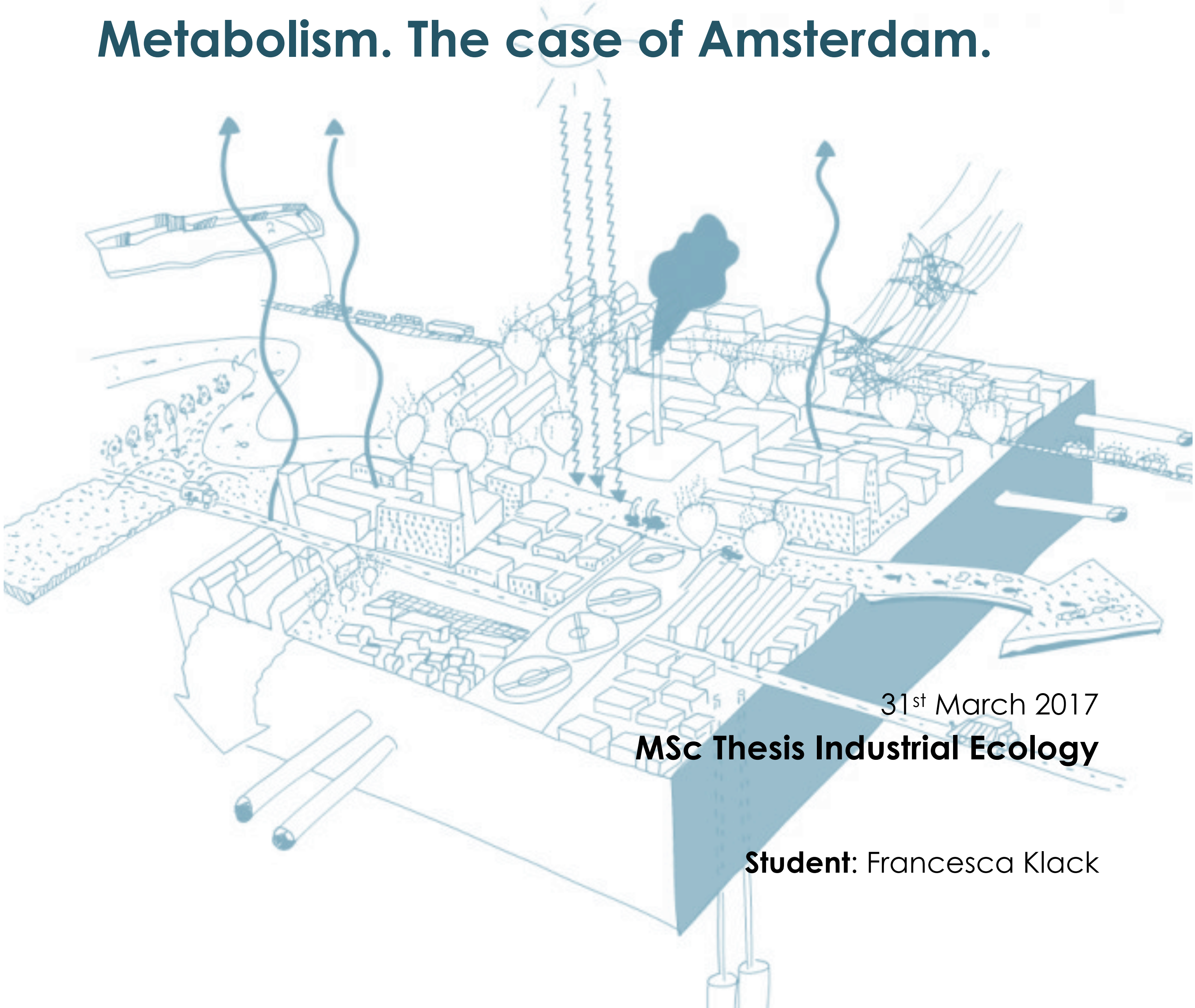
WHAT DECISION-MAKERS WANT?

The Influence Of Key-decision-makers' Preferences On Urban Energy Metabolism. The case of Amsterdam.



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MSc Thesis Industrial Ecology

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INDUSTRIAL ECOLOGY A SYSTEMIC APPROACH TO SUSTAINABLE DEVELOPMENT

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Executive Summary

Increasing trends in urbanization and population growth (Arrobbio & Padovan, 2016; Nations, 2015), large availability of cheap energy sources and the great energy consumption of cities have contributed to the "*frequency and magnitude of ecological, economic and social shocks encountered by today's urban environments.*" (van Timmeren et al., 2015). Acknowledging the burden brought by cities (i.e. 75%) on the overall energy consumption, and the fact that the urban energy metabolism is strongly influenced by the socio-technical system and the networks of decision-makers involved represent the problem scope that this thesis is investigating. The metabolic perspective has been used to analyse this phenomena as a complex system. In particular we looked into the multiple nodes of decision-making, where several networks of actors actively make decisions that influence the overall urban energy metabolism. Among the nodes of decision-making, the ones composed by key-decision-makers constitute the focus of our research. These key-decision-makers, according to their roles and individual preferences, exert a direct influence on the energy metabolism, but currently there is a lack of knowledge in this regard, even though their influence is recognised as an important driver of the energy system (Baccini and Brunner, 2012; Broto et al., 2012; Newell and Cousins, 2014; Swyngedouw, 2006; Zhang, 2013).

