campbell and colleagues (2003) reported that economic adjustments of the electricity billing system in Zimbabwe negatively affected lower-income households. Metered energy supply indeed reduced their purchasing power and availability of services. In this instance, electricity policy adjustments failed to account for adverse effects on the most vulnerable society groups. Key findings from Bartiaux and colleagues' study (2015) on existing inequalities in Portuguese and Belgian cities, reported that energy-related policy strategies contributed to the adoption of more sustainable and cleaner technologies, the acceptance of energy efficient solutions and other energy-conservation practices in residential buildings. These findings arguably showed that government energy policies and programmes can unequally impact different household groups within the residential sector (Campbell et al., 2003).

The reviewed literature on contextual equity supports the argumentation that, for the "sake of net societal gain" (McDermott et al., 2013, p. 418). Here, net societal gain could be regarded as the improvement of well-being or quality of life, energy-related policies may limit the accessibility of resources to certain household groups in the society.

b. Business actors

Some studies suggested that the dynamic conditions of energy transitions exercise broad influence on markets, creating opportunities for entrepreneurial individuals in the field of technology advancements (Busenitz et al., 2003). On the contrary, Alvarez and Barney (2007) claim that entrepreneurs are in fact the architects of new market opportunities, creating innovative business models and ideas in a particular market field, which were previously non-existent.

In must be stated that, the conditions for enabling or constraining entrepreneurship, which depend upon the political, cultural, social and economic contingent environment, are beyond the scope of this study. Nonetheless, based on the selected literature, market institutions are seen as playing a critical role along political institutions. Thus this factor is integrated in regards to the adoption of cleaner and more energy-efficient alternatives to fossil fuels use (Campbell et al., 2003; van der Kroon et al., 2013).

Grounded on the reviewed literature review and theoretical discussion, the next section clarifies the relevance of the aforementioned theoretical notions and models for the research project at hand.

2.2.2 Application on the case study and assumptions

The reviewed literature emphasized some relevant aspects for the application of this framework to the scope and objectives of this thesis.

First, existing evidence from literature studies in developing countries showed that a combination of household-level factors tend to either facilitate and/or constrain the use cleaner and more efficient energy sources, depending on the context (Leach, 1992; Nansaior et al., 2011). Accordingly, the first assumption is as follows:

> *Solar and energy efficiency technologies may be exclusively utilised on top of the energy ladder for certain energy uses/services (perfect switch), but to address the overall spectrum of domestic energy services in the short-term, a combination of energy sources and technologies may be necessary (energy stack)*, under certain conditions, which this thesis attempts to explore.

This assumption refers to the first part of overarching research question in section 1.4.

Secondly, section 2.2.1 reported that both government interventions and business actors may have diverse effects on the adoption of more sustainable energy alternatives to conventional fuels (Campbell et al., 2003; Nissing & von Blottnitz, 2010).

For instance, high upfront costs of solar thermal installations for domestic water heating could shift the consumer demand towards cheaper options, such as electricity or (natural) gas, for satisfying the same energy service. By comparison, policy interventions in the form of energy subsidies could increase the cost competitiveness of solar energy technologies *visa-à-vis* fossil fuels. This would facilitate the widespread adoption of e.g. SWHs, whereby domestic energy services are satisfied. Accordingly, it is assumed that:

> *Energy equity in distributive terms may be undermined or facilitated by institutional factors in the context of sustainability transitions.*

Hence, this assumption is related to the second part of the overarching question outlined in section 1.4, where Institutional factors are employed to analyse, on a higher level, equal sustainability transitions in the residential field.

Conclusively, this section provided a review of key literature findings in light of their applicability to the limited objective of this thesis. Further, it supported the application of the above theories and concepts in this thesis, due to them enabling to link dimensions of influencing factors on two levels of analysis, i.e. the individual household-level (ELM), and the sectoral sustainability transitions. Inequalities of energy consumption patterns among different household groups were considered throughout the theoretical discussion and linked to the two analytical levels. The proposed framework is based on the idea that a multiple-dimension approach is ideal to explore energy consumption patterns. This guides the design of the following analytical framework.

2.3 Analytical Framework

This section explains the analytical framework grounded on the theoretical concepts explained in the previous chapter, and distinguishes among five factor dimensions. The holistic approach of the present framework allows for the exploration of a broad spectrum of barriers and opportunities as influencing factors supporting or inhibiting sustainability energy consumption in the residential field. Moreover, the primary local data collection performed in line with the analytical approach may provide evidence of additional influencing factors.

Building on existing literature, barriers and/or opportunities to climbing upwards along the household energy ladder were discussed (Campbell et al., 2003; Hosier, 2004; Masera et al., 2000). In this instance, climbing on top of the ladder signifies exploiting opportunities for the adoption of solar energy and energy efficiency technologies. Opportunities could be seen as individual households' abilities to satisfy energy-related needs, e.g. physical accessibility to resources, technologies and services, via cleaner and more energy efficient sources/technologies (Brizga & Līce, 2013). It follows that barriers could refer to influencing factors that somehow constrain the households' ability to adopt more sustainable energy alternatives to fossil fuels.

In order to enable for a simplification of the complex energy context presented in the literature, factors influencing energy consumption patterns on the household- and sustainability transitions-level are operationalised respectively in Table 1 and 2.

Table 1. Analytical framework on factors for climbing the energy ladder

Factor dimension	Factor	Operationalisation		Literature sources
		Barriers	**Opportunities**	
Individual household-level of analysis				
Demography	Household locality	Household having rural locality	Households having urban locality	Campbell et al., 200; Mekonnen and Kohlin, 2008; van der Kroon et al., 2013
Technology and Infrastructure	State of technology and infrastructure	Lock-in of physical infrastructural conditions Inefficiencies of residential buildings characteristics	Reliability of energy technologies (thus services)	Sovacool, 2017; van der Kroon et al., 2013
Economy	Household income Cost competitiveness	Household income variability Cost advantage of fossil fuels High upfront costs of sustainable energy technologies	Household income rise Regular income flows Cost advantage of sustainable energy technologies	Elias & Victor, 2005; Hiemstra-van der Horst & Hovorka, 2008; van der Kroon et al., 2013
Culture	Cultural acceptability	Socio-cultural (culinary) habits and preferences Display of socio-economic status	Energy-saving habits	Hiemstra-van der Horst & Hovorka, 2008; Masera et al., 2000; Nansaior et al., 2011; Nissing & Blottnitz, 2010

The first part of this framework refers to the literature on energy consumption behaviour and choice by Campbell et al. (2003), Heltberg (2004) and other scholars. The higher level of analysis is presented in the next table, which contemplates the potential influence of policy interventions and market opportunities in supporting or inhibiting the sustainability transition in the residential sector.

Table 2. Analytical framework on institutional factors for sustainability transitions

Factor dimension	**Factor**	**Operationalisation**		**Literature sources**
		Barriers	**Opportunities**	
Higher institutional level of analysis				
Institutions	Government policy interventions	Lacking of understanding of contextual energy consumption and/or inequalities	Policy support of quality and maintenance of sustainable technologies	Campbell et al., 2003; Heltberg, 2004; Gatersleben & Vlek, 1998; Brizga & Līce, 2013 Nissing & von Blottnitz, 2010
	Business actors	Centralised energy system	New business models and technologies	Busenitz et al., 2003; Alvarez & Barney, 2007

The aforementioned integrated analytical levels recognise that the influencing factors for energy consumption are intertwined. For instance, the extent to which households are able to exploit the opportunity of adopting rooftop solar panels may first be influenced by the urban locality of certain households. This could be further influenced by the structure of low-storeys residential buildings and/or policy regulations obliging developers to install solar technologies.

Conclusively, this chapter illustrated and discussed major theoretical factors explaining households climbing on top of the energy ladder (sub-question 1.1). The ELM was revised to address critiques that some scholars previously raised, and to fit the model into the objectives of this research project.

This framework is grounded on the need to deepen the understanding of the extent to which a diversity of household groups can climb on top of the energy ladder, in order to enable sustainability transitions (sub-question 1.2). Based on the present framework, the research approach and methods follow in the chapter.

3. Methodology

This first part of this chapter (section 3.1) presents the methodological approach chosen for the present research. In relation to the scope and the objectives of this project, the research process combines multiple data collection methods, which are addressed as transparently as possible. Data processing and analysis are explained in section 3.3. Ethics issues considerations are addressed in section 3.4.

The present research was executed in numerous stages. First, a thorough literature review was performed at the preliminary stage (research proposal). In the second stage, desk research was carried out simultaneously with the preparation to the fieldwork in the location of the case study, in Beijing, China. Prior to departure, approval of the research strategy and related tasks to be performed during the mobility period was granted by both the hosting institution in China (Beijing Normal University [BNU]) and the Climate-KIC Master Label programme in the Netherlands, supported by the European Institute of Innovation and Technology. Delays occurred in processing the visa documentation. The third stage consisted in the actual empirical research. During stage four, the data collected were processed and analysed in light of the overarching research question and in consideration of research ethics. The last stage focused on finalizing the thesis report.

3.1 Methodological approach

The approach of the present thesis followed a qualitative research methodology, grounded on explorative research through literature review and an empirical case study (Figure 6). Overall, the factors that may facilitate or inhibit energy use patterns of diverse household groups and sectoral sustainability transitions were identified utilising a combination of mixed method. These mirrored the interaction with a heterogeneous group of stakeholders.

The desk research consisted in the review of existing scientific knowledge on the subject at hand and of literature in line with the chosen case study (Figure 6). This choice was based on the review of existing literature, for instance, the work of Jacobson, Nghiem, Sorichetta and Whitney (2005). The authors notably argued for “including equity related trends, [which] cannot be determined without consideration of disaggregated data” (pp. 1825-1826).

In order to carry out the objectives of this research, the approach hence followed a case study methodology (Figure 6, right side).

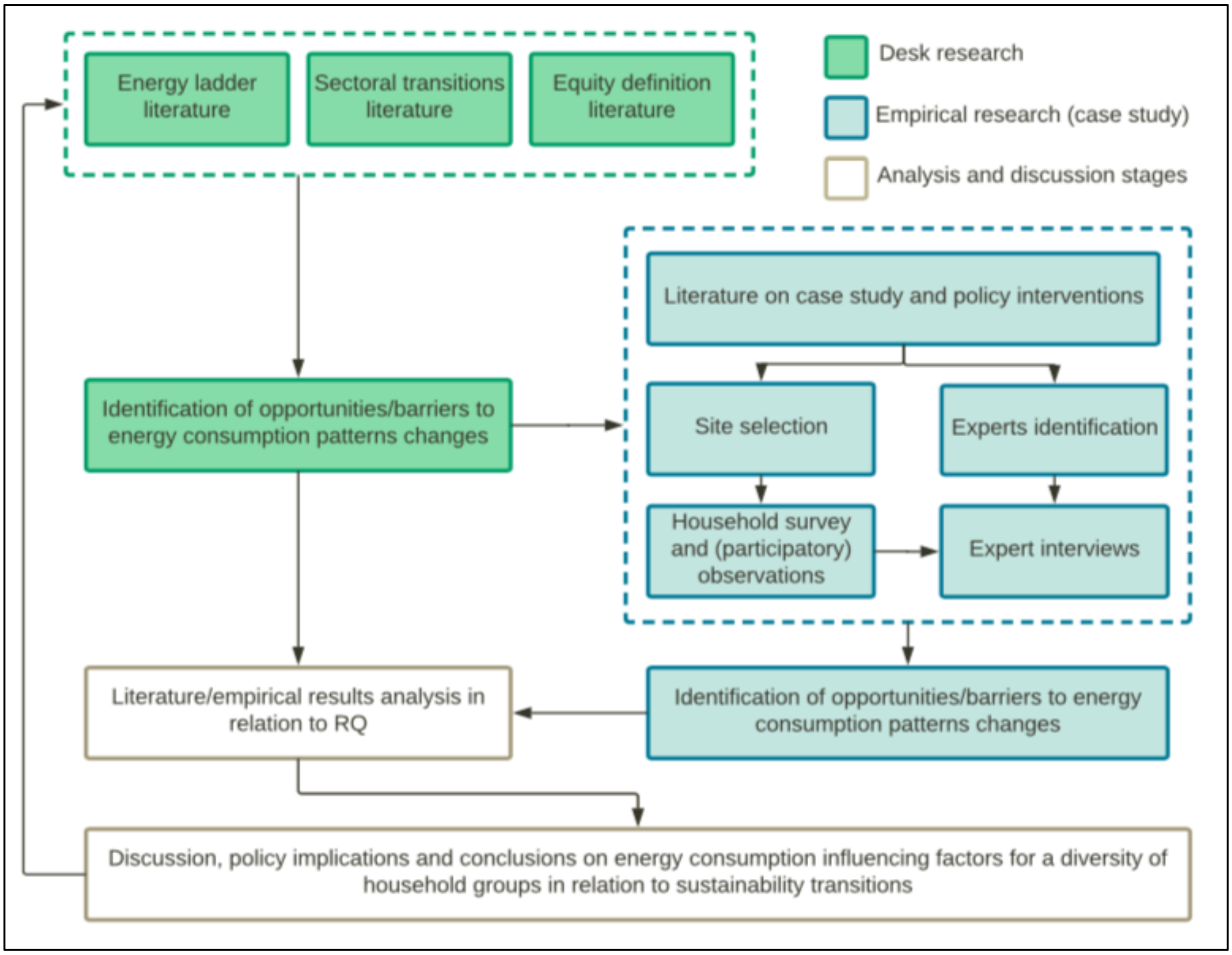


Figure 6. Research framework.

Case study

Beijing Municipality - the capital of People's Republic of China and centre of economic, social, technological and cultural development - has been undergoing deep structural changes in terms of demographics and economy (TU BERC, 2016). As aforementioned in the introductory chapter, the urban sprawl and economic development were found to affect people's lifestyles and to have implications for residential energy consumption (Campbell et al., 2003).

Beijing thus constitutes an appropriate case study in this research field. As a matter of fact, national statistics reported that the population in the Chinese capital grew from 1.297 million people in end-2012 to 1.345 million people in end-2016 (National Bureau of Statistics of China [NBS], 2017). Additionally, the recent deregulation of

China's urban registration system (*hukuo*) has been leading to a progressive affluence of rural migrants to Beijing (Zhifeng, 2009). The urban fringe is therefore expanding to enclose outer areas (suburban areas).

A point must be briefly clarified here. Often, there exist a tendency in the literature in equating rural households with low-income or poor households (Nissing & von Blottnitz, 2010). The authors reported, however, that most poor communities do live in rural areas and China is no exception. For instance, at the end of 2015, the disposable income per capita of urban households was 52,859.2 Yuan, and the one of rural households was 20,568.7 Yuan (National Bureau of Statistics [NBS], 2016). Fully recognising this, the distinction prevailing in this thesis relates to urban, suburban and rural household groups. This represent to a certain degree diverse income levels. In their study, van der Kroon and colleagues (2013) also refer to this distinction.

3.2 Data collection methods

This section explains the methods devised for this research, in order to allow readers to trace the secondary and primary sources this thesis was based on. As previously mentioned, secondary research methods included literature review on theories and model applied to design the framework of this thesis, and for the analysis of this case study. Primary data was collected through household surveys, direct (participatory) observations of the housing areas, and expert interviews to triangulate previous findings.

3.2.1 Literature review

The literature review was performed in line with the research sub-questions 1.1 and 1.2, as outlined in the introductory chapter. The process of reviewing theories and models is firstly explained. Secondly, the reviewed literature on the case study at hand is discussed, along with related literature sources.

Theories and models literature review

The design of the theoretical framework in chapter 2 was preceded by a preliminary review of the literature published in leading academic and scientific journals in renewable energy and domestic energy use policy between 1992 and 2017. The review relied on Google Scholar and Scopus search engines. To be included in this literature review, an academic article, report or other published sources had to include (at least one of) the following keywords: *household energy consumption, household behaviour and choice*, *fuel switching*, *sustainable energy* and *energy transition*, as well as *equity* and *energy access.* Based on these keywords, two models were selected in the preliminary literature review: the energy ladder model (Hosier, 2004; Leach, 1992), and the Needs-Opportunities-Abilities (NOA) model (Gatersleben & Vlek, 1998). As for the energy ladder model, the majority of literature is presented in the form of case studies from developing countries, especially Sub-Saharan Africa, India and China (Hosier, 2004; van der Kroon et al., 2013). The NOA model was identified from the work by Darnton (2008), who reviewed a series of theories and models on behavioural change including higher levels of scale, such as the civil society and institutions. Moreover, existing literature was included in regards to *contextual equity* in the proposed framework (Bartiaux et al., 2015; McDermott et al., 2013).

In order to ensure there was no existing literature on the energy ladder having solar energy and energy efficiency on the top rung of the ladder, the intense literature review included numerous articles in the field. The articles included, among all, barriers to energy carriers/fuel substitution (Leach, 2002; Pachauri et al., 2012; Reddy & Reddy, 1994), the domestic energy/fuel choices of lower and middle-income groups (Heltberg, 2004; Hosier & Dowd, 1987), and the differences in rural and urban households' consumption patterns (Campbell et al., 2003; Nansaior et al., 2011). The review was also comprised of scientific articles that critically discussed the theoretical foundations of the ladder, whilst suggesting alternatives to the traditional model (Hiemstra-van der Horst, Hovorka, 2008; Hosier, 2004; Masera et al., 2000; Sovacool, 2017; van der Kroon et al., 2013). These articles were employed in chapter 2.

Case study literature review

The initial set of keywords was expanded to encompass *China, Beijing, equity, rural/urban energy consumption*, *building energy efficiency*, *solar energy*, *energy services* and *energy equity*. As a result, articles referring to the energy ladder model application in China were identified (e.g. Elias & Victor, 2004). Finally, scientific knowledge on the concept of equity was integrated. This was done in relation to energy policy implications in China and Beijing, for instance in Sovacool (2017), Unruh & Carrillo-Hermosilla (2004) and Zhang et al. (2017). The research also relied on evidence from other studies conducted in the same climatic region (Cold Winter Zone) in Northern China (Ma, Mao, Shan, Zhang, & Yang, 2017).

By narrowing down the research, other keywords were included in the literature search: *solar water heater, solar PV, improved stoves, building energy efficiency, urbanisation, air pollution,* and *technology acceptance* (Liu & Liu, 2016; Smith et al., 1994), but also *solar energy/energy-efficiency policy* (Lo, 2014; Wang et al., 2014; Wang, Han & Lu, 2016). Finally, data on rural and urban household characteristics were sourced from the *Beijing Statistical Yearbook 2016* (Beijing Municipal Bureau of Statistics [BMBS], 2016).

Historical and current reports on solar energy and energy efficiency technologies as well as climate and air pollution issues, were based on international publications by the IEA

(2011; 2017a; 2017b), the IPCC (2014), the OECD/IEA (2015) and the REN21(2016). Other online sources included periodicals such as *The Guardian* and the *South China Morning Post*.

Policy interventions

The following policy interventions were considered in the analysis (table 3).

Table 3. National-level and corresponding local-level policies

National-level (release date)	National authority	Local-level (release date)	Local administrative authorities	Summary of Beijing municipal policy objectives
Renewable Energy Law (January, 2016)	National Development and Reform Commission (NDRC)	Mandatory building requirements for SWH installation (2007)	Beijing Municipal Planning Commission	Subsidised support to enterprises for the commercialisation and deployment of SWH technologies in residential buildings
Energy Conservation Law of the People's Republic of China (November, 1997) 12th Five-Year Plan (2011-2015)	National Development and Reform Commission (NDRC)	Design Standard for Energy Efficiency of Residential Buildings of Beijing (DB11/891-201) (2013)	Beijing Municipal Commission of Development and Reform; Beijing Municipal Planning Commission	Achieve the “Beijing 65% Energy Saving Standards”; in the civil residential construction sector; accelerate the application of SWH systems and promote energy conservation and emission reduction
13th Five-Year Plan (2016-2020)	National Development and Reform Commission (NDRC)	Coal ban	Beijing Municipal Commission of Urban Planning and Land Resources and Beijing Municipal Commission of City Management	Prevent and control air pollution via coal to electricity or coal to gas transition; coal ban for domestic fuel combustion stoves

The literature sources comprise of Urban et al. (2016) for the 2007 mandatory building regulations. Liu and Liu’s work (2016) was considered for the *Design Standard for Energy Efficiency of Residential Buildings of Beijing*, published by the TU BERC (2016). Information on the coal ban was retrieved from the Beijing Foreign Affairs Office (2017), online journal articles from the *Global Times* (2017), the *China Daily* (Jinran, 2015; Zheng, 2015), and the *South China Morning Post* (Zhou, 2017).