Through a case study research and the use of Choice modelling, the preferences of key-decision-makers involved in an urban energy metabolism, more specifically in relation to the built environment, have been hereby investigated; in order to gather insights on the impact and relevance they have on such energy metabolism. Furthermore a methodological investigation is proposed to strengthen the results of the main research. The combination of Choice modelling and Agent-based Modelling is suggested and conceptually established through the MAIA framework. In order to perform our analysis we decided to focus on the city of Amsterdam as a case study.

From our investigation we were able to identify 7 Nodes of Energy Requirements and 6 Nodes of Decision-making. Afterwards we developed a Choice experiment, through which we explored the preferences of a sample of key-decision-makers (from the 6 Nodes of Decision-making) when asked to choose among a set of technological systems to be implemented to reduce the energy consumption in the Built Environment. The results of our Choice Model showed that the aspect that is taken into account the most, by key-decision-makers, in such decisional-contexts, is the difficulty of implementation. Meaning that the more a technological system's implementation is perceived as arduous the less likely is to be chosen and therefore implemented. Other two decisive aspects are the amount of energy savings theoretically brought by the technological system and finally the implementation cost, to be undertaken by the municipality through subsidies. The societal and environmental implications are broad and are reflected by the resulting energy metabolism: important influence, as that key-decision-makers exert, is directed toward minor implementations not disruptive nor drastic which do not prioritize and aggressively address the reduction of energy consumption.
Afterwards, we suggest and conceptualize the combination of CM and ABM through the 5 structures of MAIA framework. Our conceptual model is a simplistic version of the urban energy metabolism, aiming at capturing the interaction dynamics between the key-decision-makers and the energy system. These dynamics are studied mostly through the conceptualization of a discussion's situation among key-decision-makers happening in response to excesses of energy consumption in the energy metabolism. The decision-making criterion used by the key-decision-makers is given by the results of the Choice Model.

Acknowledgment

I would like to take the opportunity to express my sincere gratitude to all the people who helped, guided and supported me throughout the development of this thesis.

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Pr.dr. Ellen van Bueren, for taking the time to meet and discuss my progress; for helping me in connecting with the City-zen project; and mostly for being the critical and attentive guidance I needed in order to not get ahead of myself and keep my scope and goals manageable and therefore valuable.
Finally PhD Yashar Araghi, for the essential mentoring through the interesting Choice Modelling world; for always taking the time, out of his own research, to meet and help me moving forward; for the guidance through software and coding unfamiliar to me; for believing in my research and asking me the questions about it and about my future plans that helped me to put the whole research into a larger perspective.

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Francesca Klack, March 2017

Table of Content

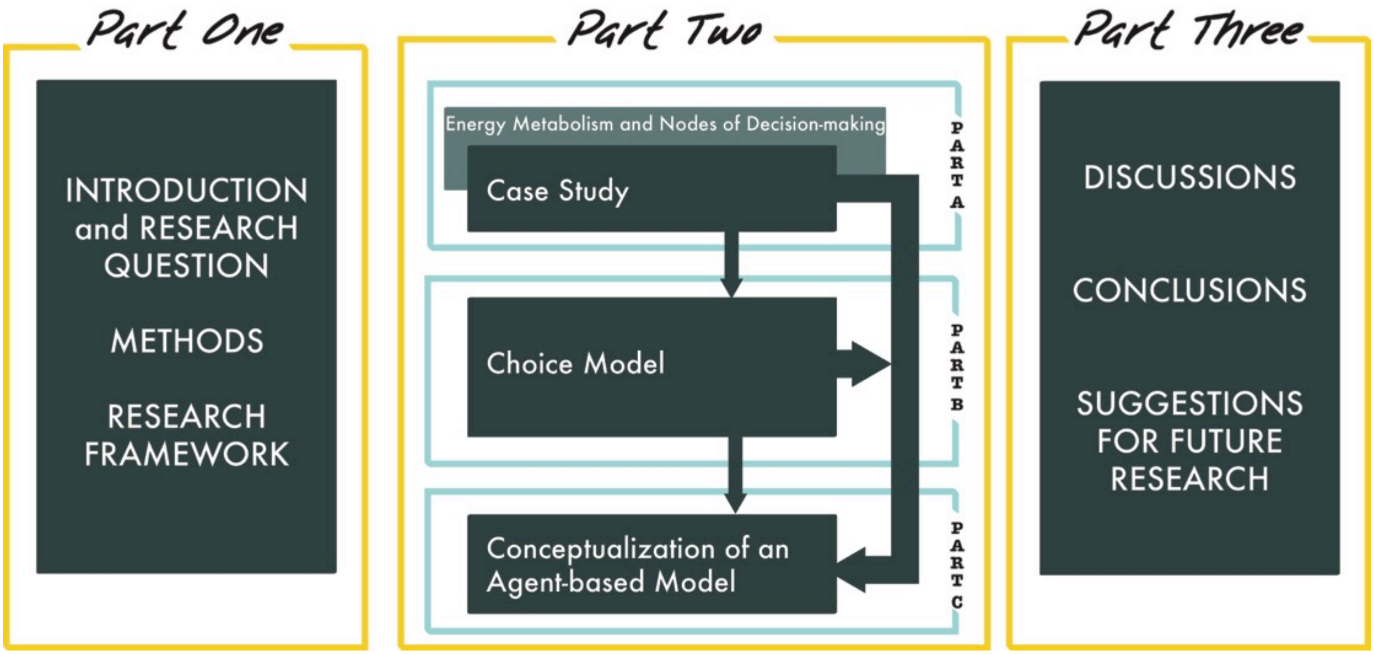
List of Abbreviations

ABM	= Agent – based modelling
AMA	= Amsterdam Metropolitan Area
AMS	= (Amsterdam research centre for) Advanced Metropolitan Solutions
CM	= Choice Modelling
ETS	= Emission Trading System
GHG	= Green House Gas
IAD	= Institutional Analysis and Development (framework)
IE	= Industrial Ecology
IO	= Input-Output
LCA	= Life Cycle Assessment
MAIA	= Modelling Agent systems based on Institutional Analysis (framework)
MEFA	= Material and Energy Flow Accounting
MFA	= Material Flow Analysis
MNL	= Multinomial Logit
MRA	= Metropoolregio Amsterdam
OECD	= Organization for Economic Cooperation and Development
PE	= Political Ecology
RUT	= Random Utility Theory
SER	= Social and Economic Council of The Netherlands
SFA	= Substance Flow Analysis
UM	= Urban Metabolism

List of Figures

List of Tables

Thesis Overview



PART ONE

Chapter 1
INTRODUCTION

1.1 Problem Definition and Research Scope

The constant growth in population, and the connected growth in urbanization (Nations, 2015) result in higher and higher environmental impacts linked to urban areas such as resource exploitation, climate change, bio-diversity loss (Arrobbio and Padovan, 2016; Blok et al., 2015; van Timmeren et al., 2015). **Cities are completely relying on energy supply and energy-technologies** fuelling every single activity happening within them (Arrobbio and Padovan, 2016; Blok et al., 2015; Fath et al., 2010), and energy supply only is accounted for 26% of global GHG emissions (UN HABITAT, 2011). Furthermore, the urban energy consumption is currently responsible for 75% of the global energy consumption (Arrobbio and Padovan, 2016). Within the urban energy consumption, households are accounted for 23%, and considering the total built environment (including non-residential sector and excluding industry) this value rises to 34% (Blok et al., 2015).

Another way to look at the urban environments is considering the magnitude of the impacts of cities as equal to the magnitude of the **potential** connected to them. Cities can, in fact, be seen as **drivers of environmental change** (Arrobbio and Padovan, 2016). In 2014 United Nations report, trends in urbanization are connected with sustainable development. It is highlighted the fundamental role *played* by urbanization either in fostering or impeding a sustainable development:

> *"With good planning and governance, the increasing concentration of people in urban settlements can facilitate economic and social development, while also offering opportunities to mitigate the adverse impact of consumption and production on the environment. However, rapid and unplanned urban growth threatens sustainable development when the necessary infrastructure is not developed or when policies are not implemented to protect the environment and ensure that the benefits of city life are equitably shared."* (United Nations, 2015, p. 1).

Therefore in the current research we specifically look into the **urban energy system**, in this context declined as **Energy Metabolism** since we adopted a metabolic perspective, more specifically into their potential represented by 'good planning and governance', which Key-decision-makers embody.

In particular, considering the variety of elements included into an urban energy system we narrowed down our scope onto a focal and fundamental element for the development of a sustainable energy system: the energy requirements in **the built environment** and the **energy saving** potential held within it (Lauwers et al., 2011; SER, 2013; Municipality of Amsterdam, 2015a; "City-zen Objectives," 2016). This focus incorporates a sufficient level of complexity, which reflects the greater complexity of the overall UM perspective.

1.1.1 The metabolic perspective and the Nodes of decision-making

The metabolic perspective is based on the concept of Urban Metabolism (UM), which provides a suitable method to understand the organization of cities, and to measure the magnitude of its energetic flows (Kennedy, 2007). UM is "*a multi-disciplinary and integrated platform that examines material and energy flows in cities as complex systems as they are shaped by various social, economic and environmental forces*" (Arrobbio and Padovan, 2016). For the interested reader a thorough investigation of the UM and Energy Metabolism concepts, implications and literature can be found respectively in Appendix A and B. The most important aspect of the metabolic perspective, for our research, is that it takes into account **multiple nodes of decision-making** at multiple levels (political, urban planning, resource management, mobility, building, service), **where different networks of actors actively make decisions that influence the overall urban metabolism**. There are several types of decision-making nodes and consequently there are several types of decision-makers. Within this broad variety we decided to investigate a specific type, here named key-decision-makers, because of their strong influential role.