3.2.2 Sample selection and participatory observations

At the household-level of analysis, household surveys and participatory observations were performed. Attention was paid on ethical issues when processing data for the results analysis, which is treated in section 3.3.

Sample selection

The Beijing Statistical Yearbook 2016 provides a division of the municipality into 2 core functional areas, 4 urban function extension areas, 5 new areas of urban development, and 5 ecological conservation areas (Beijing Municipal Bureau of Statistics [BMSB], 2016; “Miyun Reservoir water,” 2017). Based on this, research site areas were randomly chosen. Rural individual households were sampled from districts in the ecological conservation areas: Miyun (old and new Simatai village), Huairou (Laowa rural village) and Mentougou (Cuandixia village). Suburban households were sampled from residential communities east of Haidian district (urban function extension area), where residents reported to have rural hukou (i.e. Caocangcun and Beijinatong communities). Survey respondents with urban hukou were from Chaoyang, Haidian, Xicheng and Fengtai districts (Figure 7).

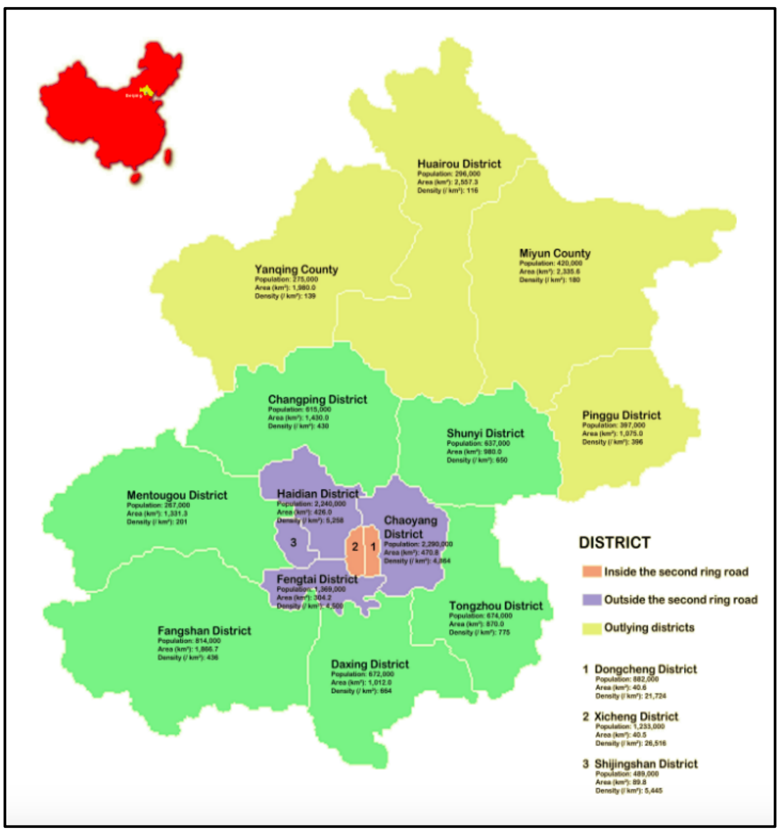


Figure 7. Beijing (2017, June 28). *Beijing Maps-Districts* [digital image]. Retrieved from https://beijingconflict.wordpress.com/maps/

Site visits and participatory observations

Site visits and participatory observations of the housing areas were conducted from July to August 2017 targeting household groups in three spatial locations (urban, suburban and rural). They were supportive in the identification of stimuli or barriers at the individual-household level, altogether with household surveys (Painuly, 2001).

3.2.3 Household survey

Household surveys is a valuable method to collect detailed data on household-level characteristics and deepen the theoretical understanding of factors facilitating and/or constraining residential energy consumption, and also inequalities (Campbell et al., 2013; Painuly, 2001). The questionnaire is included in Appendix I.

Questionnaire description

The household survey was conducted from July to august 2017. A total of 15 questions plus a section for suggestions/comments were designed both in English and Chinese-Mandarin and spread across the four household-level categories: technology and infrastructure, economy, demography and culture. Moreover, the survey was designed bearing in mind the three household clusters (urban, suburban and rural).

Accordingly, a recent White paper on urban-rural digital divide in China reported the large gap in urban-rural Internet usage: 201 million rural Internet users against 550 urban Internet users in 2017 (China Internet Watch, 2017). Face-to-face household questionnaires were therefore preferred for rural and suburban residents, whilst urban residents were asked to complete the survey online, and could access the link to the software QuestionPro (used for the survey) from any device. Prior to the start of each questionnaire, all respondents were informed on the purpose of the study and the anonymity of their responses. Respondents could also withdraw anytime (Bryman, 2016).

The questionnaire sought to collect data on residential energy consumption, which was disaggregated into 5 energy services to identify the end-use patterns at the time of the survey. Here, respondents were asked to indicate the types of sources and technologies used for the respective purpose of usage (question 8), and the level of indoor thermal comfort (questions 6-7-9). This was based on previous literature on technology and infrastructure factors influencing energy use. Respondents were also asked to provide information on household-level demographics (e.g. gender, age, district name and residence permit or *hukou*) (questions 1-4). Accordingly, by questioning on their type of residence permit, it was possible to exclude respondents giving misleading answers, such as inexistent district names in Beijing, particularly in the computerised survey, where the student was not able to directly interact with urban respondents.

Some issues were addressed prior to the start of the survey. In order to minimise the ambiguity of questions, the questionnaire underwent two revisions by Professor Tu and by Dr. Lin at the hosting university (BNU), and it was translated in Chinese Mandarin. Respondents tendency to “satisfice” was also considered, defined as reducing the amount of effort to answer (Bryman, 2016, p.205). This resulted in a questionnaire kept as brief as possible. However, this could not prevent residents from dropping out before completion or omitting answers.

Questionnaire completion

This urban survey scored 206 viewers, and a completion rate of 40.35%: 57 incomplete questionnaires, 34 dropouts and 23 completed questionnaires. Most of the dropouts and/or incomplete answers occurred when residents were asked to provide information on their energy expenditure (questions 11-15, Appendix I). The explanation for this is possibly threefold: residents may be unwilling to disclose this type of monetary-wise information, secondly, they may be unaware of their actual energy expenditure. The latter case is common in social research (Bryman, 2016). Often respondents are unwilling to invest efforts to optimise their answer (provide the “best and most appropriate answer”), therefore dropping-out or neglecting the questions (Bryman, 2016, p.205). Thirdly, in spite of the attempt to minimise the ambiguity of questions, the fact that respondents may understand the question needs to be considered (Bryman, 2016).

In some cases, residents initially accepted to answer the questionnaire, however, it soon became clear their discomfort in answering a structured set of questions, for which the approach changed to a more open conversation where the student verbally asked questions on the basis of the structured questionnaire. This resulted in an atmosphere of greater understanding between the student and the respondents/residents, which leads to the next section discussion on advantages and limitations of the employed survey methods.

Advantages and limitations of survey methods

On the one hand, a computerized survey questionnaire can generally be more convenient as respondents can complete it whenever they want and it can simultaneously be distributed to larger samples than in on-field face-to-face surveys (Bryman, 2016). However, this survey fell short in collecting a large set of data, due to the aforementioned reasons.

On the other hand, face-to-face surveys usually had several advantages. First, it was possible to re-formulate questions to respondents. Second, the student could probe further after the questionnaire completion. As a matter of fact, further data were collected through open questions during the post-questionnaire interaction with local residents. For instance, some rural residents provided data on the house indoor temperature, the convenience of using coal delivered to the village by local suppliers, and the reliability of the grid network (in terms of unscheduled electricity outages). However, it was acknowledged that face-to-face questionnaires could result in residents giving the most socially desirable answers, rather than truthful ones (Bryman, 2016).

Moreover, all sampled rural and suburban areas were reached by public transport and visited unannounced. This often presented some difficulties as residents initially appeared unwilling to interact with the student and the Chinese native-speaker translator. Nonetheless, as a foreign-looking student performing research, this usually attracted the attention of inhabitants in the area, which allowed the student to approach more residents, as they usually gathered around the spot where the first survey was being conducted (e.g. in front of a local supermarket or their house). In some cases, the residents also offered to showcase their house, in which case the student could ask for their consent to take pictures of the house appliances and facilities, e.g. cookstoves.

Last but not least, the main limitation to both on-site face-to-face and computerized questionnaires refers to the fact that the limited sample size cannot be representative of the population of the case study area. In an attempt to obtain a larger response rate, the students employed a snowballing technique (Bryman, 2016). Accordingly, the link to the questionnaire was firstly sent to personal contacts among students/staff at BNU who were living in Beijing for more than 6 months. These were then asked to forward the link. In addition, the student attempted to obtain more responses by publishing the survey link on WeChat (the main instant messaging service available on smartphone devices and computers in China).

Sample characteristics description

The majority of respondents were females and residents between the age of 15 and 59. The average age of sampled respondents in urban, suburban and rural areas is respectively 27, 63 and 50 years. The young age of the urban cluster may be due to the computerised administration of the urban household survey, and the completion mainly by students/staff at the BNU.

3.2.3 Expert semi-structured interviews

In order to triangulate the data collected through the aforementioned methods, 6 expert semi-structured interviews were conducted with academics in the field of technology, building environment and economics, with engineers/entrepreneurs and with one corporate manager from a construction company located in Beijing. One expert replied via e-mail correspondence (a full list of experts in available in Appendix II). Semi-structured interviews were preferred to structured interviews in this case, as they favored the non-standardisation of the process, for which reason they are often employed in exploratory and qualitative-based research (Bryman, 2016).

The interviews consisted in addressing questions related to the factors included in the analytical framework (section 2.3). In fact, Tables 1 and 2 were utilised as a combination of topics to be covered, and guiding the interaction with experts. Factors embedded in Table 1 were used to triangulate the results from previous household surveys and participatory observations. Theoretical factors in Table 2 were as guidelines to explore the dimension of institutions on the higher analytical level of this research. Not only did this approach enable a certain degree of flexibility when interacting with different experts, but it also allowed to probe deeper for additional factors (Bryman, 2015).

Most of the interviews were done face-to-face in Beijing, while others via digital communication. All interviews were recorded and transcribed to add reliability to the results analyses and to the research overall (Bryman, 2016). The results from the coding process of interviews is available in Appendix III.

3.3 Ethical considerations

In consideration of research ethics, all participants took part in the survey or in interviews on a voluntary basis and could withdraw from the process (or ask to stop the recording of interviews) anytime (Bryman, 2016). All respondents/interviewees were informed (via e-mail correspondence, at the beginning of the computerised household questionnaire or in person) on the identity of the researcher, affiliated university institution, the purpose of this research and the the type of data to be collected. Also, experts were asked to provide verbal informed consent prior to the start of the interview recording (Bryman, 2016).

Almost all interviewed experts gave explicit permission to mention his/her name and/or title in this thesis. The privacy of other non-consensual participants is protected by not mentioning any personal name nor the name of possible affiliated organisations/institutions in this paper. Moreover, the photos included in this thesis were taken after obtaining residents' verbal permission.

Other data from the observation of energy consumption practices in other locations are neither elaborated nor analysed in this thesis. This is because there was limited student-resident interaction and no opportunity to apply the informed consent procedure to obtain residents' verbal permission to use the information for the purpose of this study.

3.4 Data analysis

The analysis of the first household-level analysis is based on a household-level dataset constructed by surveying households in randomly sampled areas. Based on the BMBS (2016) dataset, residents living in one specific area for more than 6 months are considered part of the permanent (or permanent migrant) population in that area. Hence, only respondents living in Beijing for more than 6 month were included in the results analysis. Accordingly, the selected respondents are from the districts of Chaoyang, Haidian, Xicheng and Fengtai, i.e. 15 in total.

In the aftermath of the field research, each questionnaire was processed and the answers were integrated with on-site (participatory) observations. Considering the limited sample, and in order to answer the overarching research question, the household-level of analysis was triangulated with desk research and expert interviews.

Through the processing of primary data, expert interviews were coded according to the analytical framework (section 2.3). Common themes were sought, in order to identify major underlying opportunity and barriers/challenges in the households' adoption of solar energy technologies and energy-efficient measures.

Information from semi-structured interviews was a valuable source of primary data, which allowed to combine literature findings with the professional experience and expertise of interviewees (Lozano, 2013), Also, interviews helped to formulate some policy implications and to indicate priorities to be addressed in the future (Painuly, 2001).

When combining these results, it is clear that each of the criteria and variables that were analysed do not stand alone, but are interrelated with each other. In other words, when discussing the key findings of this thesis, one aspects cannot be entirely understood in its influencing role if others are not considered. The present research is thus based on assumptions from the literature on the energy ladder model, empirical findings, logical reasoning and qualitative results from performed interviews.

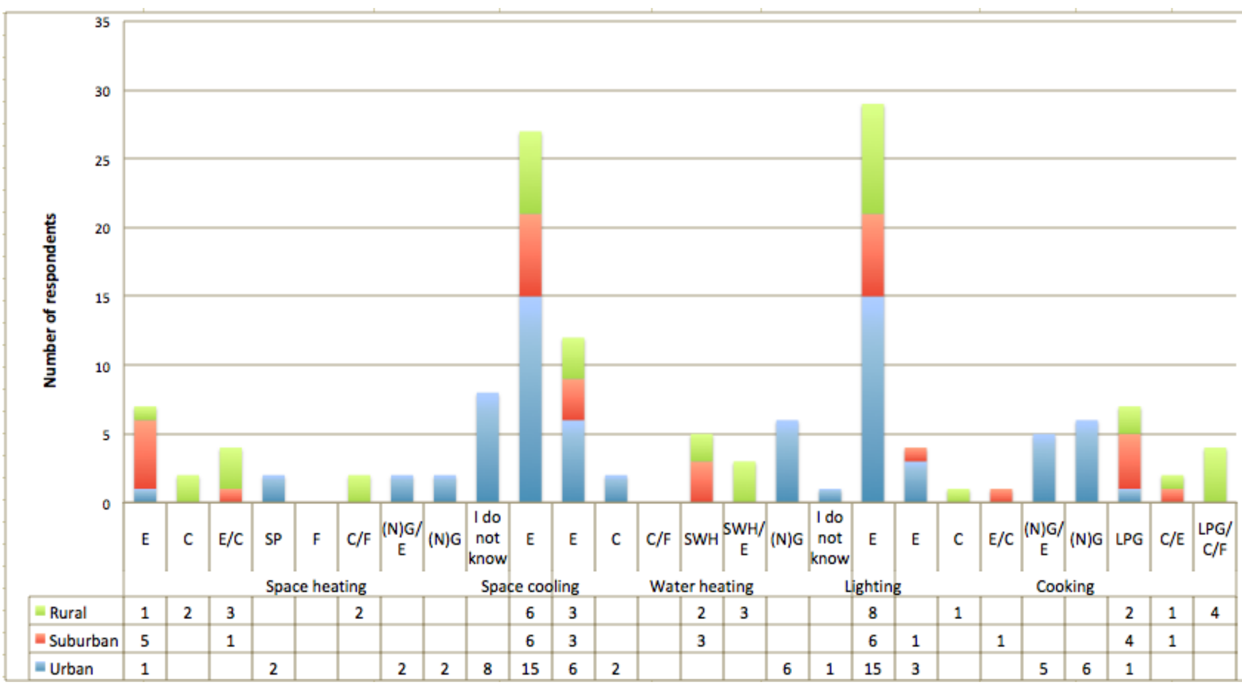
In line with the multiple methods selected for this research project, the results are analysed in the following chapter.

4. Results Analysis

This chapter presents and analyses the data collected from secondary and primary sources during the research project, with additional insights from reviewed technical reports and publications on the case study at hand, as outlined in the methodological chapter. Section 4.1 illustrates the results from the household questionnaires and participatory observation. In section 4.2, the analysis comprises of factors related to the household energy ladder (sub-question 1.3). Sub-question 1.4 is subsequently addressed in the last analytical section (4.3), concerned with institutions in the context of sustainability transitions. This is followed by the results discussion and concluding remarks.

4.1 Household energy consumption

This section graphically presents the results from the survey on household energy consumption, conducted from July to August 2017 (Figure 8). It comparatively illustrates the types of energy sources used by different household groups at the time of the survey (question 8, Appendix I).



	Space heating									Space cooling	Water heating							Lighting	Cooking							
	E	C	E/C	SP	F	C/F	(N)G/E	(N)G	I do not know	E	E	C	C/F	SWH	SWH/E	(N)G	I do not know	E	E	C	E/C	(N)G/E	(N)G	LPG	C/E	LPG/C/F
Rural	1	2	3			2				6	3			2	3			8		1				2	1	4
Suburban	5		1							6	3			3				6	1		1			4	1	
Urban	1			2			2	2	8	15	6	2				6	1	15	3			5	6	1		

Figure 8. Household consumption of energy sources per service and household group.
Note. E=electricity; C=coal; SP=solar power; F=firewood; (N)G=(natural)gas.

The comparison is performed hereafter according to each energy service, in line with the scope of this research project, i.e. space heating, space cooling, water heating, lighting and cooking. (The past tense is used in the next section, in consideration of the fact that energy use patterns might have changed in the meantime this research was finalised).

Space heating

In sampled rural areas, 2 respondents (37%) were found to utilise coal and electricity in new Simatai village, 2 (25%) only utilised coal only (1 respondent in old Simatai village and 1 in Cuandixia village), and 2 (25%) used coal and firewood (1 respondent in old Simatai village and 1 in Laowa rural village). One respondent (12.5%) only used electricity in Cuandixia village. One rural respondent expressed the willingness to invest in solar PV (rural respondent 6, personal communication, July 23, 2017)

By comparison, 5 (84%) surveyed suburban residents used electricity for space heating, and one (16%) consumed both electricity and coal in Baijiatong residential community.

As for urban areas, 8 (53%) surveyed residents indicated that they were not aware of the source of their energy supply. In support of the lack of this type of information, official statistics were drawn from He and Reiner's study (2016). The authors reported that 75.3% of rural households and 94.4% of urban households in Beijing are covered by a district heating network. Also, 2 (13%) suburban respondents used electricity and natural gas, 2 (13%) used natural gas, and 1 (6%) used electricity. Notably, 2 (13%) urban respondents owned solar panels for space heating. No respondents in other sampled areas were found to utilise solar PV. However, it was observed that some neighbouring houses in rural areas had installed this type of technology.

Space cooling and lighting

In this sample, all households totally switched to electricity for space cooling and lighting, except for 2 individual rural households, who reported not to use electricity for space cooling.

Water heating (for domestic hot water)

In rural areas, 2 (25%) respondents used a SWH in old simatai village, 3 (37.5%) used electricity (in Cuandixia village and in new Simatai village) and 3 (37.5%) used both (in new Simatai village and in Laowa village).

In former rural areas, from a total of 6 suburban respondents, all owned a SWH. Notably, 3 (50%) still used it for hot water needs in Caocangcun residential community, whilst 3 (50%) switched to electricity in Baijiatong residential community. For instance, one resident switched to electricity due to malfunctioning of its installed SWH (suburban respondent 4, personal communication, July 15, 2017). In urban districts, 6 (40%) respondents used electricity, 6 (40%) used (natural) gas, 2 (13%) used coal and, 1 (6.7%) did not know the energy type consumed.