1.1.2 Key-decision-makers

With key-decision makers are intended all those actors with knowledge and influence over a big portion of the system. The strength and effectiveness of their choices are here considered as greater than that of the general community since they have effects not only on him/herself but also on a bigger group; and they can define the alternatives the general collective can choose among, especially in social, political and economical systems that are, still, mainly traditional and where, therefore, the decision-making processes are mostly top-down. It is possible to identify these actors as: managers and CEO, architects and designers, building contractors, aldermen, urban planners and policy makers, etc. In general, they all make top-down decisions about energy projects that may lead to deep impacts on the overall metabolism of the city.

1.1.3 Research gap

There are two research gaps this thesis is trying to address, one theoretical and one methodological. The **theoretical gap** concerns the way UM and Energy metabolism have been studied so far. Several studies about UM (Baccini and Brunner, 2012; Broto et al., 2012; Newell and Cousins, 2014; Savini et al., 2015; Swyngedouw, 2006; Zhang, 2013) highlighted the important role of key-nodes of decision-making as drivers of the energy flows within the urban ecosystems as well as potential drivers for urban system's innovation. Nevertheless the large majority of the literature reviewed (Baccini et al., 1993; Baccini and Brunner, 2012; Decker et al., 2000; Kennedy et al., 2007; Kennedy and Hoornweg, 2012; Balogh et al., 2014; Fath et al., 2010; Kuznecova et al., 2014; Zhang et al., 2014) focuses mostly on the quantification of the material and energy flows. So there is yet **no literature** looking into the **influence** that the decision-making behaviours of the **key-nodes of decision-making exert** in shaping the emerging energy system. A more thorough description of the literature reviewed can be found in Appendix A and B.

The **methodological gap**, which is an addition to the theoretical gap, concerns the current approach to the study of decision-making processes and decision-makers in urban contexts. They are, in fact, mostly studied as static elements (Chorus, 2015; Chorus et al., 2011). Instead it is of high importance, when using a metabolic perspective in particular, to consider them as dynamic elements and therefore study the interaction dynamics between decision-makers' choice outcomes and the urban environment they are part of. Therefore, considering the current **knowledge gaps,** this thesis is intended to be an **explorative research** combining different concepts (UM, Energy metabolism, Energy efficiency) while focusing on specific areas within them (Decision-making process, Key-decision-makers) that have been investigated the least, and suggesting a methodological approach to study the interaction dynamics between them (combination of CM and ABM).

In conclusion, considering all these aspects, this research intends to provide an overview of the energy metabolism and its nodes of decision-making while analysing the influence dynamics between them.

1.2 Research Goal

According to the previously defined research problem and scope, the research goal of this master thesis is to investigate how the actors that are part of the key-nodes of decision-making (defined as **key-decision-makers**) make decisions concerning the **implementation of energy savings measures in the Built Environment** that could affect the whole Urban Energy Metabolism. In particular we will do so by investigating the **preferences** of key-decision-makers.

1.3 Research Question

In order to guide the research the following question has been formulated:

> **How do key-decision-makers' preferences interplay with the Urban Energy Metabolism considering the energy consumption in the Built Environment?**

In order to provide and answer to the research question and to guide the research, four sub-questions have been formulated.

1) **What are the components, characteristics and boundaries of an urban energy metabolism?**
2) **Who are the key-decision-makers involved in the urban energy metabolism?**
3) **What are the preferences of the different key-decision-makers involved in the urban energy system?**
4) **How can the interactions dynamics between key-decision-makers' preferences and the energy system be observed?**

In order to be able to investigate in depth the urban energy metabolism and the decision-making processes of the actors involved, a **specific urban context** and an **energy-related area** have been selected as a case study, the municipality of **Amsterdam and the Energy consumption in the Built Environment**.

1.4 Research Approach

The approach that is undertaken in this thesis in order to answer to the main research question is here introduced.

Through desk research we will firstly investigate the selected case study, Amsterdam' energy system, in order to highlight its features and define characteristics and components of an urban energy metabolism; but especially to identify the key-decision-makers involved. Even though we make use of a case study, the exploration developed throughout this thesis has the potential to be applied to many other Urban Environments.

The preferences of the different key-decision-makers will be investigated and modelled through Discrete Choice Modelling. Furthermore, in combination with the results of the Choice Model, a conceptual agent-based model will be developed through MAIA framework, to give more insights on the influence key-decision-makers and their choice preferences exert on the urban energy metabolism.

1.4.1 Methodological Combination

Through ABM a complex adaptive system such as Amsterdam's energy metabolism can be modelled and the **dynamism of the nodes of decision-making** and their **influence on the energy system** can be observed. The agents in the model represent the decision-makers in real life embedded in an environment, Amsterdam's energy system, within which they execute different actions, enact roles, make choices and interact with other agents. From an ABM simulation, patterns and emergent behaviours can be observed and analysed (Bonabeau, 2002; van Dam et al., 2013). More specifically the **influence dynamics and the interplay between key-decision-makers**, considering their preferences, and the energy system can be captured; direct implications of **key-decision-makers' influence on the energy metabolism** could be also observed. Therefore we consider appropriate and important including, as part of our research, a **conceptualization of the combination of the Choice Model's result within an Agent-Based Model**. The implementation of the model is, however, outside of the scope of this thesis.