Cooking

Surveyed rural residents used LPG and coal as the main cooking energy sources: 4 (50%) respondents used a combination of LPG, coal and firewood (in old Simatai village, Laowa village and Cuandixia village), 2 (25%) used LPG in new Simatai village, 1 (12.5%) used coal in Cuandixia village and 1 (12.5%) used a combination of coal and electricity in new Simatai village (Figure 9).

By comparison, 4 (67%) suburban respondents used LPG, 1 (16.7%) used electricity in Baijiatong residential community, and 1 (16.7%) electricity and coal, again in Baijiatong.

In urban areas, 40% of respondents used (natural) gas, 20% electricity, 33% used both energy sources, and 6.6% (one respondent) used LPG.

Figure 9. Structural adjustments to adapt the kitchen to improved electric cookstoves, new Simatai village. July 23, 2017.

Based on the data collected from household questionnaire responses, the energy consumption in the sampled areas of Beijing features a substantial mix of energy types. In other words, sampled households were found to opt for a less linear diversification of their energy portfolio.

4.2 Household energy use factors

Based on the previous results, this section aims to provide evidence for the first assumption of the proposed theoretical framework, outlined in section 2.2.2. In relation to sub-question 1.3, this section offers in fact an attempt to deepen the understanding of contextual factors in Beijing, by exploring the extent to which solar and energy efficiency technologies may be utilised on top of the energy ladder, to satisfy certain energy uses/services.

Some additional insights from publications related to the case study at hand (outlined in the methodological chapter) as well as findings from expert interviews are also employed in the present analysis. This is done in order to triangulate the data collected during household surveys and (participatory) observations.

4.2.1 Demography

The first factor dimension to be analysed is demography. In the reviewed literature, urbanisation was indicated as the major demography-related factors for climbing up the ladder. This is analysed accordingly to the framework in chapter 2.

Urbanisation

In the theory, increasing urbanisation was found to facilitate the use of more modern energy sources (Hosier & Dowd, 1987). Based on the empirical evidence (questionnaire question 8 and participatory observations), the majority of respondents in urban areas were found to use either electricity or natural gas for space heating and cooling. In suburban areas, the types of energy were close to the urban ones, but with the additional consumption of solar energy for hot water needs, and no utilisation of natural gas. By comparison, direct fuel combustion of coal and firewood were still important energy sources for cooking and partly for space heating in rural areas. In fact, one rural respondent answered question 7 of the questionnaire, by reporting the usage of coal to produce heat for the traditional Chinese kang bed (rural respondent 4, personal communication, July 22, 2017).

Despite the limited households sample, the results show that, as the extent of urbanisation progresses from rural villages to urban districts, electricity becomes the dominant energy source (and natural gas). For instance, one respondent in the suburban residential community of Bajiatong reported to have used SHW in the past, but to have switched to electricity since the electrification of the residential community (suburban respondent 6, personal communication, July 15, 2017). Whilst the accessibility to modern energy, e.g. electricity, has progressively become more even across rural and urban fringes, findings from expert interviews reveal that the consumption gap is instead growing between lower and higher-income households. Accordingly:

"China have quite big difference between rural and urban. They always have this difference. And I believe, during… Since this reform, the difference is getting larger and larger." (Yi Jiang, personal communication, August, 2017)

In consideration of the above urban-rural gap, the next section presents the context-related technology and infrastructure characteristics that were part of the theoretical discussion on energy consumption patterns across a diversity of households.

4.2.2 Technology and infrastructure

Context-related infrastructural and technological factors were found in the literature to facilitate or constrain the ability to climb up the household ladder, to satisfy domestic energy needs.

Infrastructure lock-in: centralised energy network

Results from expert interviews revealed that NUH is the predominant way to provide urban space heating in cold and severe-cold regions, such as Beijing (Yi Jiang, personal communication, June 28, 2017). As a matter of fact, coal still accounts for the 62% of power supplied to the northern urban heating (NUH)[4], which operates from November 15 to March 15 (TU BERC, 2016; Ma et al., 2017). The reviewed technical report by the OECD in cooperation with the IEA (2015) showed that the centralised system has historically relied on coal boilers, as shown in Figure 10.

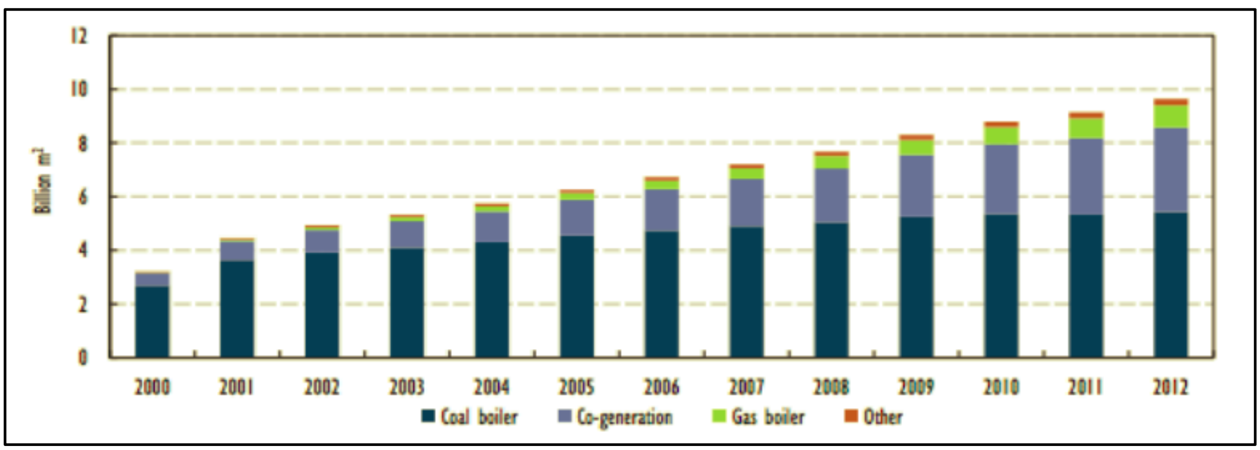


Figure 10. NUH-heated floor area by equipment share (2000-2012).

[4] NUH refers to areas with centralised district heating networks for space heating in northern China, including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and areas of Sichuan (BERC TU, 2016)

Figure 10 clearly shows that coal-fired power plants still provided the majority of space heating to northern Chinese cities as of end of 2012. Notably, during one of the interviews, Professor Jiang from TU reported that the country has been progressively co-generating electricity for space heating with gas-fired plants:

"[Coal power plants are] Closed, but there's still power plants, natural gas power plants. So still we have to keep the district heating". (Yi Jiang, personal communication, June 2017)

This statement does not relate to rural areas (at least in relation to the sample of this research), where there was no centrally supplied energy, and some households still used coal-fired stoves (rural respondent 3, personal communication, July 22, 2017; rural respondent 6, personal communication, July 23, 2017).

Infrastructure lock-in: building energy inefficiencies
The reviewed literature indicated the inadequate level of insulation as one of the major constraint to energy efficiency in buildings, especially in rural areas and in cold climatic zones (Lo, 2014), where the sampled areas of this research are located.

Results from the computerised household questionnaires (questions 6-7, Appendix I) revealed that most residents in urban housing areas had winter central heating, and that they were satisfied with the indoor temperature of the building. However, 2 respondents reported indoor overheating (in Chaoyang urban district). By comparison, all suburban resident (equipped with central heating system) reported to be satisfied with the average indoor temperature in their building, ranging from 18°C to 21°C. On the contrary, the thermal comfort for rural residents inside their houses is very different. Half of the surveyed residents (4 respondents) reported to feel too cold during winter, someone even indicating a winter average indoor temperature below of 16°C or below (rural respondent 6, personal communication, August 2017).

In terms of energy use at the household-level, the results revealed that the centralised energy supply prevented sampled urban residents from controlling the indoor temperature, which may lead in some cases to energy losses (overheating). As as a matter of fact, urban residents:

"have no choice to install solar heating systems or use the daily use [of] electricity for lighting or taking shower or something like that, actually, they have no choice." (Hongxia Duan, personal communication, December 4, 2017).

In suburban areas, this appeared to not be an issue. From participatory observations during the fieldwork in Caocangcun residential community, it was observed that buildings were also undergoing substantial renovation to improve the envelope insulation, particularly doors and windows (Figure 11).

Figure 11. Energy efficiency improvement in door and windows, Caocangcun. July 15, 2017.

Structural energy-efficiency improvements in residential buildings may explain the adequate level of indoor thermal comfort reported by suburban households in the questionnaire. Other household groups would also largely benefit from such measures, however, these were not observed in e.g. visited rural towns/villages. There exist therefore an impellent need for adopting advanced technologies and measures to reduce the increasing environmentally-unaware energy consumption (of not only rural households). Some of the priority areas were indicated during interviews, and include buildings envelope insulation, equipment and appliances:

"[F]focus on a fabric-first approach focusing on making the building efficient first." (Rokia Raslan, personal communication, August 11, 2017)

According to Derek Cowburn, advanced and energy-efficient buildings feature dramatic changes in energy consumption, which can lead to significant energy savings in the occupant's energy use:

"*[...] not only did you have this big IoT*[5] *and systems-level approach, but at the same time you also have this sudden drastic change in the type of energy that these devices are consuming"* (Derek Cowburn, personal communication, November 30, 2017)

[5] Internet of Things (IoT) addresses the upsurging quantity of devices and appliances connected to the network and to the Internet, which can be managed to provide a huge amount of information on people and processes (TU Delft, 2017).

In conclusion, the aforementioned building energy-efficient measures could be included in a threefold strategy for regulating buildings energy, based on interview results:

"I think there should be a three main goals of new energy standards there: decreasing energy use while balancing it with maintaining healthy environments and future-proofing buildings." (Rokia Raslan, personal communication, August 11, 2017)

Healthy environments notably relates back to the indoor thermal comfort outlined at the start of this section. As for additional measures that may increase the future-proofing of buildings, this research project focused on energy efficiency improvements along with solar technologies adoption in buildings. Accordingly, these are discussed in the next section.

Reliability
In section 2.2.1, the reliability of technologies was reported to be a factor influencing energy stacking (Elias & Victor, 2005; van der Kroon et al., 2013). The interrelation with rural household after they answered the questionnaires allowed to obtain detailed information on the reliability of the electricity grid in some rural villages. For instance, empirical evidence in old Simatai rural village points at the scarce reliability of electricity supply due to unexpected outages, from a few minutes to a few hours, especially during heavy summer-time storms. This is indicative of a community-level issue on the reliability of electricity supply (rural respondent 2, personal communication, July 22, 2017).

Residential buildings characteristics
According to the IEA report (2011), SWH denote one of the most advantageous applications of solar energy for heating and cooling. Due to their well-established technical feasibility, they were reported to be the bulk of solar heating in China's residential building sector (Ma et al., 2014). Their local application depends however on structural building features, as observed during observations in sampled locations (Table 12).

Table 4. Examples of site areas visited during the fieldwork. Beijing municipality, July 22, 15 and 6, 2017.

1. Simatai old village (rural)	**2. Bajiatong residential community (suburban)**	**3. Chaoyang district (urban)**
		

From the picture in the middle, it is visible the application of solar energy technology, specifically SWHs on the rooftop. Rural residential buildings/houses, and also suburban, have specific advantages in SWHs applications because of the presence of low-stores buildings and availability of space (Ma et al., 2014).

By comparison, if one considers the energy supply in an individual urban household living in an high-storeys residential building in Beijing, the provision of both heat, electricity and gas is very centralised and the structural features of such buildings constrain the installation opportunities of solar technologies to satisfy all occupants' energy consumption (Yi Jiang, personal communication, August, 2017).

Finally, empirical evidence showed that rural and suburban areas do feature adequate rooftop space for SWHs installations. In addition, there exist an incentive for rural residents to use this type of technology due to the unreliability of the electricity supply, and/or the non-existence of the centralised grid network. Energy staking by means of SWHs and solar panels technologies hence results possible. For one particular energy service, domestic hot water, perfect energy switching has large potential in both rural and suburban areas. However, its adoption is limited in urban areas (e.g. high-storey buildings).

4.2.3 Economy

Household income rise

In relation to household-level economic factors, income is predominant in the energy ladder literature. Related findings emerged during the analysis of expert interviews. Professor Jiang from TU claimed that with economic development "*income increased, and people also want to have better comfort*" (personal communication, August 24, 2017). The interviewee was not only referring to areas undergoing urbanisation, but also to rural areas:

"But now people are using so much energy because more energy they think is better. And our goal is to turn this back, use more scientific concepts to build better buildings, to use less energy and to provide a better indoor environment." (Yi Jiang, personal communication, August 24, 2017).

The expert also commented on the the fact that wealthier rural households tend to consume more energy for space heating in buildings, whereas it is critical to invest in buildings envelope insulation. It is noteworthy the interrelation among rising income, increasing living standards (demand for comfort), buildings structural characteristics and household geographical location. In relation to solar thermal:

"*If you put the poor families, the rich families and the middle, you find that middle family and even poor family have more solar thermal application than rich family, so it means that renewable is made for people, it changes their life.*" (Yi Jiang, personal communication, June 27, 2017)

In consideration of this statement and the aforementioned data, quality of life and comfort are becoming important energy use influencing factors among all household groups. The rise in demand for comfort is related to increasing household income, so it is energy consumption. Based on these results, as income increases, rural households – having poorly insulated houses - tend to consume more of polluting energy sources (i.e. coal) as their income increases. By comparison, suburban respondents feature advanced and energy-efficient building envelopes as become more urbanised. Finally, urban households with centralised grid system inefficiencies were found to consume more energy, partly due to technological inefficiencies, e.g. air conditioners that function regardless of the room/house occupancy (Yi Jiang, personal communication, August 24, 2017). Depending on the level of income and location, different technologies are thus combined in the energy portfolio of diverse household groups.

Household income variability

In relation to income variability, the three respondents reported to have irregular income, from agricultural practices in Laowa and from the seasonality of tourism-related activities in Simatai, being close to the location of one side of the Great Wall of China. In old Simatai village, 2 respondents used electricity and coal, whilst one respondent in Laowa utilised coal to produce heat for the traditional Chinese kang bed. While irregular income flow can influence the energy portfolio, for which households may tend to use the cheapest energy option, the strength of the influence of this factors compared to the above infrastructural conditions in unknown based on the qualitative analytical approach employed in this research.

Cost advantage of energy sources

SWHs are considered an economically viable option in China. For instance, a SWH thermosiphon for one family unit could cost around EUR 700 in European countries, but EUR 150 in China as of 2011 (IEA, 2011). However, based on the results from the interaction with rural household after the questionnaire, because the costs of solar technologies in the house involve high investments, it is unlikely that rural and suburban households would adopt such options without supportive financing schemes.

Moreover, prices of fuels/energy sources other than solar energy are assumed to have a negative effect on the adoption of the latter, as more polluting fuels and carriers, e.g. coal stoves or gas boilers, may seem less costly to some households (van der Kroon et al., 2013).

From the interaction with sampled rural households at the end of the questionnaire, it was found that rural households could purchase 3 to 4 tonnes of coal at a subsidised price, and the coal was supplied directly to sampled rural villages or towns by local authorities before the start of the heating season (rural respondent 6, personal communication, June 23, 2017).

As for LPG, respondents revealed that public subsidies were covering 50% of the total price of each LPG tank, in substitution for coal-fired stoves (rural respondents 7-8, personal communication, August 5, 2017).

4.2.4 Culture

Habits of energy-saving behaviour

Based on the interaction with individual households in rural areas, when asked about their electricity consumption for lighting, respondents revealed their tendency to save energy in their daily practices, e.g. switching off the lights in the house, or even turning down the set point of the house space heater thermostat (rural respondent 6, personal communication, July 23, 2017).

The behavioural tendency of turning off space heaters in some sampled rural areas was found to also be an economical option to reduce the energy bill (rural respondent, personal communication, July 23, 2017; rural respondent 7, personal communication, August 5, 2017). This behaviour is likely to be related to the questionnaire results on household indoor comfort (outlined in the previous section on building energy inefficiencies). For suburban residents, is was interesting to notice that they had, to a certain extent, maintained the energy saving behaviour, although they have access to the same centralised district heating system and electricity supply as in urban residential buildings.

In urban areas, results from the performed interview with Professor Jiang suggest that urban households are less characterised by an energy-saving behaviour than their rural counterparts. In accordance to this:

"We cannot say that the behaviour plays an important role in the energy consumption and the use of buildings, it is really dependant on the type of the system." (Yi Jiang, personal communication, August 24, 2017)

Whereas a plurality of interrelated factors may play a role In this instance, overall, traditional energy systems characteristics seem to be critical factors from the ability of households to access and to adopt more sustainable energy. In relation to this, it is worth reporting the claim by Dr. Duan, on the energy use behaviour of urban residents:

"They just want to use [electricity], but they don't want to know [from which sources it is supplied]. [T]here is no information." (Hongxia Duan, personal communication, December 4, 2017).

This seems to indicate a higher problem from the energy supply side, rather than just an intrinsic behavioural issue.

Socio-cultural habits and preferences

Households' culture-related factors, particularly culinary traditions emerged from the interaction with some rural households, and seemed to negatively impact the adoption of sustainable energy alternatives. For instance, a total of 5 out of 8 respondents in rural areas have rice cookers (questionnaire question 5), despite the high electricity consumption of these type of appliances. Moreover, it was observed that coal and firewood are still employed for cooking traditional food, where firewood is only used to trigger the combustion in the stove.

Additional findings from the household questionnaire revealed that some residents were not purchasing the type of coal supplied by local authorities (honeycomb), but preferred to buy a more expensive type of coal, stating that the more expensive coal type was more convenient (rural resident 8, personal communication, August 5, 2017). When asked to specify what the respondent meant by convenience, the rural resident said that the government-supplied coal was not totally melting into the stove, for which after cooking or burning it, they had to take it out. The coal residues were then adding up to the quantity of household waste (rural respondent 7, personal communication, August 5, 2017).

Display of socio-economic status

Results from expert interviews revealed that the technology tends to acquire a different status connotations in diverse household groups. For lower-income households, it signified an improvement in the quality of life and lowers the energy costs, as in the case of SWHs (Yi Jiang, personal communication, August 24, 2017). According to Professor Jiang, higher-income households, particularly in urban areas, do not consider energy saving important in the choice of energy-consuming appliances and domestic facilities. Additionally, the results that emerged during the interview with Aart de Geus seem to suggest that with technological advancement of solar technologies, therefore their progressive affordability, their adoption may tend to be less of an affordability issue and more a matter of priority to households (Aart De Geus, personal communication, June 14, 2017).

4.3 Institutions in sustainability transitions

This section presents the analysis of primary sources from expert interviews and the revision of policy documents, as listed in Table 3 in the methodological chapter. This section particularly focuses on three energy sources/technologies targeted by policy interventions: SWHs, energy efficiency and coal.

Prior to addressing the above cases, it is noteworthy that this level of analysis is concerned with the fragmentation and lacking of coordination among entities, functions, departments and manufacturers, which emerged from several expert interviews. For instance, Professor Lin at BNU commented in relation to the efforts of the government to phase out coal from the energy mix, and reported a division at higher government levels: the carbon market is currently a responsibility of the National Development and Reform Commission, whereas the design of a carbon tax is performed by the Ministry of Finance (also Treasury Department). Responsibilities also result unclear, in spite of the high centralisation of the energy supply management. The latter is exacerbated at the local-scale, if one considers the multiplicity of market players, e.g. government authorities, energy suppliers, solar manufacturers and installers (Lin Weibin, personal communication, August 25, 2017; Rokia Raslan, personal communication, August 11, 2017).