This methodological combination consists mostly in using results from the choice experiment to model the behaviour of the agents within the ABM. For this specific research this translates in defining the parameters describing agents' characteristics and preferences, and other environmental components, using the Choice Model's results.

Another benefit of this combination is that it provides for a level of uncertainty connected to ABM. In fact, using real-life data resulted from the choice experiment to model the individuals' parameters gives a realistic value to the assumptions made to model agents' behaviour. The combination of the two modelling tools have been already applied by several authors (Brown, 2013; Cui et al., 2010; Dia, 2002; Vag, 2007) successfully, demonstrating the feasibility and potential of this combination.

Chapter 2
METHODOLOGICAL APPROACH

In this chapter we present the methodological approach chosen to fulfil the research goal. We do so by firstly presenting and explaining the methods and frameworks chosen. Afterwards we introduce and explain the actual Research Framework, in particular by firstly presenting a list of all the steps taken during the research, in chronological order, and finally by individually describing the three components (Part A, Part B, Part C) of the Research Framework.

2.1 Methods

In this section the methods and approaches chosen for this thesis are explored and theoretically explained.

2.1.1 Choice Modelling

The basic concept behind Choice Modelling (CM) is that individuals have preferences that influence their decisions and the outcomes of their choices.
Choice modelling is a methodological approach aiming at studying how individuals make choices, more specifically what are their preferences, through quantitative statistical methods (Henser et al., 2005). A suitable definition is given by Devinney and Lin (2011):

> *"Choice modelling is a popular stated preference method used for understanding stated choice among discrete alternatives. A choice study uses experimental designs to create sets of alternatives that vary in their attributes and features and that statistically model the choices made and not made to yield measures of the relative importance of each attribute."* (Devinney and Lin, 2011, p. 1)

The first step to identify and study relevant choices is to assess the range of options, named *alternatives*, among which the individuals can choose. Consequently, for each alternative the important characteristics, named *attributes*, that distinguish one another have to be listed and defined. Attributes have different *levels* that describe the different values they can assume (Henser et al., 2005). Once the alternatives, attributes and attributes levels have been defined, different *choice sets* have to be created through the "*systematic factorial manipulation of independent variables*" (Devinney and Lin, 2011) done by a specific software, which creates specific combinations of the attributes levels for each alternative, using a statistical logic (MNL, or Multinomial Nested Logit) and specific mathematical designs (Orthogonal, Full-factorial, …) so to make sure that all the possible combinations are compared.
These being the basis of the design of the choice experiment, two principal sets of data might derive: *revealed preference* and *stated preference* data. The first consider choices already made in real situations while the latter consider choices to be made in hypothetical situations. In this research the stated preference dataset has been chosen and it will be obtained through the choice modelling experiment. This meaning that actors

are approached, through a questionnaire and through interviews, with choice alternatives, describing hypothetical situations. Their choices are then statistically analysed in order to find the utility value linked to the different attributes of each alternative, and consequently give information about their choice preferences. This dataset has been preferred because it allows taking into account technological solutions that have not been implemented yet as different alternatives, and to investigate which features of new or existing solutions for the energy system play a major role in the decision-making process.

The CM method is based on the statistical concept of utility and the utility function, which both have their basis in microeconomic theory (Louviere et al., 2000). A more in-depth description is given in the following section.

2.1.1.1 Random Utility Theory

> *"Discrete choice models assume that the probability of an individual choosing a given option from a finite set of alternatives is a function of the context variables and the relative attractiveness of the option under consideration. The attractiveness of the alternatives is described and quantified by a utility function which individuals typically seek to maximise. To determine if an alternative will be chosen, the value of its utility is compared with the utility of the alternative options and transformed into a probability value between 0 and 1."* (Dia, 2002, p. 342)

The random utility theory is the conceptual heart of Choice modelling and has its basis on the microeconomic theory that states that individuals, when facing different choice alternatives, will supposedly choose the one that provides the highest utility (Devinney and Lin, 2011; Henser et al., 2005). The assumption that the decision-makers act trying to maximise their level of satisfaction is also referred to as the rule of 'utility maximising behaviour' (Henser et al., 2005). From this concept it is derived the utility function:

$$U_i = V_i + \varepsilon_i$$

Where U is the total Utility associated with alternative i, V is the observable contribution to the utility, and ε is the random or unobserved contribution. The same function has to be repeated for each alternative in the choice sets.
Considering that the variable V is where the set of attributes are included, the same function can be rewritten in the following form:

$$U_i = \beta_{0i} + \beta_{1i} f(X_{1i}) + \beta_{2i} f(X_{2i}) + \beta_{3i} f(X_{3i}) + \cdots + \beta_{ki} f(X_{ki}) + \varepsilon_i$$

Where β_{0i} is a parameter named the alternative-specific constant and it is not related to any of the observed attributes, and β_{1i} is the weight (or coefficient) to be estimated for attribute X_1 and alternative i. The attributes not included in the part of the function with the observed contributions, are, by definition, included in the unobserved contribution parameter and are considered to be of equal impact for each alternative.
This expression also represents the functional form used to individuate utility with a multinomial logit model.

2.1.1.2 Multinomial Logit Model

Multinomial Logit (MNL) is a regression model that is used when the dependent variable under inquiry is a nominal (and therefore unordered) variable (e.g. energy-policy choices), and to predict the probabilities of different possible outcomes (more than 2), which are the dependent variables, given a set of independent variables (attributes and attributes levels). MNL models can be *standard or conditional* according to whether the explanatory variables (or independent variables or attributes) vary across individuals but not across choices (standard MNL) or whether they vary also across choices (conditional MNL).

In the MNL choice model the probability that an individual q will choose the alternative i can be written as:

$$P_{iq} = exp(V_{iq}) \Big/ \sum_{j=1}^{J} exp(V_{jq})$$

where V_{jq} is the linear function describing the utility of the *jth* alternative, and it can be written as:

$$V_{jq} = \sum_{k=1}^{K} \beta_{jk} X_{jkq}$$

2.1.2 Agent-based Model

The agent-based perspective is grounded on the complex adaptive systems approach (van Dam et al., 2013). A complex adaptive system, as defined by John H. Holland (retrieved from van Dam et al., 2013) is:

> *"[…] a dynamic network of many agents (which may represents cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a complex adaptive system tends to be highly dispersed and decentralised. If there is to be any coherent behaviour in the system, it has to arise from competition and cooperation among the agents themselves. The overall behaviour of the system is the result of a huge number of decisions made every moment by many individual agents."* (van Dam et al., 2013, p. 44)

Through ABM a complex adaptive system such as Amsterdam's energy metabolism can be observed and modelled.

From an ABM simulation, patterns and emergent behaviours can be observed. Through this approach the system as a whole is analysed (holistic approach), acknowledging that a system can not be reduced to the sum of its components because of the significance of the interactions that occur among them (Bonabeau, 2002; van Dam et al., 2013). Therefore the scope of agent-based models is to create a software representation of certain concepts, entities, actions, interactions, and mechanisms of a system and to observe how the system and its components act and react to the internal and external dynamic conditions, as well as to explore the possible states of the system (van Dam et al., 2013).

Looking at the overview of the structure of an ABM, shown in figure 2.1, we can clearly see that there are two main components: the Agents, which have States and behavioural Rules, and the Environment.

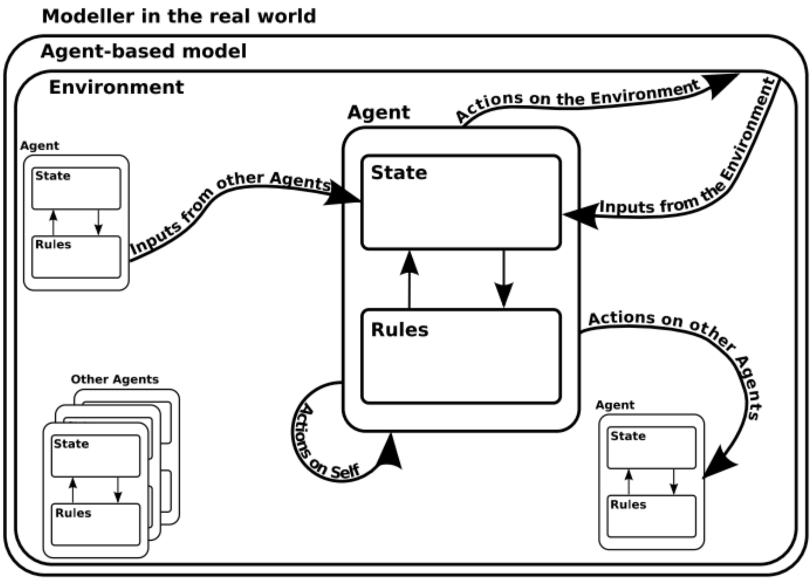


Figure 2.1 _ Structure of an Agent-based Model (van Dam et al., 2013)

The Agent

An Agent constitutes the basic entity of an ABM, it might follow rules that determine its behaviours, actions and decisions. It has a state constantly prone to changes according to its behaviours, to the different inputs it can receive from the environment, within which it exists, from its own past actions and from the interactions with other agents.

The Environment

The Environment represents the "world" where agents, and everything else in the model are situated and can interact with each other. Such environment provides a structure, either static or dynamic, and all the information that is required and useful for the agents.

These two concepts, Agent, with its states, rules and actions, and Environment, with its structure and information, represent the basis of an ABM. To guide the modeller through the modelling process Nikolic et al. (van Dam et al., 2013) divide the totality of the design process in 10 practical steps. These steps are further grouped into three main stages: **Conceptualization, Implementation,** and **Experimentation**. The first, Conceptualization, represents the fundament and heart of the whole modelling process. Ghorbani (2013) proposes a framework to guide the conceptualization of agent-based social simulation, based on Ostrom's IAD framework (figure 2.2) and on the practice of developing meta-models largely used in computer science, named MAIA. Both these frameworks will be presented later in the chapter.
The steps within the Conceptualization stage, proposed by Nikolic et al. (van Dam et al., 2013) are included in Appendix C. The MAIA framework is introduced in the following section, since it has been chosen to investigate the methodological combination of CM and ABM. MAIA constitutes a suitable bridge between the two methodologies. This methodological exploration is tackled in the last part of the thesis and it represents a methodological add-on to the main research question.