4.3.1 Solar hot water heaters

Government policy interventions

Local policy makers were found to have a vital role in defining the opportunity for the adoption of SWH for domestic hot water use in diverse household groups. Based on the interview with Professor Jiang at TU, the solar industry developed at a rapid pace with no government support (subsidy) at the late 1990s. Since 2007, municipal government authorities has started to regulate the mandatory incorporation of SWH in residential buildings (Table 3):

"So then some local government say (said), you must stop that. Every house, every apartment, with all these kinds of solar application system, we cannot allow you to sell this building. Something like 2007, 2008, they have this kind of policy. But then, we find some problems." (Yi Jiang, personal communication, June 27, 2017).

Insights from the interview carried out with Professor Jiang from TU reveal that the way the 2007 building regulation was formulated generated opposite results. The building regulation was in fact supposed to boost the installation of SWH (already commercialised with no government support), however, the public intervention only resulted in a distortion of the market competition. It is noteworthy that solar technologies were benefitting from the subsidy based on the quantity of SWH that were installed on the building. Based on the interview results, the insufficient quality and scarce maintenance of technologies (owing to the lack of understanding of the market mechanism by policy-makers) seem to have negatively influenced the reputation of such technologies. This constitute a barrier for further adoption of SWHs.

Quality and maintenance issues in relation to SWH technology are addressed in the next two paragraphs (quality and maintenance issues).

Quality issues

In the aforementioned building regulation, no requirement was initially given in relation to the quality standards of SWH. This is resulted in:

"[Solar energy technology manufacturers] want[ing] the cheapest, regardless good or not, as long as the subsidies are there, [...] the water comes and they comply with regulations. Then what happened? The whole industry, at the beginning continue to go up, then they go down, the quality go poor, and then they customers got problem." (Yi Jiang, personal communication, June 2017).

Professor Jiang claimed that this inevitably harmed the solar technology reputation in the aftermath of the 2007 government mandate.

Findings from other interviews reveal that the scarce quality of solar technologies could still persist in Beijing: "*[...] I think around Beijing there're a lot factories making PV or solar thermal, and what you see over there is that the quality and the reliability are less than the products which are being sold to the Western world. So, apparently, nobody knows how they're functioning in China.*" (Aart De Geus, personal communication, June 14, 2017).

Maintenance issues

It is noteworthy that the critical internal failure of the industry at the time of the 2007 policy intervention, regarded the fact that companies started to compete to instal as many SWHs as possible, in order to comply with obligatory building standards and take advantage of public incentives. This had consequences for the after-sales services phase. Professor Jiang explained that installers in rural town and village were leaving without providing any reference contact to households, in case of malfunction of the technology, for instance, water leakages.

Accordingly, results from household surveys reported the case of one household switching to electricity in Baijiatong residential community, due to water leakage issues and lacking of maintenance services from the SWH installation company (suburban respondent 4, personal communication, July 15, 2017). In relation to local installers of SWH or other technologies, Dr. Raslan asserted during the interview:

"[H]aving somebody you can talk to, a point of installation makes you... That person becomes link between you and a big company, [...] whereas they might have difficulties in accessing the larger organisations." (Rokia Raslan, personal communication, August 11, 2017)

Dr. Raslan argued for the importance for residents of accessing services after the technology is installed, hence locally-sourced maintenance and operation services.

Seemingly, the lack of maintenance services was recently found to still be a critical issue in some urban buildings in Beijing:

"The two-year warranty will soon be over, after the warranty, there is no one to find manufacturers to repair." ("这两年保修马上就过了，过了保修以后就更没有人找厂家修了。") (Beijing area free installation, 2016).

The article reports the case of more than 85% non-functioning SWH installed in one building (part of a residential complex) in Chaoyang district, and their substitution with gas boilers for domestic hot water. Not only does this confirm the empirical results of this research on quality and maintenance issues found in sampled rural and suburban areas, but it is also revealing of perpetuating issues in Beijing urban districts.

Arguably, it was possible to identify a result-oriented and quantity-oriented approach embedded in the socio-cultural technology field. Based on the interviews with engineers and entrepreneurs Derek Cowburn and Aart de Geus, findings suggest that conventional technology and industry experts in energy-related sectors, residential buildings in this case, are lacking, to a certain extent, of the culture of projecting and planning ahead, which also emerged as an issues in relation to policy decision-making (Aart De Geus, personal communication, June 14, 2017; Derek Cowburn, personal communication, November 30, 2017).

Improvement in the quality of life and low-costs

In the 1990s, scientists at TU patented the innovative and cost-effective indigenous SWH (vacuum tube) (Yi Jiang, personal communication, June 27, 2017). The interviewee reported that large uptake of the technology was witnessed in rural areas, particularly after its commercialisation in the late 1990s. Based on the interview results, the substantial improvement in households' quality of life at low costs from the usage of this technology contributed to drive its high installation rates. Nevertheless, as previously mentioned, problems emerged in the aftermath of government-led interventions in the solar thermal industry (Yi Jiang, personal communication, June 27, 2017). Accordingly, Dr. Duan stated:

"[*I]t totally depends on the policy. How policy would direct your consumption, how the policy would change people's lifestyle*." (Hongxia Duan, personal communication, December 4, 2017).

In line with the above statement, the engineer and founder of Lumencache, Derek Cowburn, indicates that policy interventions and instruments can achieve better results if targeted to *"improve the general livelihood of everybody, [...] their tax-base, [...] their city operational costs."* (Derek Cowburn, personal communication, November 30, 2017). Awareness-raising policy measures may include building standards like the *Green Building Evaluation Systems*, which is implemented in Beijing. This information was retrieved from the interview with the manager of a large construction company in Beijing (Engineer Manager, personal communication, August 25, 2017).

The empirical analysis clearly points at some flaws in policy interventions that targeted the solar energy industry of SWH. Notably, it seems as if a resolution has more recently taken place. Accordingly, as part of the national 12FYP and based on the *Energy Conservation Law of the People's Republic of China* (1997), as reported in the list of policy documents in Table 3, Beijing municipal government initiated a series of intervention aimed to renewable energy development and energy efficiency improvements, e.g. the Beijing 65% energy saving standards (Liu & Liu, 2016). This is analysed in the next section.

4.3.2 Energy efficiency measures in residential buildings

In 2013, the Beijing municipal government issued the *Design Standard for Energy Efficiency of Residential Buildings of Beijing* (DB11/891-2012), to achieve the “Beijing 65% Energy Saving Standards” in residential buildings (Liu & Liu, 2016, p. 2).

Government policy interventions

The 2013 municipal standards demands architects and designers in the building construction industry to comply with the compulsory requirements during the construction assessment phase. It could be expected that such stringent standards would bring valuable results in the energy efficiency of future residential buildings.

“Actually China now advocates on green building [codes and standards]. That is why the Green Building Certification System is formulated. [...] including energy saving, material and resource saving, water saving, environment quality and construction control, and other major sectors.” (Engineer Manager, personal communication, August 25, 2017).

However, the engineer manager however reported problems as for the widespread implementation of the regulation.

One example of the application of the set of standards included in the publication is the renovation plan of a 1988 residential building in Huixin West Street, Chaoyang District (Liu & Liu, 2016). The project featured high-efficiency in its building envelope (external walls, doors, windows) (Liu & Liu, 2016). Thus it proved the technical feasibility of adopting more energy-efficient solutions to reduce domestic energy consumption. It is noteworthy that no provisions were stated in such standards in terms of energy-saving measures after the building is occupied. Which is indicated in the literature as negatively influencing the domestic energy consumption.

Habits

Furthermore, Liu and Liu (2016) reported that, despite the above improvements, the window-opening behaviour of occupants needed to be carefully considered. The latter needs to be optimised to comply with building energy savings standards. In this regards, results from the survey performed in the context of this research revealed that the majority of respondents did not have a control valve or were not used to adjust the indoor temperature (questionnaire question 9).

The renovation project in Huixin West Street in Beijing, is an example of the importance of occupants’ behaviour and how this influence the building energy consumption performance after its occupancy (BERC TU, 2016). Generally, occupant behaviour can include windows, lights, thermostats, blinds and plug-in appliances (BERC TU, 2016). This section focuses on windows and temperature control valves. The authors reports that, technically, the renovation project brought substantial improvement in the building envelope thermal performance - previously poorly insulated and lacking of end-use control measures-, thus in line with the Beijing 65% Energy Saving Standards. However, residents window-opening behaviour continued even after receiving training on how to utilise newly installed temperature control valve in single apartment units (Liu & Liu, 2016). Traditional habits of opening windows and social un-acceptance of new end control measures to adjust the indoor environment temperature is bound to sub-optimal outcomes of renovation project, not only in the Huixin West Street project.

Business actors: acceptance of new technology and business ideas
Based the interview with Derek Cowburn, founder of LumenCache, China has an advantage in learning from foreign experiences in the field technological developments, and its interest in foreign knowledge and expertise, new business models and technologies has been recently growing, in order to take advantage of the cost-competitiveness of renewables and energy efficiency. The interview results showed that entrepreneurial ideas and solutions to energy efficiency challenges in the residential sector, as in the case of Lumencache, are increasing in importance, especially in a transitioning environment like the one in China.

This is considered in light of other results from primary sources, which are related to opportunities for technical experts and business ideas. As for energy generation from solar thermal, an informant in the solar thermal industry located in Beijing stated that the municipality features only one demonstration project of a solar thermal power generation plant. This is operated discontinuously for testing and research purposes, and is unlikely that it would be used for practical applications and in a sustained way, at least in the short-term (solar thermal expert, personal communication, December 6, 2017).

Other key findings from other interviews revealed that the current technology advancement seems rather far from bridging the gap between demonstration projects and testing purposeful for research in Beijing (Aart De Geus, personal communication, June 14, 2017). In consideration of technical constraints and the need for innovative business models and technologies, Dr. Duan claimed that subsidies from government authorities could not provide long-term support for the adoption and scaling-up of renewables, which could be instead better addressed by business actors (Hongxia Duan, personal communication, December 4, 2017).

4.3.3 The coal ban in Beijing rural areas

The Beijing *coal replacement by clean energy programme*, including a coal ban, was meant to shift rural consumers energy choice from coal to either electricity or gas use (Beijing Foreign affairs Office, 2016). The success of the programme was therefore based on the quantity of CO_2 reduced, in order to achieve the greatest emissions reduction for the largest portion of the society (Wiedenhofer et al., 2016).

Government policy interventions

The programme in combination with the ban were expected to save 7 million tonnes in CO_2 by the end of 2017, in line with the local and national energy targets to combat climate change and air pollution (Wiedenhofer et al., 2016; Zhou, 2017). From desk research on the coal ban case, it emerged that some Northern-China local communities, including Beijing, were left without means for space heating during the winter season 2017-2018 ("The realization of heating without coal," 2017). This more likely undermined their capability to have adequate indoor heating, which ought to be equal to or above 18°C in order to provide an healthy environment for occupants (WHO, 2016).

A system internal failure in planning and designing the policy emerges from the above data, as the ban was meant to prevent rural households from burning coal in winter, but the grid infrastructure to supply space heating was lacking. While the ban may have had great benefits in terms of air pollution and increased quality of the environment as well as personal health, it limit the ability of some household groups in rural areas to satisfy their energy needs.

4.3.4 Solar PV

Government policy interventions

Specific local policies for distributed solar in residential buildings in Beijing were not to be found, to the best of my knowledge. As for solar PV technologies, opportunities for adoption in the domestic market were constrained by the past national export-oriented policy approach, particularly from 2004 to 2008, and its high costs (Schwartz, 2014; Urban et al., 2016). In this regards, Schwartz (2014) reported that the national solar installed capacity target addressed in the *Mid- to Long-Terms Renewable Energy Plan* (2007) was minor, only aiming to reach 1.8 GW of installed solar power by 2015. Nonetheless, Rafiq, Bloch and Salim (2014) claimed that solar PV has been recently undergoing a shift from centralized grid distribution to market-driven PV distributed generation systems, although large-scale solar projects are increasingly playing a role in the national energy mix. In addition, results from the household survey reported potential for the dispatch of distributed solar PV.

Locally-provided information and cost competitiveness

The questionnaire analysis revealed the willingness of one rural respondent from sampled households to invest in solar PV, after being informed on the benefits of the technology from a local company and having received information catalogues. Nevertheless, high upfront costs were presented as a barriers to the technology adoption (rural respondent 6, personal communication, July 23, 2017).

4.3.5 Additional findings

Government policy interventions - Procedural equity

From the analysis of policy interventions, e.g. the coal ban, it emerged a *modus operandi* for the implementation of the policy that could preclude the capability of target groups - affected by such programmes - of understanding and feeling ownership over the project in place. Based on this analysis, it is arguable that current energy-related policies and instruments aimed at reducing residential energy consumption are based on a centralised system and were designed with no input from the portion of the society that consumes energy and is directly affected from policy interventions. As a matter of fact, all energy-related interventions are left to the centralised decision-making authority of the NEA (Hauff et al., 2014). Not only does this system potentially exacerbate existing context-related distributive inequalities, for instance in relation to energy technologies, but it might even exacerbate social distress in a situation of procedural inequalities, where procedura equity is defined as “political recognition of vulnerable and marginalised social groups” (Bartiaux et al., 2015, p. 413). This dimension was not integrated in the present framework for household sustainability transitions, but as it emerged from the analysis, it is clearly a valid dimension that could improve the scientific knowledge generated from this research.

Accordingly, McDermott et al. (2013) claimed that the way institutions are structured and actors participate in the decision-making process may determine the context for power imbalances, and come into conflict with the notion of an equitable or balanced accessibility to resources and control over the consumption behaviour of households (Brizga & Līce, 2013). Based on Guo, He and Lian (2017), perceived control, knowledge and transparency over a specific project, for instance installation of SWH in the house, are likely to increase public acceptance of and trust in the project. Instead, such “Decide-Announce-Defend” approach in China (Guo et al., 2017, p. 702) of imposing the policy upon low-income rural communities with no accessibility to gas pipeline networks could hamper the transition to sustainable energy sources, in terms of equity.

4.3.6 Synthesis of the result analysis

Finally, from the results analysis, a series of factors arose that stimulate or limit household energy consumption. Accordingly, the extent to which solar energy and energy efficiency could be adopted on top of the energy ladder differ per energy services and by household groups.

The table below presents an synthesis of the qualitative analysis, grounded on previously recorded and transcribed expert interviews. The complete overview of the coding process of experts' quotes is available in Appendix III. A complete interview transcript of the performed interviews is available from a different file, due to the lengths of the document.

Table 5. Synthesis of the result analysis

Factor dimensions	Barriers/challenges	Opportunities/enablers
Demography	Large energy demand by diverse household groups due to socio-economic development	Technological progress in cities
Technology and Infrastructure	Height of urban buildings constraint the adoption of solar technologies Lacking of a end-use measures to control energy consumption in buildings Poor SWH technology quality Inefficiencies of centralised systems: Overheating in urban buildings and window opening behaviour Urban residents have no o choice nor control over energy consumption in urban areas	Solar raises living standards of households Rural residents have choice over the building design and energy consumption Energy efficiency of building equipment can be increased in urban areas Distributed solar potential in rural areas Emerging Internet of Things to increase energy efficiency
Economy	Higher energy consumption and demand for comfort with higher income Irregular income flows High solar installations upfront costs (cost disadvantage)	Competitiveness as solar installations increase

Culture	Energy-consuming behaviour of higher-income households Culinary traditions	Traditional energy-saving behaviour Investment in solar installations is a matter of consumers' priority
Institutions - Government policy interventions	Poor quality of SWHs technologies in the aftermath of policy interventions Poor maintenance in the aftermath of policy interventions Lacking of understanding of the market by policy-makers Government-led fossil fuel subsidies Insufficient integration of solar facilities in building codes and standards	Improve health and well-being while adopting sustainable energy sources Emerging concept of green building in energy codes and evaluation standards Policy-makers commitment and political support to make the lead towards achieving sustainability targets Leapfrogging by learning from other countries experiences Deregulation of prices and market-orientation Locally-provided information
Institutions - business actors	Centralised energy supply and system	Potential for foreign investors in the domestic market Opportunities for cutting-edge technologies in the domestic market
Socio-technical regime	Quantity-orientation versus quality-orientation approach Lacking of long-term planning Lacking of the maintenance and durability of technology and infrastructure mind-set Translating demonstration projects into practice	Efficiency in building construction leading to technology advancements
Fragmented energy-related political and market entities	Fragmentation of agencies, departments and responsibilities Fragmentation of the energy supply chain	

Briefly, urbanisation was considered to have a positive effect on the adoption of cleaner and more efficient types of energy sources. Based on the assumption that synergies among demand and supply exist, and given the unsustainability and inefficiencies of the current centralised system for heating and power, in sampled urban and suburban areas, the increasing demand implies more consumption of polluting energy sources, e.g. coal and gas. This also applied to rural areas, where there was not grid network. In fact, direct fuels combustion was found to be increasing.

Furthermore, rising income levels across all household groups was found to boost the demand for indoor comfort, which implies more energy consumption. These factors were regarded in consideration of the economic barriers, i.e. high cost of sustainable energy technologies. The cost advantage of fossil fuels, e.g. cost competitiveness of government subsidised electricity, with respect to solar energy has a negative effect on the opportunity to switch to cleaner and more efficient technologies.

Households' culture-related factors, including culinary traditions, were found to negatively impact the adoption of sustainable energy alternatives, nevertheless, the interview results reveal that households, especially in rural areas, feature energy-saving behaviour. This may contribute to a more energy-efficient consumption, if suitable technologies that increase energy savings are also supplied and accessible to diverse household groups.

Additional findings emerged from the processing and analysis of expert interviews and desk research on the case study (as outlined in chapter 3).

The next chapter offers an attempt to analyse the above results in light of the theory, focusing on critical findings to be discussed as theoretical and practical (policy implications) contributions.

5. Discussion and conclusions

This section discusses the key findings of this research project in regards to the overarching research question (*To what extent and owing to what factors can households climb up on top of the energy ladder towards the adoption of solar energy and energy efficiency technologies in Beijing? And can sustainability transitions encompass a diversity of household groups?*). The contributions of this research are then discussed in relation to the theory and some practical policy implications. Further, limitations to the framework and to the research (including methods) are discussed and new research directions are proposed. Concluding remarks and a concise answer to the overarching research question follow.

5.1 Results discussion

Climbing on top of the ladder

The results analysis from the present case study confirmed the critical paradox found in the literature on energy transition. Hiemstra-van der Horst and Hovorka (2008) explain it as follows: it is rare not to recognise an energy ladder pattern in such case studies, however, it is even rarer to find a case "in which the data do not contradict one or more of the model's assumptions" (Hiemstra-van der Horst & Hovorka, 2008, p. 3336).

For example, with Beijing population growing from 11 millions in 2000 to 21 millions in 2014 (Jacobson et al., 2015), with technology advancements, along with stable income flows of urban households, energy-consuming lifestyles, more demand for comfort (TU BERC, 2016), the model assumed that Beijing urban households would have climbed up the ladder and adopted more distributed solar energy and energy-efficient technologies in residential buildings. Nonetheless, this is not completely the case in this instance. In relation to the first assumption in section 2.2.2, this section will discuss the above findings.

The results suggest that energy stacking may be prolonged if adequate infrastructure and technologies are not made accessible to diverse household groups, hence facilitating the adoption of cleaner and more energy efficient alternatives to fossil fuels. The next paragraph will discuss previous findings on fossil fuels use, whilst the next one will bring into the discussion sustainable energy alternatives.

The above findings first showed that (coal-fired) electricity is very flexible and a widely used carrier in diverse localities. Whereas in suburban and urban areas (coal-fired) electricity is the dominant modern energy source, direct coal combustion still plays a central role for space heating and cooking in rural areas. In addition to coal, large investment by the Chinese national and local governments were found to support CHP or gas-fired centralised heating and power systems. From the interview results in section 4.2.2 (Technology and Infrastructure) with Professor Jiang, a transition seem to be occurring from coal-fired plants to combined heating and power generation plants

(CHP) in Beijing. These results were confirmed in desk research findings from technical reports, revealing a progressive switch to gas for centralised energy supply since 2002 (OECD/IEA, 2015) (Figure 10). Accordingly, in a recent statement as deputy director of the Beijing Development and Reform Commission, Zhang Wancai declared that gas consumption in Beijing was expected to increase by 24 additional billion meters by the end of 2017, when the city consumed 11.3 billion cubic meters in 2014 (Zheng, 2015).