2.1.2.1 The MAIA framework

MAIA framework was developed by Ghorbani (2013) to firstly guide and help social scientists or researchers unfamiliar with programming, in developing Agent-based simulation Models that incorporates institutions and roles.
MAIA, acronym that stands for Modelling Agent systems based on Institutional Analysis, is grounded on Ostrom's IAD (Institutional Analysis and Development) framework, on the practice of developing meta-models largely used in computer science, and on the assumptions that in every social system interactions take place within institutional structures and, contrarily to individual behaviours, social institutions and rules can be elicit and captured my the modeller more easily.

IAD framework

Institutional Analysis and Development (IAD) framework, proposed by Ostrom et al (1994) and being developed and tested for over 30 years, is an institution-driven tool, and it is shown in figure 2.2.

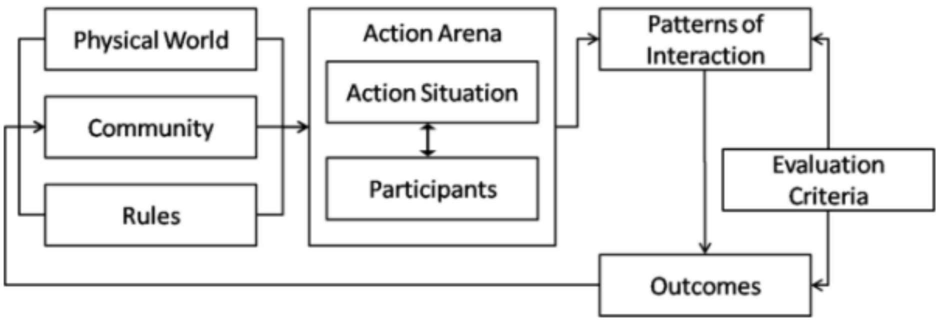


Figure 2.2 _ The IAD framework (Ostrom et al. 1994)

On the left-hand side are depicted the elements underlying a social system: institutions but also the material resources, used and produced, which compose the physical world. These elements influence actors' behaviours that are held in the operational environment, in the centre, named the action arena. On the left-hand side the patterns of interaction and the outcomes are observed according to an established set of evaluation criteria.

MAIA meta-model and its components

Grounded on the IAD framework and the institutional theory behind, MAIA's meta-model is organised in 5 structures where are included the related concepts (Ghorbani et al., 2013). The overall framework is shown in Appendix D.
The 5 structures are:

1) Collective Structures
2) Constitutional Structure
3) Physical Structure
4) Operational Structure
5) Evaluative Structure

In the following sections these are individually illustrated and briefly explained referring the keen reader to further readings (Ghorbani, 2013; Ghorbani et al., 2013; Ghorbani et al., 2015; Verhoog et al., 2016).

The Collective Structure

In the collective structure are represented actors (*agents*) and their attributes. Agents can be *individuals* or *composite agents*, where the second stand for a collection of individual agents that are associated with similar agents, like a company, a party or a family (Ghorbani et al., 2013; Yeh et al., 2008). In this structure the agents are described independently from the role they have in society. Instead here the important aspects are their attributes, personal characteristics and properties such as: gender, age, personal values, belongings, information, intrinsic behaviours, beliefs and so on. According to the system that is being analysed and the model requirements different attributes and properties will be taken into consideration. A zoom-in from the overall diagram on the Collective Structure is presented in figure 2.3.

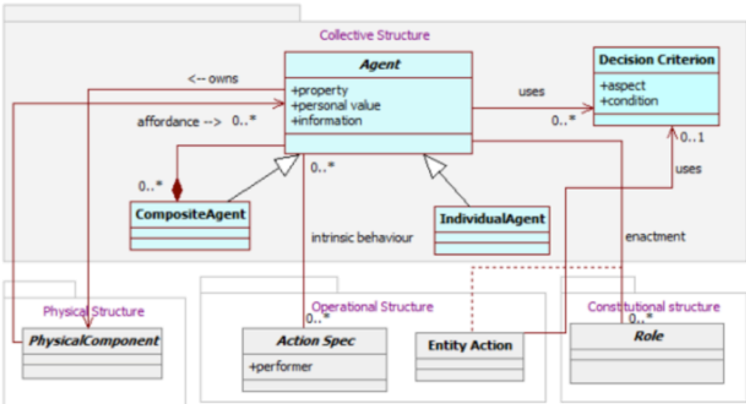


Figure 2.3 _ The Collective Structure in MAIA (Ghorbani et al., 2013).