Section 4.2.2 of the analysis also pointed at the unreliability the electricity supply for some rural areas that were visited during the fieldwork (i.e. old Simatai village and Laowa rural village, Miyun county), for which energy stacking behaviour may relate to. This is consistent with the existing literature on the household energy ladder, reporting that the inadequate reliability of electricity networks determined the adoption of multiple energy sources (Martins, 2005).

As for cooking, coal is being increasingly substituted by LPG. One could expect a switch from coal to LPG in the short term, based on the number of sampled households in both rural and suburban areas who are already utilising government-supplied LPG (rural respondent 5, personal communication, July 2017). In line with the energy stacking assumption, Martins (2005, p. 378) argued that "it may make economic sense to use electricity for lighting and LPG for cooking". In the short-terms, this may solve immediate air pollutions issues at low-costs, especially in rural areas. Nevertheless, such combination of pollution fuels (energy stack) appears unsustainable in the long-term.

Generally, it is likely that suburban areas will acquire structural characteristics of the energy supply in urban areas, whereas rural areas could feature progressively the current situation of suburban areas. These results confirm the findings of Nansaior et al's study (2011), where the authors assumed that the development of communities follow a linear path, whereby cities show the most advanced technologies, which are incrementally adopted in suburban areas, and eventually in rural areas.

As for solar energy and energy efficiency, the analysis results more complex. It is arguable that, whereas the pathway towards sustainable energy use could be undertaken by climbing up the energy ladder, currently, there may be a limit to the number of urban households who can adopt SWH, due to the structural features of high-storeys urban buildings (with limited rooftop surface). These emerged from observations of housing areas (Figure 12) and experts interviews.

Although household socio-cultural energy-related preferences and habits seemed to bear less explanatory power than technology and policy forces, the qualitative-based analysis revealed an emerging pattern of energy-consuming behaviour (section 4.2.4). These are in line with the TU BERC publication (2016), which reported that, with increasing wealth in both urban and rural areas, more energy-consuming lifestyles often lead to purchasing more electronic appliances and increase electricity consumption (TU BERC, 2016). Studies found that the combination of socio-economic development and rising use of energy-consuming home appliances could offset the amount of energy savings from technological energy efficiency improvements, defined as rebound effect (Wang et al., 2016). Accordingly, Hosier (2004) observed that wealthier households tend to also consume larger energy quantities as they climb upwards along the ladder.

Empirical evidence in support of the above statements emerged from the key findings of expert interviews. It was argued that, with household income rise, living standards for indoor comfort tend to increase. Specifically, rural households tend to consume more coal for heating, whilst both rural and urbanised households are expected to increase the amount of home appliances purchases (Rokia Raslan, personal communication, August 11, 2017; Yi Jiang, personal communication, August 24, 2017).

Moreover, it is clear that public building regulations are currently a major determinant of cleaner and more efficient technologies adoption. This is in line with recent literature that argues for the assertive public influence on the energy consumption in urban areas (Campbell et al., 2003). Solar energy had a momentum, where it was exclusively used for domestic hot water purposes (SWH). However, the absolute extent to which solar energy was used on top of the energy ladder for water heating needs was limited by government policies, falling short in understanding the solar thermal market. This was in fact developing without any government subsidy. Based on the present results, the misdirected public subsidies to SWH favored instead the switch to electricity for water heating in suburban areas (suburban respondent 1, personal communication, July 15, 2017). This resulted in a lost opportunity for the widespread adoption of the indigenous SWH technological “breakthrough”, as also reported by Urban et al. (2016, p. 534).

A market-oriented approach may have favoured the adoption of solar technologies as low-costs solutions within households’ energy portfolio (energy stacking). In line with the literature, it was also found that (besides energy supply reliability) economic factors do influence the adoption of cleaner and more energy-efficient technologies, although the extent of their influence is unknown.

In regards to this, the findings from the interview with Professor Lin at BNU revealed that, as solar energy becomes economically viable over time, the cost advantage of subsidised fossil fuels is likely to decrease. This is consistent with the key findings from the study by Colenbata et al. (2016), arguing that sustainable energy alternatives can acquire cost competitiveness over fuels, by factoring in the negative externalities (i.e. social and environmental costs) of fossil fuels use, plus the financial risk from fuel price volatility, e.g. gas, in the macroeconomics arena.

In relation to sub-question 1.3, at the household-level, households may not always climb on top of the ladder. When placing energy-efficiency technology improvements on the top rung, urban and also suburban household have more opportunities to climb upwards than their rural counterparts (for instance owing to building regulations, energy-saving requirements and technology advancements in urbanised areas). By contrast, when considering solar energy technologies on top of the ladder, suburban and rural households seem to rather climb upwards, whereas urban household seem to be locked-in to centralised fossil fuel use and buildings unsuitable for solar installations.

Hence, from the analysis, the asymmetry among household groups seem not relevant in terms of energy sources, but in terms of technologies. This point was initially introduced in chapter 2 (section 2.2.1), based on the reviewed study by van der Kroon et al. (2013). The scholars argued that synergies between sources and technologies were key to better understand the potential adoption of cleaner and more energy-efficient options. In line with the empirical evidence, the adoption of solar energy was found to be constrained by factors related to, among all, the technology poor quality, lacking of maintenance, high costs and difficult adoption in urban buildings (since the rooftop space is limited).

Equity considerations in sustainability transitions

In relation to the second assumption of this framework (and sub-question 1.4), at the sectoral level of energy use, households climbing the energy ladder were not always found to connected with a sustainability transition. This seem to not be possible in the short term. Nevertheless, it could be assumed that, at a certain point it time, households with different characteristics and consumption patterns may converge towards a sustainable energy use pathway, still depending on context related factors. In support to this argumentation, the analysis reviewed a series of policy interventions, which were aimed to combat climate change and air pollution, however leading to sub-optimal achievements in other areas of sustainable development, i.e. the social dimension (Unruh & Carrillo-Hermosilla, 2004).

For instance, the inclusion of the coal ban in the present analysis is especially interesting in light of the fact that in December 2017, the Chinese government had to loosen the coal ban in all northern cities, including Beijing, in the aftermath of media campaigns and social discontent of affected communities and local schools (Zhou, 2015). As a matter of fact, such assertive approach to achieve an egalitarian target in principle (the greatest benefit for the largest societal group) overlooked at the fact that the gas-powered grid network that in principle had to perfectly substitute coal combustion was non-existing in those areas targeted by the coal ban ("The realization of heating without coal," 2017). Policy interventions in the form of bans that prohibit the use of polluting energy sources seem to have detrimental effects on the quality of life of targeted groups, deprived of means (energy sources and techno-infrastructure elements) for heat their house. This confirms the findings by Mekonnen and Kohlin's study (2008, p. 17) on energy consumption in Ethiopian large cities. The authors indeed argued for the significance in policy design on technology availability.

It is interesting to notice that the transition process itself defines, to some extent, what equity is about. Presuming, for instance, that there had been a top-down transition towards solar energy technologies to generate electricity for space heating, equity concerns would have related to the fact that rural households had been using more cleaner energy sources than their urban and/or suburban counterparts. The latter groups would have been constrained by the height of urban buildings and the number of occupants in proportion to the roof surface, determining how much hot water would have been produced. Another infrastructural constraints in megacities like Beijing is the shade from adjacent buildings (TU BERC, 2016).

However, from the household-level perspective, since no transition to the top energy ladder level was accomplished, the equity concerns that relate to this research are totally different. In terms of *equity in access*, diverse household groups have or do not have the ability to access technologies along the energy ladder, which underlies contextual inequalities in the residential sector. In this regard, Munro, van der Horst and Healy (2017) pointed at the inner definition of modern energy in the SDG-7, which may be the root of countries' efforts to assertively phase out inferior energy sources by 2030 that would allow to achieve what claimed by the development goal, but not moving away from those form of spatial inequalities. It is noteworthy that the transition process itself determines what could be eventually regarded as equity concern, which is aligned with McDermott et al.'s work (2013, p. 425), asserting the existence of a context-based "progressive transformation of inequity".

From interviews it was in fact possible to identify a shifting concern from urban-rural inequality to inequality within the surging suburban population that is located at the border of the urban fringes. As former rural areas, the income, lifestyle and energy-related consumption behaviour seem different from the energy use in cities, but they feature the same energy supply infrastructure as in cities, meaning on-grid electricity provision and centralised space heating, which seem inadequate or non-existent in some rural areas visited during site visits. Having diverse energy consumption behaviour and household characteristics, such as income, but similar if not identical energy supply potentially creates substantial differences with the urban fringe, both in terms of capabilities to consumer energy and in terms of distribution of benefits and costs of providing solar energy and energy-efficiency improvements in residential buildings.

Based on the above discussion, relevant contribution to the theory are discussed in the next sections.

5.2 Contributions to the theory

This section presents the contributions of this research project to the theory. As far as it would be presumptuous to assume that this research would contribute in a significant way to the existing literature, it provided empirical applicability for the energy ladder conceptualisation, and for the proposed framework overall. Data were also triangulated with desk research and expert semi-structured interviews (Bryman, 2015).

First, this section reflects on whether it was possible to address the critiques to the ELM, based on the result analysis above. Secondly, the notion of inequalities across household groups enabled to link the analysis performed at the household-level with the higher dimension of institutions in sustainability transitions. From this, it was possible to address sub-question 1.4, on the extent to which empirical evidence of contextual inequalities would have implications diverse household groups in the sustainability transition context. This is discussed in the aftermath of the four critiques to the ELM in this section.

The discussion of sustainable energy consumption and equity continues in the subsequent section (5.3), addressing practical contributions in terms of policy implications derived from the present key findings.

In chapter 2, four critiques to the traditional ELM model were drawn from the literature. In this section these critiques are discussed in light of the data collected and analysed during this research project. This is done in an attempt to clarify the contributions of this project to the literature on the energy ladder conceptualization. Then the theoretical discussion moves onto the contribution to the study of sustainability transitions.

First critique

First, it was argued that the linear and predefined path assumed in the traditional ladder model was not being representative of energy use patterns in developing countries (Hosier, 2004; Masera et al., 2000). The case study on solar energy and energy efficiency use in Beijing lent itself as a good example to argue for the revisitation of the model, in line with the critique above. The data collected showed that rural households - who did not have accessibility to domestic hot water - adopted SWHs and leapfrogged on top of the ladder at once, without consuming transitional energy sources (located in the middle rungs) (Hosier, 2004).

Results also suggested that developing countries like China[6] can learn from the lessons learned in developed countries, and upwards leapfrog more than one rung at a time on the invisible ladder. This indicates China’s opportunity to pursue a more sustainable energy use pathway at a rapid pace, where its fundamental cultural habits

[6] Again, this statement is based on the the WEO database (IMF, 2015)

and traditions are maintained, as also claimed by Professor Jiang during the interview at TU.

Second critique

Secondly, the pursuit of energy stacking clearly emerges from the analysis of suburban and rural households energy use. By comparison, urban households (obligatorily) switched to centralised heating and power networks, supplied from coal-fired and gas-fired plants. This partly confirms the traditional assumption of an energy ladder based on socio-economic development (Leach, 1992).

Nevertheless, whereas these findings suggest that higher-income households in cities do have a less diversified energy mix than their lower-income counterparts, other factors emerged from the empirical research.

Accordingly, the unreliability of the electricity supply, also low energy security, in some rural villages was found to have influence on the multiple energy mix (energy staking) of this household group. Arguably, the energy supply of urban areas (and also of suburban areas) is reliable, and one could argue that households living in these areas may not need to diversity their energy portfolio. Based on the evidence from this research, as household climb up the ladder, energy stacking seem to be shrinking to electricity and natural gas.

In conclusions, for each energy service, the energy mix is slightly different, with space heating and cooking featuring the highest combination of energy sources (Hiemstra-van der Horst & Hovorka, 2011, Nansaior et al., 2011) (graph in Figure 8).

Third critique

In relation to the third critique, some empirical evidence of the basic notion embedded in the ELM was found, for which a switch from traditional to modern fuels occurs as income rises in the context of cities. Nonetheless, the findings of this research provided evidence of low-income households in rural areas also accessing modern energy sources. This corroborates the results of other literature, arguing for the complexity and multi-dimensionality of interrelated factors beyond socio-economic development (household income), which arise at the local level and create a set of unique conditions for households to climb the energy ladder (Campbell et al., 2003; Heltberg, 2004; Hiemstra-van der Horst & Hovorka, 2008; van der Kroon et al., 2013).

Fourth critique

Last but not least, the fourth critique relates to the higher level of analysis suggested in the framework. This refer to the fact that the homogenous societal energy transition in the residential energy use may be unrealistic (Campbell et al., 2003). In line with the authors' study on Sub-Saharan African communities, the research explored context-related infrastructural and technical factors across the three diverse groups and found that energy consumption patterns were unequal across sample areas, mainly due to the distribution of and accessibility to energy technologies.

Contrary to Campbell and colleagues (2013, p.554) however, the results did not show a clear “dichotomy” among household groups. This is because even lower-income households in rural areas had accessibility to LPG tanks for cooking and to the electricity network for lighting, space heating/cooling and domestic hot water in some cases (i.e. new Simatai village and Cuandixia village). Nevertheless, there are localised peculiarities that are difficult to entirely address. For instance, another factor was considered in the analysis, i.e. household income variability. Based on the data collected, this related to irregular income flows from e.g. agricultural practices (rural respondent 6, personal communication, July 23. 2015). The analysis seems to suggest that income variability could prevent the certain lower-income household groups from being able to benefit from the consumption of cleaner and more efficient energy sources. To corroborate this, the rural respondent expressed the willingness to adopt solar PV, however, irregular income flows and the high-upfront costs were constraining this (section 4.3.4). Heltberg’s study (2005) also found that household fuel choice in Guatemala where determined by irregular income flows from agricultural work and informal good sales, limiting households adoption of LPG.

Moreover, some rural respondents reported to often switch off lights (section 4.2.4). This may be regarded as a cultural habit of saving on energy. However, it may also be an indication of the low-income conditions of the households. Therefore, in distributional terms, energy-saving in rural areas may be regarded as tradition practiced or forceful habit to save on the household income (Bartiaux et al., 2015). However, this matter must be regarded with careful attention, also in light of the lack of detailed data on the income level of the households under the scrutiny of this study. Remarkably, it is not a matter of energy type in this case, but of whether households have the choice or not to save on their energy consumption. These results corroborate the importance of integrating contextual inequalities of disposition of access across a diversity of household groups, when attempting to understand and manage energy consumption.

Institutions in sustainability transitions

With the integration of the NOA model into the proposed framework, it was possible to extend the aforementioned need for changes at the individual household level to the level of residential energy use, and even to the necessity for societal change. Literature on the NOA model in fact advocated that “the societal context needs to be right if required behaviour is to result” (Lucas et al., 2008, p. 458).

To put this into perspective, based on the circularity of the model, as in chapter 2, such change is rooted in contextual technical and infrastructural conditions affecting the household, and also in the institutional factors that are imposed upon the capabilities of diverse household groups to benefit from the consumption of energy, in order to steer energy consumption in the residential sector according to political targets and aims. In turn, the movement of household groups climbing the energy ladder would reflect on the agenda-setting of policy interventions at the institutional level.

Finally, the application of the proposed framework and the discussion in light of existing scientific knowledge allowed to identify a set of forces that strongly influenced energy consumption patterns in this case study. First, it is arguable that politics and policy were lacking of an understanding of market forces underlying the commercialisation of solar technologies. This resulted in the failure to incorporate high-quality technologies and continued maintenance services into building energy codes and standards. Secondly, flowing from the recognition of climate and air pollutions problems/challenges (as outlined in the introductory chapter), both political willingness and the policy-making approach initiated a set of policies and regulations to support changes towards a more sustainable energy consumption in the residential sector.

The theoretical discussion and empirical analysis performed in this research project confirmed other literature studies on that there cannot exist an universal energy ladder, and that households tend to feature multiple energy combinations, especially lower-income rural households, depending on contextual factors. In line with this, the next section draws on the results from the above analysis and illustrates some related policy implications.

5.3 Contributions to the practice

This section discusses some policy implications derived from the key findings of this project, with the primary focus on whether the proposed framework could allow for a better understanding of equal sustainability transitions and the relation with energy policies. Secondly, policy-related technological considerations are explained.

5.3.1 Policy implications

One of the aims of this research was to explore differences in energy consumption among diverse household groups, and what it means for the achievement of sustainability transitions when different households have unequal *contextual disposition of access* to cleaner and more energy-efficient technologies. These considerations are critical given that policies that do not consider the existing contextual disparities may create further disempowerment and be a reason for future social discontent (Pachauri et al., 2012). Also, inequalities have often been addressed in term income gaps or other asymmetries in monetary measures, as aforementioned in the introductory chapter (Pachuari et al., 2012). Thus, the exploration of influencing factors in this research offers a contribution to policy-making, by attempting to deepen the current understanding of which factors inhibit or stimulate inequalities in regards to the distribution of energy sources/technologies, and thus services among household groups.

Energy-related policies and equity concerns

The results in this research reported a case of social discontent in relation to the implementation of a coal ban ("North China's coal ban," 2017; Zhou, 2017). Such policy instrument was misdirected to household groups that could not access to the grid heating network nor alternative off-grid source, and even more importantly technologies, to compensate for the mandatory and government-led deprivation of coal. Future policies may need to plan policy instruments more carefully, and quest:

"[Is the policy intervention] addressing an immediate problem? But also how sustainable is this solution?" (Rokia Raslan, personal communication, August 11, 2017)

Here, sustainable could encompass an intervention that fosters the continued use of type of energy that does not further damage the resources of the planet nor personal health, and it is economically viable, as reflected by the three sustainability pillars (Brundtland et al., 1987). It is noteworthy that solar and energy efficiency technologies were reported to be low-cost solutions to reduce GHG emission from buildings energy use, therefore allowing for substantial energy savings and cleaner as well as more efficient energy consumption (IEA, 2017A; 2017b; Urge-Vorsatz & Novikova, 2008). Having acknowledged the potential of such technologies, and according to the conceptualisation of contextual equity, the more vulnerable members of the society that seek to satisfy their energy needs would largely benefits from their low- or even zero-operational costs. In line with this, Colenbate and colleagues (2016) argued that there exist large opportunities for megacities in Asia to shift to more decarbonised development pathways, with no need to initiate profound short-term structural changes, which are cost-effective and reduce negative climate externalities.

Nonetheless, current high upfront costs associated with e.g. solar technologies still are likely to lead to unequal abilities to derive benefits from their adoption and usage, which vary across diverse household groups in their specific context (Pachauri et al., 2012). This may be due to households tending to avoid the payment of substantial lump sums, as in the case of solar installations, preferring to continue using conventional fuels (van der Kroon et al., 2013).

Rather than having as the ultimate policy goal extensive electricity accessibility in rural areas, the local government may pay more attention on the actual improvement of both the "quality of life and productivity" from energy consumption in housing areas (Colenbata et al., 2016, p.153). The authors also reported that it is paramount "that decision-makers place issues of equity and inclusivity at the centre of urban policy making and planning" (Colenbate et al., 2016, p. 155). It is noteworthy that whilst certain solutions may be appropriate to solve short-term impending issues, it is advisable to adopt a long-term decision-making mindset, which findings from expert interviews reveal to still be a critical missing element in the approach of some technology experts in Beijing (Aart De Geus, personal communication, June 14, 2017).

Household energy consumption choice and information

Zhang and colleagues (2017) claim that the promotion of more sustainable consumption along all social groups play a critical role in influencing consumption behaviours and patterns in terms of quantity of energy. In cases where households have the capability to choose their energy sources, energy-related educational measures can also influence this choice. As of now, energy supply choice is however impossible in urban high-stories building complexes with central heating supply, but there is great potential for promoting green labels on energy-efficient housing appliances (Zhang et al., 2017). The extent to which households are totally disempowered in relation to their energy consumption choice (due to the centralisation of energy systems) is progressively expanding to encompass suburban areas, and to rural areas since the government commitment to cut domestic carbon emissions from fuel combustion. What it is noteworthy in equity terms is not the limited range of energy sources accessible to households, but their energy-related consumption choice.

Based on the empirical application the proposed framework, this seems to be a political and technological question.

Targeted policies for diverse household groups

The results of the analysis in Beijing could be defined as typical of a “stratified society” (Reddy and Reddy, 1994, p. 570). Following from empirical evidence and reviewed literature, emerging consumption patterns are arising in all three localities. Lifestyle preferences and occupants behaviour that ignores the negative externalities of energy-related choices may play a greater role in the future of building energy consumption (already taking place in cities), and therefore may require attention from the policy side (Liu et al., 2013; Zhang et al., 2017). By contrast, the willingness to adopt cleaner and energy-efficient technologies seem to be emerging in rural households (section 4.e). These results therefore suggest that policy instruments may need to target specific household groups and their needs.

In relation to the literature, Reddy and Reddy’ study (1994) in Bangalore, the differences among urban-suburban-rural households reflected their income gap, which increased the complexity to design energy policies specific for each income group. Energy inequalities indeed often mirror existing income, gender and other inequalities (Pachauri et al., 2012).

In order to better accomplish this, Professor Lin from BNU suggests that direct money flow to households, rather than energy subsidies, can be a solution to steer energy consumption patterns towards more sustainable and long-term cost-effective energy alternatives (Lin Weibin, personal communication, August 25, 2017). As previously mentioned, policymakers would also need to integrate non-market policy instruments (energy use awareness raising) to economic incentives, such as information campaigns, maintenance and support services, e.g. trainings on the technology usage (Liu, 2016).

Understanding and managing fragmentation

Taking an holistic approach in future-proofing the building energy system is an important argument advocated in both primary results from expert interviews and in the reviewed literature. The latter relates to the need for adopting a holistic approach that would see the combination of higher level factors to set the right external context and the push for change in behaviour that would enable the transition towards overall "societal change" (Lucas et al., 2008, p. 458). By applying these theoretical notions to the present case study, evidence from expert interviews was found to empirically support the above literature statements, for which "policy makers should equally emphasize a new ambition for urbanization: smart, green, low carbon, and inclusive" (Ye, 2013).

From the analysis in section 4.3.2, there is an emerging need to overcome the fragmentation of the energy sector, in order for information to be shared and managed across different entities. One way to approach the fragmentation of public departments, information agencies or energy suppliers may be embracing such fragmentation, understand the factors underlying it and manage it while trying to establish an interaction among various stakeholders, market and non-market actors.

On this account, Professor Jiang from TU argued for the importance of the collaboration with research institutes in data collection on buildings energy consumption, from which policies targeted to change occupants behaviour can be designed. Further data collection on building energy-related consumption and occupants' behaviour is in fact useful to maintain the energy performance of the building at optimal levels even after its occupation. Dr. Rslan defined the issue of data collection as a "*massive undertaking*" (Rokia Raslan, personal communication, August 11, 2017), and it requires synergies among departments, functions and agencies involved the energy and information flow management and processing.

While the approach explained above may be a rather indirect way, another more direct approach may refer to codes and regulations on clear buildings energy efficiency and performance, which ought to reduce complexity. Regulations are important in initiating collaboration among different (and presently fragmented) departments, as also claimed by Professor Yi Jiang. The interviewee in fact suggested that through certification, public authorities can know whether an enterprise is reliable or not (Yi Jiang, personal communication, August 24, 2017).

5.3.2 Policy-related technological and practical considerations

In addition to major policy implications, this research provides other practical considerations that could be taken into account in policy-making. These relate to a series of desirable improvements in residential buildings. These measures may be integrated to future-proof existing buildings, in considerations of the need to balance socio-environmental needs, and based of cost-effective approaches (Rokia Raslan, personal communication, August 11, 2017).

Improving the energy efficiency in each urban apartment units is important to encourage systems that are progressively designed to adjust to low-energy usage modes (Derek Cowburn, personal communication, November 30, 2017). Colenbata et al. (2016) reported that policy interventions targeted at reducing the carbon emissions in buildings could also increase the opportunities for fuel switching towards cleaner alternatives in the residential sector. Accordingly, the analysis used the example of a government-led renovation project in Huixin West Street in Beijing, where occupants' energy-inefficient (window opening) behaviour resulted in sub-optimal energy-saving outcomes from the building renovation project (Liu & Liu, 2016). The author of this case study suggested that end-use control measures "should be more convenient to operate, and more effective to adjust (Liu & Liu, 2016, p.2). This is considered also in light of statistical findings from previous studies on Beijing residential buildings, which reported average room temperature in buildings with district-level heating between 17-22°C (Zhang & Yoshiro, 2010). The average temperature in Beijing was found to be higher than in other cities with individual heating systems, e.g. Shanghai (15°C), which may suggest the need to invest in decentralised temperature control (Zhang & Yoshiro, 2010).

Accordingly, synergies between technology and consumption behaviour emerged from the interview with Professor Jiang at TU. The interviewee pointed at the need to maintain the traditional energy-saving behaviour of households, by installing energy-efficient equipment, e.g. for space cooling needs, that can be regulated according to the state of occupancy of each room and each unit in the building (Yi Jiang, personal communication, August 24, 2017). Throughout this research, another example of domestic equipment running when it is not needed was found in the NUH network in northern China (TU BERC, 2016).

In addition, measures to overcome the social acceptability of individual households in relation to new more energy-efficient technologies in their apartment building are reported by Liu (2016) in the same TU best practice publication. In the demonstration project carried out in Changchun, in Jilin Province, northeast China. In this case, occupants with individual metered charging were offered an economic incentive to adjust the indoor temperature control valve below 23°C. Results from the case study monitoring process show that 57% of previously overheated apartments lowered the temperature set point after the economic reward. This way, optimal results were achieved in energy savings and building energy efficiency and thermal performance by installing individual metered charging and end control measures coupled with actual economic benefits (Liu, 2016).

This suggests that energy inefficiencies, both inside the building and in the energy infrastructure, must be promptly deal with, in line with the study by Diamond et al. (2013) on sustainable buildings energy performance in China.

Improving inefficiencies in building energy use overall include, among all, inadequate envelope insulation of buildings (OECD/IEA, 2015). Accordingly, Lo (2014) reported that, as of 2014, 76% (4.13 billion m^2) of residential buildings in northern China were inadequately insulated, contributing to the energy inefficiency of the centralised (predominantly coal-fired) building heating system. As for Beijing, the municipality is located in the cold climate zone, with coldest mean monthly temperature being around -10°C, therefore with significant space heating requirements (Diamond et al., 2013). In relation to energy sustainability concerns (e.g. climate, air quality, personal health), long-term improvement in the energy-efficiency of building envelopes (at low- or even zero-costs) could substantially reduce the economic burden of space heating on households. In additions, these could reduce the direct combustion of fuels for heating in rural areas, which have tremendous consequences for the quality of the environment and personal health (IPCC, 2014; WHO, 2016).

It is, however, a complex task. The analysis revealed the interrelation among rising income, increasing living standards (demand for comfort), buildings structural characteristics and household geographical location (section 4.2.3), as influencing factors of diverse household groups’ energy use.

A deeper understanding of the aforementioned synergies is paramount for policy design, especially as rural households’ increasing economic status is expected to lead to an increase in the demand for comfort and domestic energy-using equipment in buildings in the next two decades (Gross, 2015; TU BERC, 2016). Accordingly, the increasing residential energy consumption partly may find resolution in the implementation of subsidisation plans to support the replacement of low-efficient and high-carbon intensive home appliances in rural areas (Munro et al., 2017; Zhang et al., 2017).

However, households may often not be aware of the alternative cleaner and more-efficient energy options or they do no have choice over their energy portfolio, and/or they live in poorly insulated houses (especially rural residents).

Business actors opportunities emerged from the data reported in section 4.3.2 of the analysis. This indicated that China could have the capacities and political will to leapfrog towards cleaner energy consumption, which was also assumed in the theoretical framework of this research, as part of the first critique to the traditional ELM. In line with this, an an article published in Renewable Energy World, Schwartz (2014) reported the declaration by President Xi Jinping on the need for a new economic model, which focuses on the domestic market, and, among all, features (technology) innovation as well as larger efficiency in several sectors, including a re-thinking of the energy sector to minimise its negative environmental externalities and does not exacerbate the existing ones. These are arguably ambitious goals, however the country seem to have already stepped forward in this context.

The 13th FYP (2016-2020) are by far achieved and the country set new targets for solar installed capacity. Moreover, the slow but continued stabilisation of economic growth (6.5%/year), followed by even slower but declining patterns of energy consumption could substantially support the structural energy transition of the country towards sustainability (Schwartz, 2014). Overall, China can learn from parallel experiences and lessons learned in other countries, in terms of policy interventions, technology development and innovative business ideas/models (Alvarez & Barney, 2007). Interestingly, Cabraal (2004, p.130) points at "small, usually entrepreneur-driven, often somewhat informal, businesses" that can keep a high level of quality in the technology and its components. These businesses operate locally, thus, they are accessible to residents in the area, and usually provide high-quality business services (Cabraal, 2004).

Nevertheless, it is worth mentioning that this statement implies a degree of choice on which energy technology to consume among households. As aforementioned, empirical evidence from this research point at the fact that individual households are more influenced by higher-level factors, such as policy and technology accessibility, thus not having decision-making power as agents over their range of energy choices, also considered in the study by van der Kroon et al. (2013). These higher-level factors have large potential to allow consumers to make informed decisions on e.g. energy-consuming appliances, such as the decision of buying a multi-unit air conditioner that cools even non-occupied rooms, and thus consumes large quantities of energy, resulting in an inefficient adoption and use of appliances (Yi Jiang, personal communication, August 24, 2017).

Clearly, there exist a widespread international, national and local interest in understanding both barriers or challenges and opportunities that arise in relation to switching from fossil fuels to renewables and energy efficiency use in energy systems and in all its related sectors (Gielen et al., 2015; Lo, 2014).

In light of the above discussion and contributions of this research project, major opportunities arose for Beijing residential energy sector could be identified. Some emerged from the contributions to the practice of this research, hence from a technology perspective. It refers to advanced building envelopes, particularly important in cold climatic areas such as Beijing, and to end-use measures to control occupants' energy use, supported by changes in the centralised energy infrastructure. Notably, such measures could be integrated into buildings in combination with solar energy technologies, promoting both awareness through solar demonstration projects and on-site energy consumption to respond to current and future environmental challenges, as outlined in this research (Gielen et al., 2015). As a matter of fact, results from primary sources reported that occupants' behaviour may play a more significant in the future energy use in buildings, for which reason technology-related policies aimed to understand occupant's behaviour per unit, support energy systems flexibility and steer low energy-usage modes are critical.

Overall, this research recognises that such structural changes in energy systems can be achieved to different extents and by undertaking a plurality of pathways. Some are more successful in reaching sustainability in the targeted sector, while others need to understand how to clearly set objectives and manage synergies and trade-offs among different factor dimensions. Also, multiple suitable research approaches exist to the issue at hand. Criticisms on existing theories - if constructive and evidence-based - must be carried on and supported by continued research, in order to keep with the pace of transforming energy systems. Some limitations to the research approach chosen for this project are discussed below, along with evidence for its suitability and suggestions for improvements.

5.4 Limitations, improvements and future research directions

This section presents and discusses the limitations of the proposed framework and of the research (e.g. methods, data collected), which allow to shed light on possible improvements and on new insights for future research. Additionally, the reliability and validity of the results are utilised to support the value of the proposed framework.

5.4.1 Framework limitations

Socio-technical regime

A socio-technical dimension emerged throughout the research project (section 5.6), and was not addressed in the initial framework employed in this research project. This points at the first theoretical limitation.

Arguably, the proposed framework fell short in addressing the conditions for the diffusion of a specific technology innovation into a broader context. The pace of technological innovation and experimentation is indeed a critical factor for the domestic energy consumption from more sustainable energy sources technologies (Sovacool, 2017). Accordingly, Sovacool (2017, p.577) defines "technological contingency" as a set of conditions that may stimulate or limit the adoption of new technologies, for instance owing to the lacking of technological innovation.

Nonetheless, the exploratory approach adopted in this framework still allowed for the identification of the slow acceptance of the SWH niche technology by households. This occurred in the aftermath of misdirected policies, which were implemented without a thorough understanding of the market for SWH (section 4.3.1 in the analysis). As much as an holistic approach was taken, this research fully acknowledged that this framework does not represent the plurality of variables and dimensions that could influence energy consumption patterns, and many factors might be neglected owing to the framework limitations. Furthermore, the very dynamic nature of sustainability transitions is difficult to enclose in a unique framework. Nevertheless, the key findings of this research project are in line with the majority of reviewed literature studies in this context, which adds reliability to the results and contributions of this framework.

It is noteworthy that the publication by the OECD/IEA (2015) reported a progressive decrease in the quantity of buildings having centralised heating system (i.e. NUH), as a result of the tendency to demolish and rebuild within the present socio-technical mind-set. Hence, future research may explore the effects on the sustainability of building design and construction, in light of the ongoing changes occuring at the the higher level of the socio-technical dimension.

Conclusively, the inclusion of an extensive set of contextual factors can only find a resolution in empirical research. The value of the proposed framework and application of theories and models relied on their analytical flexibility and clarity. Considering the progressive socio-economic development, and the increasing pressure to provide energy to satisfy the diverse but equally energy-consuming needs of rural, suburban and rural households, the barriers/challenges and opportunities raised in this discussion are likely to be critical elements in the future. These findings could hence be integrated to enrich the existing scientific knowledge on equal sustainability transitions.

5.4.2 Research limitations and future research directions

This section presents major research limitations. Partly, this was already carried out in chapter 3, in relation to the limitations of the household survey methodology employed in this research project.

Further in relation to data collection, the data in this research could not provide detailed information in terms of household income not income variability, due to the unwillingness of individual respondents in disclosing this type of information. Nonetheless, the lack of this information on household income was overcome by retrieving data from the Chinese NBS database (NBS, 2017). Seemingly, it was not possible to determine whether the behaviour of switching off the lights originated from underlying cost-saving reasons or households' habits, for which reason further studies may better investigated such micro-level factors.

Moreover, the proposed framework was not designed to statistically assess the causality of certain explanatory variables (e.g. income variability) on changes in residential energy consumption, therefore the results could be subject to the personal interpretation of the student. Generally, the energy ladder literature makes extensive application of statistical models (Zhang & Guo, 2012; van der Kroon et al., 2013).

However, rather than accounting for the impact of a series of single causal factors that aim to explain the processes of energy use across household clusters, this thesis focused on the discursive explanation of energy consumption patterns and inequalities using a qualitative-based approach. The latter aimed to underpin the relevance for policy-making of theoretically- and empirically-based debates that are broad-reaching in terms of the factors they assert to explore. Furthermore, major findings are confirmed by existing literature, and results from household questionnaires were triangulated by expert interviews, accordingly to social research (Bryman, 2016). In its limited scope, this thesis enabled to identify a set of factors that facilitated and/or constrained, to a certain extent, energy consumption. These were identified based two levels of analysis in the course of the research, and located in a specific context.

Hence, micro-scale research is preferable as performed in this case and in this context, to deepen the understanding of the field of household energy consumption. A s a matter of fact, the literature on the energy ladder is mainly based on cross-sectional micro-data from household surveys at a specific point in time (Masera et al., 2000). This could be done also in light of context-related peculiarities that need to be acknowledged by and addressed in policy design. Specifically, the analysis could include the energy consumption across household groups in suburbs of the megacity, where former rural households are provided with urban buildings energy infrastructure. This in-depth type of analysis would provide further and more detailed data on the locations that need priority in adopting energy efficiency and renewables technologies. Thus future research may look at beyond the rich-poor and urban-rural traditional constructs, also in consideration of the emerging new middle-class.

This could also be performed by means of longitudinal studies. These may look at the influence of e.g. the internalisation of negative and positive externalities into the power generation and distribution price of renewable energy sources, not only solar. This may be relevant in consideration of the launch of China's national emissions trading market at the end of 2017, already setting the ambitious target of becoming the largest one at the global level to mitigate climate change emissions (Bradsher & Friedman, 2017). It would be therefore interesting to also include the long-term influence of such macro variations in future research on sustainability transitions.

5.4.3 Further research directions

In regards to the fact the present results showed that electricity co-dominated the energy portfolio of sampled urban residents (progressively along with gas), it would be important to probe the extent to which electricity-related technologies and infrastructure (grid network) could be taken advantage of, and dispatch heating and power from large-scale solar energy, rather than coal-fired and/or CHP plants. In the case this shift occurred in the energy supply, households having accessibility to the centralised system would be able to climb up the ladder, whilst off-grid households would not. This bring about concerns in regards to the contextual disposition of the technology accessibility across a diversity of household groups. This could be carried out by deeply looking at essential components of the equity framework by McDermott and colleagues (2013, p. 422), the question of "equity among whom".

Additionally, the importance of preferences did not receive full attention due to the nature of this case study and the influencing factors deemed more important, further research may want to examine more attentively the internal/behavioural household ranking of energy sources characteristics. A ranking could be established by performing micro-scale research on distinct households' budget strategies in relation to energy consumption preferences and priorities, and in consideration of changing patterns with socio-economic development.

Finally, Reddy and Reddy (1994) interestingly stated that "as society becomes more egalitarian, energy ladder based on income should disappear" (p.570). In order to assess the practicality of such assumption, a deeper and more thorough analysis would be necessary to better understand the impacts of a highly centralised government authority and decisional power on energy consumption, which is beyond the scope of this study. Building on the collected data in the course of this project, future research could explore how a more progressive and equitable strategy to stimulate the adoption of sustainable energy alternatives would originate from a more participatory system (in the sense of voicing their energy preferences and willingness to pay for energy services), where consumers are aware of the impacts of their energy consumption and choices. This could be done by refining expert interviews with a focus on procedural equity in regards with specific policy interventions that "create its own set of winners and losers" (Sovacool, 2017, p. 570).

5.4.4 Generalisability of results

The results are restricted in their generalisability, as the analysis was carried out in strict relation to the specific context of Beijing Municipality. However, the framework adopted a multi-dimensional approach, which could valid in relation to other cases, for instance in developing countries where cities are rapidly expanding, and where there is renewable resources endowment (Campbell et al., 2003; Sovacool, 2017).

In conclusion, the analytical approach of this research project (owing to what factors and to what extent) brought to light some major contributions to the theory and to the practice. Limitations mainly refer to the complexity of the plurality of factors for changes in energy use patterns across diverse household groups. The framework, however, provided valuable additions to the existing knowledge and some future research directions. Finally, the next section provides a concise answer to the research question.

5.5 Conclusions and answer to the research question

This research was conducted considering three household groups in Beijing (urban, suburban, rural) and by disaggregating the household energy consumption in five energy services: space heating/cooling, water heating (domestic hot water), cooking and lighting. If all households do not promptly and perfectly switch to cleaner and more efficient energy technologies, unsustainable energy stacking behaviour (combining traditional fuels with modern and sustainable energy types) is likely to endure.

In regards to the research question, households may not always climb on top of the ladder. Particularly, when energy-efficiency technology improvements are placed on the top rung, urban and suburban households have more opportunities to climb upwards than their rural counterparts. This may be explained by building regulations, energy-saving requirements and technology advancements in urbanised areas. By contrast, when solar energy technologies are considered on top of the ladder, centralised fossil fuel use and buildings unsuitable for solar installations tend to lock-in urban households to fossil fuel consumption. Low-storeys buildings and opportunities for decentralised solar installations are likely to facilitate suburban and rural households to climb up the ladder.

At the sectoral level of energy use, households climbing the energy ladder in connection with a sustainability transition seem not to be possible in the short term. The extent to which a diversity of household groups can displace current dominant fossil fuels and adopt sustainable energy alternatives is subject to diverse interrelated factors. It clearly depends upon diverse households' *contextual disposition of access* to cleaner, high-quality and high-efficiency energy technologies, as well as policy interventions. Accordingly, the findings showed that locked-in building infrastructure, poor technologies maintenance and network unreliability are compounding factors that prevent some households from climbing upwards the energy ladder and adopt more sustainable energy alternatives. Moreover, energy consumption patterns and inequalities were found to differ across diverse groups of households under certain government interventions. These enabled lower-income rural households to access modern energy sources/technologies, suburban households to access to the centralised grid network, and urban households to live in buildings complying with energy codes and performance standards. Based on the above analysis, households' energy consumption patterns are therefore less intrinsically motivated by socio-cultural habits and more externally influenced by techno-infrastructure as well as institutional factors. In this regards, limited or non-existent choice over the household domestic energy consumption tends to create lack of information of cleaner energy alternatives, especially in urban areas.

A combination of, among all, end-users control measures and training on their usage, building codes and energy infrastructure efficiency improvements could be combined with awareness raising on energy efficiency devices in urban areas. In rural areas, financial support to adopt sustainable energy technologies could help to address priorities related to buildings and fuel combustion efficiencies, also in light of the increasing demand for comfort and domestic energy use. Whilst policy efforts to phase out coal are laudable, authoritative policy instruments resulted challenging from the perspective of contextual energy equity.

The success in achieving sustainability transitions depends upon an attentive understanding of the above factors, for which the institutionalisation of an holistic approach is favourable. This sees the combination of centralised-decentralised energy systems, careful planning prior to the actual implementation of policy strategies, and the consideration of economic-social-environmental impacts of pathways that intend to be undertaken. Furthermore, any conclusion on household energy consumption patterns and inequalities is to be conscientiously ponderated in its contextual peculiarities across a diversity of household groups.

References

Alvarez, S. A. & Barney, J. B. (2003). Discovery and creation: alternative theories of entrepreneurial action. *Strategic Entrepreneurship Journal 1*(1–2), 11–2610. http://doi.org/10.1002/sej.4

Bartiaux, F., Schmidt, L., Horta, A., & Correira, A. (2016). Social diffusion of energy-related practices and representations: Patterns and policies in Portugal and Belgium. *Energy Policy 88*, 413–421. http://dx.doi.org/10.1016/j.enpol.2015.10.046

北京小区免费配置太阳能热水器成摆设 [Beijing area free installation of solar water heaters equipment]. (2016, May 23). *China-Nengyuan.com.* Retrieved from http://www.china-nengyuan.com/news/china-nengyuan_news_93455.pdf

Beijing Foreign Affairs Office. (2017, January 14). *Report on the work of the Government (part I)*. Retrieved from http://www.ebeijing.gov.cn/Government/reports/t1487075.htm

Beijing Municipal Bureau of Statistics. (2016). *Beijing Statistical Yearbook 2016.* Retrieved from http://www.bjstats.gov.cn/nj/main/2016-tjnj/zk/indexeh.htm

Brizga, J., Līce, E. (2013). Driving Forces, Environmental Pressures and Policy Instruments. In: U. Schrader, V. Fricke, D. Doyle, V. Thoresen (Eds.), *Enabling Responsible Living* (pp.76–96). Heidelberg, Berlin: Springer. https://doi-org.proxy.library.uu.nl/10.1007/978-3-642-22048-7_7

Brundtland, G., Khalid, M., Agnelli, S., Al-Athel, S., Chidzero, B., Fadika, L., ... & Singh, M. (1987). Our common future. Retrieved from http://www.un-documents.net/our-common-future.pdf

Bryman, A. (2016). *Social Research Methods.* Oxford, UK: Oxford University Press.

Building Energy Research Center of Tsinghua University. (2016). *China Building Energy Use 2016*. China: China Architecture & Building Press.

Cabraal, A. (2004), Strengthening PV business in China - A World Bank renewable energy development project. *Renewable Energy World.* Retrieved from http://siteresources.worldbank.org/EXTRENENERGYTK/Resources/5138246-1237906527727/Strengthening010World10Anil0Cabraal.pdf

Campbell, B. M., Vermeulen, S. J., Mangono, J. J., & Mabugu, R. (2003). The energy transition in action: urban domestic fuel choices in a changing Zimbabwe. *Energy Policy, 31*(6), 553–562.

China Internet Watch. (2017). *China Internet Statistics 2017.* Retrieved on 20-07-2017 from https://www.chinainternetwatch.com/whitepaper/china-internet-statistics/

Darnton, A. (2008, July). *GSR Behaviour Change Knowledge Review - Reference Report: An Overview of behaviour change models and their uses*. Retrieved from http://doi.org/https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498065/Behaviour_change_reference_report_tcm6-9697.pdf

Diamond, R. C., Ye, Q., Feng, W., Yan, T., Mao, H., Li, Y., … Wang, J. (2013). Sustainable Building in China—A Green Leap Forward?*. Buildings 3*(3), 639–658. http://doi.org/10.3390/buildings3030639

Elias, R. J., & Victor, D. G. (2005). Energy transitions in developing countries: a review of concepts and literature. Program on Energy and Sustainable Development, Working Paper. Stanford: Stanford University

Gatersleben, B., & Vlek, C. (1998). Household consumption, quality of life, and environmental impacts: A psychological perspective and empirical study. In K.J., Noorman & T. Schoot Uiterkamp (Eds.), Green households? Domestic consumers, environment and sustainability (pp. 141–183). London: Earthscan Publications.

Gielen, D., Saygin, D., Wagner, N., Petrichenko, K., & Tsakiris, A. (2015). *Synergies Between Renewable Energy and Energy Efficiency – A Working Paper Based on Remap 2030.* International Renewable Energy Agency, 1–52. Retrieved from http://orbit.dtu.dk/files/122135712/IRENA_C2E2_Synergies_RE_EE_paper_2015_0.pdf

Gross, R. E. (2015, July 5). Urbanization in Sardine-Packed Beijing Has Quadrupled the Size of Its Environmental Impact. *The Slatest.* Retrieved from http://www.slate.com/blogs/the_slatest/2015/07/02/urbanization_in_beijing_has_quadrupled_the_size_of_its_environmental_impact.html

Guo, D., He, G., & Lian, Z. (2017). Environmental Risk Perception and Public Trust–from Planning to Operation for China's High-Speed Railway. *International Journal of Sustainable Transportation*, *11*(9), 696–706. http://doi.org/10.1080/15568318.2017.1306761

Hauff, J., Bode, A., Neumann, D., Haslauer., F., Azevedo, C., ... & Zantout, R. (2014). *Global Energy Transitions - A comparative analysis of key countries and implications for the international energy debate* (pp. 10–12). Berlin: Weltenergierat. Retrieved from https://www.atkearney.com/documents/10192/5293225/Global+Energy+Transitions.pdf/220e6818-3a0a-4baa-af32-8bfbb64f4a6b

He, X., & Reiner, D. (2016). Electricity demand and basic needs: Empirical evidence from China's households. *Energy Policy 90,* 212–221. http://dx.doi.org/10.1016/j.enpol.2015.12.033

Heltberg, R. (2004). Fuel switching: evidence from eight developing countries. *Energy economics, 26(*5), 869–887. http://doi.org/10.1016/j.eneco.2004.04.018

Hiemstra-Van der Horst, G., & Hovorka, A. J. (2008). Reassessing the "energy ladder": household energy use in Maun, Botswana. Energy Policy, 36(9), 3333–3344. http://doi.org/10.1016/j.enpol.2008.05.006

Hosier, R. H. (2004). Energy Ldder in Developing Nations. In *Encyclopedia of Energy.* (Vol. 2, pp. 423–435). California: Elsevier Press.

Hosier, R. H., & Dowd, J. (1987). Household fuel choice in Zimbabwe: an empirical test of the energy ladder hypothesis. *Resources and energy, 9*(4), 347-361.

Intergovernmental Panel on Climate Change. (2014). Climate Change 2014: Mitigation of climate change. IPCC Fifth Assessment Report, 527–532. http://doi.org/10.1017/CBO9781107415416

International Energy Agency. (2017a). *Energy Efficiency.* Retrieved on 10/02/2017 from https://www.iea.org/topics/energyefficiency/

International Energy Agency. (2017b). *Solar*. Retrieved on 20/04/2017 from https://www.iea.org/topics/renewables/solar/

International Energy Agency IEA. (2011). *Solar Energy Perspectives*. Retrieved on 20/04/2017 http://doi.org/10.1787/9789264124585-en

International Monetary Fund. (2015). *World Economic Outlook Database April 2015 – WEO Groups and Aggregates Information*. Retrieved from http://www.imf.org/external/pubs/ft/weo/2015/01/weodata/groups.htm#oem

Jacobson, M. Z., Nghiem, S. V., Sorichetta, A., & Whitney, N. (2015). Ring of impact from the mega-urbanization of Beijing between 2000 and 2009. *Journal of Geographical Research: Atmospheres 120*(12), 5740–5756. http://doi.org/10.1002/2014JD023008

Jinran, Z. (2015, May 26). Coal-fired plants in Beijing on way out with new ban. China Daily. Retrieved from http://www.chinadaily.com.cn/beijing/2015-05/26/content_20818638.htm

Leach, G. (1992). The energy transition. *Energy policy, 20*(2), 116-123.

Liu, L. (2016). Application Case Study of the “Temperature-based” On-off End Control and Heat Allocation Technology. In S. Hu (Ed.), *Best Practice of China’s Building Energy Conservation* (pp. 17–24). China Architecture & Building Press.

Liu, L., & Liu, Y. (2016). Existing Residential Building Envelope Renovation Case Study. In S. Hu (Ed.), *Best Practice of China’s Building Energy Conservation* (pp. 1–8). China Architecture & Building Press.

Lo, K. (2014). A critical review of China’s rapidly developing renewable energy and energy efficiency policies. *Renewable and Sustainable Energy Reviews, 29,* 508–516. http://doi.org/10.1016/j.rser.2013.09.006

Lozano, R. (2013). A Holistic Perspective on Corporate Sustainability Drivers. *Corporate Social Responsibility and Environmental Management, 22,* 32–44. http://doi.org/10.1002/csr.1325

Lucas, K., Brooks, M., Darnton, A., & Jones, J. E. (2008). Promoting pro-environmental behaviour: existing evidence and policy implications. *Environmental Science and Policy*, *11*(5), 456–466. http://doi.org/10.1016/j.envsci.2008.03.001

Gupta, G., & Köhlin, G. (2006). Preferences for domestic fuel: analysis with socio-economic factors and rankings in Kolkata, India. *Ecological Economics, 57*(1), 107–121.

Ma, R., Mao, C., Shan, M., Zhang, L., & Yang, X. (2017). Occupant control patterns of low temperature air-to-air heat pumps in Chinese rural households based on field measurements. *Energy and Buildings*, *154*, 157–165. http://doi.org/10.1016/j.enbuild.2017.08.049

Ma, B., Song, G., Smardon, R. C. & Chen, J. (2014). Diffusion of solar water heaters in regional China: Economic feasibility and policy effectiveness evaluation. *Energy Policy* 72, 23–24. http://dx.doi.org/10.1016/j.enpol.2014.04.015

Martins, J. (2005). The Impact of the Use of Energy Sources on the Quality of Life of Poor Communities. *Social Indicators Research, 72*(3), 373–402. http://www.jstor.org/stable/27522207

Masera, O. R., Saatkamp, B. D., & Kammen, D. M. (2000). From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. *World development, 28*(12), 2083–2103. http://dx.doi.org/10.1016/S0305-750X(00)00076-0

McDermott, M., Mahanty, S., Schreckernberg, K. (2013). examining equity: A multidimensional framework for assessing equity in payments for ecosystem services. *Environmental Science & Policy 23*, 416–427. http://dx.doi.org/10.1016/j.envsci.2012.10.006

Mekonnen, A., & Kohlin, G. (2008). Determinants of Household Fuel Choice in Major Cities in Ethiopia (Working Papers in Economics No. 399). Sweden: University of Gothenburg.

密云水库蓄水量17年来首次突破20亿立方米 水位达144.7米 [Miyun Reservoir water volume exceeded 2 billion cubic meters yesterday]. (2017, November 20). *Beijing Daily*. Retrieved from http://bjrb.bjd.com.cn/html/2017-11/20/content_193734.htm

Munro, P., van der Horst, G., Healy, S. (2017). Energy justice for all? Rethinking Sustainable Development Goal 7 through struggles over traditional energy practices in Sierra Leone. Energy Policy, 105, 635–641. http://dx.doi.org/10.1016/j.enpol.2017.01.038

Nansaior, A., Patanothai, A., Rambo, A. T., & Simaraks, S. (2011). Climbing the energy ladder or diversifying energy sources? The continuing importance of household use of biomass energy in urbanizing communities in Northeast Thailand. *Biomass and Bioenergy, 35*(10), 4180–4188. doi:10.1016/j.biombioe.2011.06.046

National Bureau of Statistics of China. (2017). *Population and Employment Indicators.* Retrieved from http://data.stats.gov.cn/english/easyquery.htm?cn=E0105

National Bureau of Statistics of China. (2016). *Employment and Wages.* Retrieved fromhttp://www.stats.gov.cn/tjsj/ndsj/2016/indexeh.htm

National Energy Administration. (2016, December 8).《太阳能发展"十三五"规划》的通知, 354号 [*Notice No. 354 on the Thirteenth Five-year Plan for Solar Energy Development]*. Retrieved from http://zfxxgk.nea.gov.cn/auto87/201612/t20161216_2358.htm

Nissing, C., & von Blottnitz, H. (2010). Renewable energy for sustainable urban development: Redefining the concept of energisation. *Energy Policy 28*, 2179–2186. doi:10.1016/j.enpol.2009.12.004

North China's coal ban leaves many rural residents shivering in freezing temperatures. (2017, December 09). *Global Times.* Retrieved from http://www.globaltimes.cn/content/1078635.shtml

Organisation for Economic Co-operation and Development/International Energy Agency, & Building Energy Research Center of Tsinghua University. (2015). *Building Use in China - Transforming Construction and Influencing Consumption to 2050*. France: IEA Publications.

Pachauri, S., Brew-Hammond, A., Barnes, D. F., Bouille, D. H., Gitonga, S., Modi, V., … Zerriffi, M. (2012). Energy Access for Development. In T. B. Johansson, A. P. Patwardhan, N. Nakićenović & L. Gomez-Echeverri (Eds.), *Global energy assessment: toward a sustainable future* (pp.1401–1453). Cambridge University Press.

Painuly, J. P. (2001). Barriers to renewable energy penetration: A framework for analysis. *Renewable Energy, 24*(1), 73–89.

Rafiq, S., Bloch, H., & Salim, R. (2014). Determinants of renewable energy adoption in China and India: a comparative analysis. Applied Economics, 46(22), 2700–2710. http://doi.org/10.1080/00036846.2014.909577

Reddy, A. K. N., & Reddy, B. S. (1994). Substitution of energy carriers for cooking in Bangalore. In *Encyclopedia of Energy.* (Vol. 19, pp. 561–571). California: Elsevier Press.

Renewable Energy Policy Network for the 21st Century REN21. (2016). Renewables Global Status Report 2016. Retrieved from http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf

Schlör, H., Fischer, W., Hake, J. F. (2013). Sustainable development, justice and the Atkinson index: Measuring the distributional effects of the German energy transition. *Applied Energy 112*, 1493–1499. http://doi.org/10.1016/j.apenergy.2013.04.020

Schwartz, L. (2014, July 1). A Ray of Clean Energy Sunshine Peeking Through the Beijing Haze. *Renewable Energy World.* Retrieved from http://www.renewableenergyworld.com/articles/2014/07/a-ray-of-clean-energy-sunshine-peaking-through-the-beijing-haze.html

Smith, K. R., Apte, M. G., Yuqing, M., Wongsekiarttirat, W., & Kulkarni, A. (1994). Air pollution and the energy ladder in Asian cities. *Energy, 19*(5), 587–600.

Sovacool, B. K. (2017). Contestation, contingency, and justice in the Nordic low-carbon energy transition. *Energy Policy, 102*, 569–582. http://dx.doi.org/10.1016/j.enpol.2016.12.045

北京城区实现采暖无煤化 [The realization of heating without coal in Beijing urban area]. (2017, November 14). *China-Nengyuan.com.* Retrieved from http://www.china-nengyuan.com/news/china-nengyuan_news_116780.pdf

TU Delft. (2017). *Internet of Things.* Retrieved on 20-01-2018 from https://www.tudelft.nl/io/over-de-faculteit/afdelingen/design-engineering/research-areas/internet-of-things/

United Nations. (2017). *Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all.* Retrieved from http://www.un.org/sustainabledevelopment/energy/

Unruh, G. C., & Carrillo-Hermosilla, J. (2006). Globalizing carbon lock-in. *Energy Policy*, *34*(10), 1185–1197. http://doi.org/10.1016/j.enpol.2004.10.013

Urban, F., Geall, S., & Wang, Y. (2016). Solar PV and solar water heaters in China: Different pathways to low carbon energy. *Renewable and Sustainable Energy Reviews 64*, 531–542. http://doi.org/10.1016/j.rser.2016.06.023

Ürge-Vorsatz, D., & Novikova, A. (2008). Potentials and costs of carbon dioxide mitigation in the world's buildings. *Energy Policy 36,* 642–661. http://doi.org/10.1016/j.enpol.2007.10.009

Van der Kroon, B., Brouwer, R., Van Beukering, P. J. H. (2013). The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews 20*, 504–513. http://dx.doi.org/10.1016/j.rser.2012.11.045

Wang, P., Shan, M., Xionga, D., Yanga, X. (2014). A new Chinese Kang with forced convection: System design and thermal performance measurements. *Energy and Buildings 85*, 410–415. https://doi.org/10.1016/j.enbuild.2014.09.073

Wang, Z., Han, B., & Lu, M. (2016). Measurement of energy rebound effect in household: Evidence from residential electricity consumption in Beijing, China. *Renewable and Sustainable Energy Reviews 58*, 852–861. http://dx.doi.org/10.1016/j.rser.2015.12.179

World Health Organisation. (2016). *Household air pollution and health*. Retrieved from http://www.who.int/mediacentre/factsheets/fs292/en/

Ye, Q. (2013, June). *McKinsey Quarterly.* Retrieved from https://www.mckinsey.com/global-themes/asia-pacific/chinas-commitment-to-a-green-agenda

Zhang, H., & Yoshiro, H. (2010). Analysis of indoor humidity environment in Chinese. *Building and Environment 45*(10), 2132–2140. https://doi.org/10.1016/j.buildenv.2010.03.011

Zhang, J., Yu, B., Cai, J., & Wei, Y. M. (2017). Impacts of household income change on CO2 emissions: An empirical analysis of China. *Journal of Cleaner Production*, *157*, 190–200. http://doi.org/10.1016/j.jclepro.2017.04.126

Zheng, J. (May 26, 2015). Coal-fired plants in Beijing on way out with new ban. *China Daily*. Retrieved from http://www.chinadaily.com.cn/beijing/2015-05/26/content_20818638.htm

Zheng, X., Wei, C., Qin, P., Guo, J., Yu, Y., Song, F., & Cheng, Z. (2014). Characteristics of residential energy consumption in China: Findings from a household survey. Energy Policy 75, 126–135. http://dx.doi.org/10.1016/j.enpol.2014.07.016

Zhou, V. (2017, December 07). China U-turns on coal ban amid growing outcry over numbers left freezing in winter cold. *The Guardian*. Retrieved from http://www.scmp.com/news/china/policies-politics/article/2123270/china-u-turns-coal-ban-amid-growing-outcry-over-numbers

Appendix I. Rural and urban household survey

The translation of the questions into Chinese Mandarin for the household survey is reported within brackets.

URBAN HOUSEHOLD COMPUTERIZED QUESTIONNAIRE

Hello,
You are invited to participate in my survey "Your Energy Consumption at Home". In this survey, you will be asked about the type of energy you use at home. It will take approximately 10 minutes to complete the questionnaire.

No risks are associated with this project. Your survey responses will be strictly anonymous and confidential and data will be used for research purposes only. If you have questions at any time about the survey, you may contact Giulia Viero at +86 13120236821.
Thank you for your time! Please start with the survey now by clicking on the Continue button below.

(您好，感谢您参与本次“家庭能源使用问卷调查”。这份问卷旨在了解您居住场所的能源使用情况。您大约需要5分钟完成这份问卷。
您将匿名填写本次问卷，您的问卷答复也会高度保密，且仅用于学术研究，因此不会泄露您的任何个人信息。
如有任何疑问，欢迎您随时联系 Giulia（朱莉娅） Viero, 联系电话：+86 13120236821
再次感谢您抽空填写这份问卷！请点击下方按钮开始答卷。)

Household Basic Information (您的基本信息)

Q1) Gender (性别)
Male (男)
Female (女)

Q2) Age (年龄)

Q3) District name (小区（或社区）的名字)

Q4) Type of residence permit (您的户口或居住状态是下面哪一种？)
1. local Beijinger, urban hukou (北京城镇户口)
2. local Beijinger, rural hukou (北京农村户口)

3. migrated to Beijing from other parts of China, with urban hukou (外地城镇户口)
4. migrated to Beijing from other parts of China, with rural hukou (外地农村户口)
5. migrated to Beijing from other countries, staying more than six months (外国公民，已在北京居住超过半年)
6. Other, please specify (其他，请具体说明) __________

Household Energy Use (家庭能源使用情况调查)

Q5) Please select more options. What appliance equipment do you have in your house? (请选出下面所有您在家里使用的设备（可多选）)

1. Refrigerator (电冰箱)
2. TV set (电视机)
3. Computer (电脑)
4. Washing machine (洗衣机)
5. Microwave (微波炉)
6. Air conditioner (空调)
7. Water heater (热水器)
8. Electric space heater (电暖器)
9. Rice cooker (电饭煲)
10. Oven (烤箱)
11. Iron (电熨斗)
12. Fan (风扇)
13. Radio (收音机)
14. Freezer (冷藏柜)
15. Printer (打印机)
16. Water boiler (kettle) (开水壶)
17. Hairdryer (吹风机)
18. Vacuum cleaner (吸尘器)
19. Others (其他)__________

Q6) Are you satisfied with the centralized space heating in heating season (Nov-Apr)? (您对供暖季（每年11月到4月）的集中供暖满意吗)

1. Yes, satisfied (是的，满意)
2. No, my house is over-heated (不满意，家里太热了)
3. No, my house is unsufficiently heated (below 18°C) (不满意，家里不够暖和(不到18摄氏度))
4. My house does not have centralized space heating (我家里没有使用集中供暖)

Q7) Do you have do wear several layers of additional clothes in your house during heating season (Nov-Apr)? (在供暖季（每年11月到4月）时，您家里的室内温度有多少?)

1. I do (低于18摄氏度)
2. I do not (18-21摄氏度)

Q8) What type of energy do you use for the following energy services? (您家里的以下设备使用哪种能源?)

	Electricity (电力)	Natural gas (燃气（如燃气热水器))	LPG (液化石油气)	Coal (太阳能)	Solar energy (煤炭)	I do not know (我不知道)
Space heating (采暖)	❑	❑	❑	❑	❑	❑
Space cooling (制冷)	❑	❑	❑	❑	❑	❑
Water heating (for shower needs) (热水器（洗澡用))	❑	❑	❑	❑	❑	❑
Lightning (照明)	❑	❑	❑	❑	❑	❑
Cooking (烹饪)	❑	❑	❑	❑	❑	❑

Q9) Do you have any device to control the indoor temperature of your house in heating season? (在供暖季时，您的居住场所有可供您调节室内温度的设备吗？)
1. Yes, I use it (有，并且我会用它调节室内温度)
2. Yes, but I do not know how to use it (有，但是我不知道如何使用)
3. Yes, but I do not use it (有，但我不使用它)
4. No (没有)

Q10) Would you prefer to have your energy bill indicating from which sources the energy is generated? (您希望您的电费、采暖费、热水费等账单上显示相应的服务是由哪种能源生产出来的吗？例如，电可能是煤电、水电、风电、太阳能电。)
1. Yes (是的)
2. No (无所谓)
3. Other (其他) ___________

Household Energy Expenditure (居住场所能源支出情况)

Q11) What is your (share of) monthly electricity expenditure on average in winter?

(RMB/month). If you share the energy bill with other occupants in the house, please ONLY indicate how much you are required to pay. (在冬季您每月电费是多少?（人民币/月）如果您和其他人共同分担电费，请回答您需要缴纳的金额。)

Q12) What is your (share of) monthly electricity expenditure on average in summer? (RMB/month). (在夏季您每月电费是多少?（人民币/月）)

Q13) What is your (share of) monthly gas expenditure on average in winter? (RMB/month). (在冬季您每月燃气费是多少?（人民币/月）如果您和其他人共同分担燃气费，请回答您需要缴纳的金额。)

Q14) What is your (share of) monthly gas expenditure on average in summer? (RMB/month). (在夏季您每月燃气费是多少?（人民币/月）)

Q15) What is your (share of) hot water expenditure (for showering) on average in winter? (RMB/month). If your hot water expenditure is included in either electricity or gas expenditures, please indicate which one. (在冬季您每月（洗澡用）热水费是多少?（人民币/月）如果您和其他人共同分担热水费，请回答您需要缴纳的金额。如果热水由电或燃气能源提供，请指出具体是哪一种能源为您提供热水。)

Q16) Comments/Suggestions: (您对能源使用有什么想法或建议吗？请告诉我们)

Appendix II. List of interviewees and household questionnaire respondents

Field	Title and/or name	Role in the institution or organisation	Location	Interview method
Academia	1. Professor Yi Jiang	Head of the Department of Building Science and Technology at Tsinghua University (TU)	Beijing, PRC	Face-to-face interview
	2. PhD Weibin Lin	Executive Director of Center for Energy and Industry Economic Research at BNU	Beijing, PRC	Face-to-face interview
	3. Dr. Rokia Raslan	Lecturer in Environmental Design and Engineering at University College London (UCL)	-	Skype interview
Planning, construction and real estate property management	4. Engineer manager	Design and Management Department at a large state-owned design and construction company	Beijing, PRC	Face-to-face interview
Entrepreneurs	5. Aart de Geus	Engineer, Founder and Director of ArtEnergy BV in Amsterdam, the Netherlands	-	Skype interview
	6. Derek Cowburn	Engineer, founder and director of Lumencache in California, US	-	Telephone interview
Business	7. Solar thermal expert	Expert on the solar thermal industry	-	Email correspondence

Suburban respondent	**Location (date)**	**Gender/Age**	***Rural respondent***	**Location (date)**	**Gender/Age**
1	Caocangcun residential community (July 15, 2017)	Female/61	*1*	Simatai old village (July 22, 2017)	Female/40
2	Caocangcun residential community	Female/58	*2*	Simatai old village	Female/59
3	Caocangcun residential community	Male/29	*3*	Simatai old village	Male/43
4	Baijiatong residential community (July 15, 2017)	Male/80	*4*	Simatai new village	Male/29
5	Baijiatong residential community	Male/72	*5*	Simatai new village (July 22, 2017)	Female/57
6	Baijiatong residential community	Male/78	*6*	Laowa rural village (July 23, 2017)	Female/61
			7	Cuandixia village (August 5, 2017)	Female/65
			8	Cuandixia village	Male/53

Appendix III. Results from expert interviews

The table below displays the results from the process of coding expert interviews

Factor dimension	Interviewee's quote(s)	Operationalisation: Barriers/challenges	Operationalisation: Opportunities
Demography	Yi Jiang: "[T]he building stock will be… Will keep to increase in the urban, but maybe in the rural we need to build a new rural, new village. But the total building stock will reduce because the population [will] reduce. [...] maybe by 2025 there will be one billion staying in city and maybe only 300-400 [millions] staying in rural. Then you see, people go to this way, so building and energy related [consumption] will be something different."	Large energy demand in cities from socio-economic development	
	Derek Cowburn: "The buildings themselves are going to become more efficient and so when you start merging all this city-wide management products together and networks together, there's all kind of great benefits. [...] building information management can help them design better cities."		Technological progress in cities
Technology and infrastructure	Yi Jiang: "[S]o many rooftop had that (solar thermal installations). [...] However, built apartments [were] getting higher and higher, 10 floors, 20 floors, then we did not have enough space to put their [solar thermal device for every family]."	Height of urban buildings constraint the adoption of solar technologies	
	Yi Jiang: "For the technical problem, if all the people connect to this system, then you have to have a management system to control each family not to use too much. Otherwise, [...] never use hot water for you. And this is not equal, right?"	Lacking of end-use measures to control energy consumption in buildings	
	Yi Jiang: "Exactly the solar water devices pushed the Chinese homes from no hot water service into the hot water service world, that's made your life completely different, raising the living standard. "		Solar raises living standards of households

	Yi Jiang: “The solar thermal application is exactly suitable for that, and not only for roof. During the 20 years, also put solar vertical service. Just a centralised system is not practical.”		Technical adaptability of solar technologies to buildings roofs and vertical facades
	Yi Jiang: “ [I]n these kind of rural places [...] you go there is water heating system, the problem is [that is] not good. Air-to-air heat pump, air-to-air means hot air instead of hot water, then when you turn on they only need one quarter, the room can be warm, [and] when you turn off the room will be cool fast.”	Poor technology quality	
	Yi Jiang: ““[H]ere during the winter, you can find some of the buildings inside [are] overheated and then people open the windows, because it's the only way for them to get cool and then lots of lost energy, but we still do the district heating”	Overheating in urban buildings and window opening behaviour	
	Hongxia Duan: “for the residents in rural regions, actually, they have the right to build their own house, which means they have the right to choose what type of energy to use, but for urban region[s] people don’t have choice, whatever they provide, they just use it, even if they are willing to [pay for renewables], you know, they want to use. I think that’s one important barrier at the moment.”	Urban residents have no o choice nor control over energy consumption in urban areas	
	Aart De Geus: “Doesn’t mean anything if it's cold or not, but it [urban central district heating] is turned on and off.”		
	Derek Cowburn: “[In rural areas] you have lower buildings, lower buildings means that you’ve much more rooftop surface area and you can have solar and batteries probably, distributed energy is great you know. In the city we have a different application [...] but we can improve the efficiency of each one of the units inside and we can maximise the effectiveness of a battery storage system.”		Rural residents have choice over the building design and energy consumption Distributed solar potential in rural areas
	Derek Cowburn: “The next level of efficiency gains is probably coming from system-level efficiency, where all these		

	devices can talk to each other and share information about occupancy, so you're actually spending the energy only when it's needed. So this is where the whole explosion of the IoT, Internet of Things, it's coming from in building technologies.”		Emerging Internet of Things to increase energy efficiency of building equipment in urban areas
Economy	Yi Jiang: “Because when you’re getting rich, the first thing is not doing the insulation, but to do more heating, you see. So then energy use is high.” Yi Jiang: “But the income increased, and people also want to have better comfort [...] the energy use is getting higher.” Rokia Raslan: “[W]e did found issues with the supply chain and the cost of installation.” Lin Weibin: “[T]he residential electricity is the cheapest. So the solar PV in the household is not competitive. [...] in the future, China will install more wind electricity plant, or solar PV, it will depends if you can get the market, and finally it depends on the costs, price, have the competitive, even cheaper than fossil [...] so no need to give subsidies to renewable energy.”	Higher energy consumption and demand for comfort with higher income High installations up-front costs Cost disadvantage of solar energy compared to electricity	Market-orientation and cost competitiveness as solar installations increase
Culture	Yi Jiang: “For the rich family, because they think this only saves some energy, doesn’t matter, I can use electricity anytime.” Yi Jiang: “In China is very low energy intensity. Not because we have high energy efficiency. But because the Chinese people have different behaviour to the use of the building, we have different culture to run the building, that’s most important.” Yi Jiang: “Maintain, maintain the traditional human behaviour [...] here it’s relatively good, people still save a… we call it green lifestyle.”	Energy-consuming behaviour of higher-income households	Traditional energy-saving behaviour (green lifestyle of people)

	"Aart De Geus: "[A]ffordability is an issue, although I think it is less important than everybody thinks [...] Solar panel investment is now [...] a matter of priority more or less. [...] Consumers do not always think about payback time"		Investment in solar installations is a matter of consumers' priority
Institutions	Yi Jiang: "And now with the central system [...] this kind of system in most cases in China doesn't save energy, this is what happened after this policy standards and regulation."	Inefficiencies of the central system	
	Yi Jiang: "What happened to the manufacturers? They learnt that and regardless the terrible quality of the product, as long as the water comes and they comply with regulations. Then what happened? The whole industry, at the beginning continue to go up, then they go down, the quality go poor, and then they customers got problem."	Quality and maintenance issues	
	Yi Jiang: "Financial subsidy, that's not good. Because, if the government have too many subsidies [it] change the market, that's not good."	Market distortion due to government subsidies	
	Yi Jiang: "[This] means [that] even if they go wrong, doesn't matter, the government gave [subsidies to] me. So never make good maintenance."		
	Yi Jiang: "[T]he government is very very keen to energy efficiency, lot of regulation, people have better insulation and so and so… The efficiency [is] getting very high, and in the rural, the government has not put many things there, so the insulation is poor, then building insulation is poor, and maybe efficiency is poor."		
	Yi Jiang: "In this story, the government really wanted to do something better, but they did not really understand the market, and they choose something wrong, the regulation is not correct."	Lack of understanding of the market	
	Rokia Raslan: "[The study was] looking at something called 'unintended consequences' [...] looking at the introduction of standards that specifically		Improve health and well-being while adopting new energy sources

	focus not just on energy or on the building itself, but on creating an environment that supports health and well-being. [...] ”		
	Engineer Manager: “The first [key action] is to communicate with residents and get feedbacks. [...] If we make it green, we definitely promote it to our buyers.”		Emerging concept of green building in energy codes and evaluation standards
	Hongxia Duan: “They just want to use [electricity], but they don't want to know [from which sources it is supplied]. [T]here is no information.”	Lacking of information and awareness	
	Hongxia Duan: “[G]iving them [urban resident] flyers or when they have to pay their bills [...] I think this would be very helpful for consumers to understand renewables. And I think [it] could encourage to use more, if the renewables and traditional energy are at the same price.”		Increasing information and marketing on green buildings targeting consumers
	Aart De Geus: “[T]hings like reliability are very important and that’s also something to do with the young industry”	Reliability issues	
	Engineer Manager: “In [marketing] promotion, we select some key points. For some points even if you tell the buyers, they will not care. The buyers are more concerned with windows and doors, [building] solar system, those are more visible things. For example, we can tell the buyers we use the same floor drainage system, which has functions like sound isolation and energy conservation. [...] Surely energy conservation means more than that, but those are the target concerns of our buyers. If we tell the buyers about land saving, energy saving and environment protection, the buyers will not understand us and, thus, not recognize it.”		Marketing promotion
	Engineer Manager: “Buyers are more concerned with comfort. Location is part of it. There also others [concerns] like the value of the house, the aesthetic consideration, for example high class and luxurious decoration, most of them	A combination of demand and supply factors	

	have nothing to do with the green housing concept and energy saving. But I just referred to the equipment inside the building that relates to the green construction concept. But them [house owners/buyers] only think of them [indoor decoration and equipment] to showcase the house value. They believe that the [expensive] price reflects the house equipment." Human Resource Manager: "[M]aybe 70% of our residential apartment is roughcast. If you buy a residential apartment, you have to decorate it by yourself. I think that kind of apartment doesn't count as green building [...] We only apply fine decoration on high-end residential projects). It depends on the market." Hongxia Duan: "Because right now there are [a] lot of options, depends on the technology [...] The consumers, you know, their demand as well as the technology available." Hongxia Duan: "[I]f the renewable energy provider, their costs [are] so high, in a way, they're going to pass all the high cost to consumer, if the cost of generation is low I think somehow this benefits the consumer because the price would be down. In this way, consumers pay less the bill [...]. From the consumers perspectives, they would like to pay less for the bill, for the electricity consumption." Hongxia Duan: "If I want to consume more green electricity, but if the utility companies they don't provide such kind of product, how resident could use green products? That's the key issue."		
	Rokia Raslan: " I think that the standards are moving in the right direction, guided by a lot of work that's been done elsewhere. [...] They have the benefits of learning from the mistakes that have been made abroad, in Western economies."		Policy-makers commitment and political support to sustainability targets
	Derek Cowburn: "[B]ecause the way		Leapfrogging by

	China fixes its problems is that they let the old one just deteriorate, they get rid of the recycling and they just build a new one. They're incredibly efficient in building things. [...] And when they do that, they make a giant step change in technology”		learning from other countries experience
	Lin Weibin: “[T]he government wants to deregulate the energy price, it will be more market-oriented. This was the first difference [between the 13th FYP with previous programmes]. And the second different point is the government try to internalise the external cost, we call it the social cost, of fossil fuels. Especially the coal. [...] Through the institutional reform of electricity, oil and gas.”		Deregulation of prices and market-orientation
	Lin Weibin: “ They [policy-makers] want to help the lower income groups. But accordingly to the subsidy policy, who will get more benefit is not the low income groups, because the lower income groups are the lower consumers, [they] consume less. I think if the government wants to help the lower income groups, the best way is give the money to the household, but right know they give subsidies to the gas company, okay? [It] is not [a] good way.”		Internalisation of negative externalities (social costs) into fossil fuels prices
	Hongxia Duan: “You need to come up with some innovative business models, a huge amount of subsidies from the central government or local government would not be the long-term solution for scaling-up the renewable in rural regions, [someone] need to come up with good business models.”		Potential for business ideas and technologies in the Chinese domestic market
	Hongxia Duan: “According to policy, foreign investors [...] technically, they’re very welcome to invest in infrastructure and the green products for the domestic market. But [...] not sure how these good ideas could be translated into practice.”		
	Derek Cowburn: “I think that’s a great testament to what’s the value they see in the technology and we’ve been drawn into a lot of groups that want to bring the technology to China, they’ve seen the demonstrations we did last year.”		Opportunities for cutting-edge technologies in the domestic market to bridge demonstration-practice gap

Socio-technical regime	Aart De Geus: “One of the issues in China is that it always goes very rapidly in construction, [...] And therefore it looks like there's less time in thorough preparation of a plan.” Aart De Geus: “The maintenance in China is a very strange issue [...] the first year is all fine, then the second year you see some deterioration already occurring, and the third year you think they should have some maintenance, but they’re not… It’s not in their mind-set I think.”	Lacking of long-term planning Lacking of the maintenance and durability of technology and infrastructure mind-set	
Fragmented energy-related political and market entities	Yi Jiang: “[T]he government is very powerful, but still a lot of difficulty. On the local level you need to coordinate with many many people on all decisions. And each part have their own interests.” Yi Jiang: “[O]ne of the problems is that we haven’t found who should take this, then this can be better. If there’s too many people that take the responsibility, then it’s not good.” Rokia Raslan: “[I]n the UK, specifically looking at solar wall insulation and like you said, we looked at the supply chains and we look at different stakeholders and actors from manufacturers to distributors to installers. We found that, there is quite a fragmented supply chain, and I can imagine that it is the same for a lot of new renewable technologies.” Aart De Geus: “[Training facilities, even agencies equipped to provide information [...] That part of the infrastructure is under development, to put it nicely.”	Fragmentation of agencies, departments and responsibilities	