The Constitutional Structure

In the Constitutional Structure is represented the social context and we see agents as part of the society in which they enact roles. For each role there are specific entry conditions (requisites) to be met, objectives to be carried out, a set of actions that can be performed according to some rules; all these elements form the institutional settings defined and described by the role. A single agent can perform multiple roles, provided that the entry conditions are met, and multiple agents can take the same role. When an agent assumes a role certain capabilities become available to them.

In order to fulfil their objectives, agents, enacting a *Role*, perform actions and interact with other agents in different roles. It can be stated that every role depends on other roles, and this role dependency is the basis of the relationships among agents. The same deduction can be made considering that each role is driven by the fulfilment of an objective; and therefore this *objective dependency* reveal the principle according to which the relationships among agents are initiated by the specific institutional settings.

A higher set of rules governing the interactions and behaviours of roles-enacting agents is hereby necessary. This set of rules is here defined as *Institutional Statements* and are expressed using the ADICO syntax (for further readings on this topic refer to Crawford and Ostrom, 1995; Ghorbani, 2013). "*The acronym ADICO refers to the five elements that an institutional statement can comprise: Attributes (the designated roles), Deontic (prohibition, obligation, permission), aIm, Condition (for the institution to hold), and 'Or else*'" (Ghorbani et al., 2013, p. 11).

Based on Crawford and Ostrom (1995) three types of Institutional Statements are defined:

1) **Rules**. These are statements that contain all the 5 ADICO components; for instance 'A police agent may not shoot if the incriminated subject is disarmed or else he/she will be removed from the job and taken to trial'.
2) **Norms**. These are statements when there is no penalty measure, the 'Or else' elements is absent; for instance 'A graduate student has to complete the totality of its ECTS within the timeframe indicated by its course's program'.
3) **Shared Strategies**. These are statements where both the Deontic and the 'Or else' components are lacking; for instance 'House owners invest in energy saving measures when the government grant subsidies or tax reductions'.

A fundamental aspect concerning the first two structures is that: for every action that is part of a role, agents may perform a decision-making process in which they can decide whether or not to follow the rules and comply with the institutions or instead to prioritize its personal values. A zoom-in from the overall diagram on the Constitutional Structure is presented in figure 2.4.

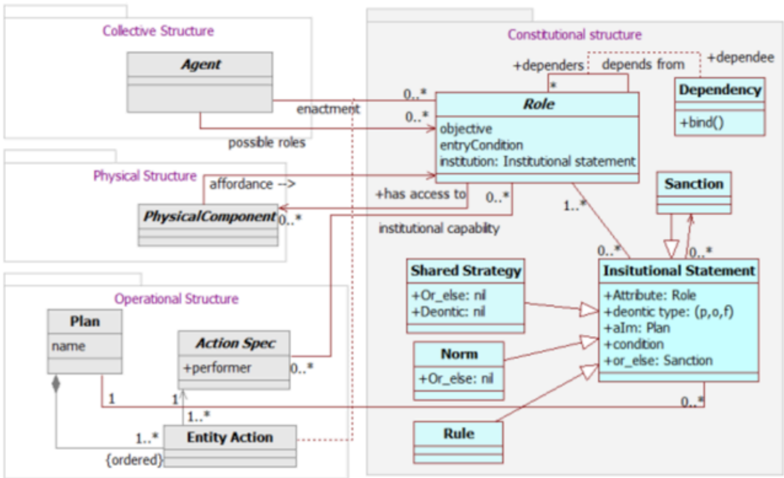


Figure 2.4 _ The Constitutional Structure in MAIA (Ghorbani et al., 2013).

The Physical Structure

In the Physical Structure are included all the physical components that are part of the system. Every physical component has specific properties, affordances (i.e. the functions of the object) and behaviours, and can be open to be used by all agents or restricted. It must be noted that even if the physical component is open to all agents, in order for them to be able to access it they need to have, in their asset, the specific capabilities required by the function of the object. If it is required by the system under study, the composition relations and the connections between physical components must be specified as well.

The Operational Structure

In the Operational Structure are included and described the dynamics that take place in the system; in other words, all the actions that all the entities present in the system (agents, roles and physical components) perform and the partial order in which they are executed.

In the simulation, in every time step, there is exactly one action arena where all the possible actions (Action Situation) are defined and listed. Every Action Situation describes

the order of a variety of related Entity Actions. Each Entity Action has a pre-condition, which control the feasibility for the vary entities to actually perform that action, and a post-condition, where are specified the consequences of that action on the system, i.e. the updates of the system's state that will follow. In every time step, each agent enters the action arena to explore the available Actions Situations. In order to perform an action, agents may enact a role that is available to them. Furthermore for every Entity Action, once the preconditions is fulfilled, the agents might need to take into consideration a decision-making process and an institution that might be associated with that action.
In every Action Situation the order of the various Entity Action is defined by a Plan. There are four type of plans that can be used:

1) **Atomic plan**: composed by a single Entity Action;
2) **Sequence**: composed by a collection of Entity Actions that are executed in the specified order;
3) **Alternative**: composed by a collection of Entity Actions from which one action is randomly chosen;
4) **Loop**: composed by an Entity Action that keeps being repeated for as long as the precondition holds.

A zoom-in from the overall diagram on the Operational Structure is presented in figure 2.5.

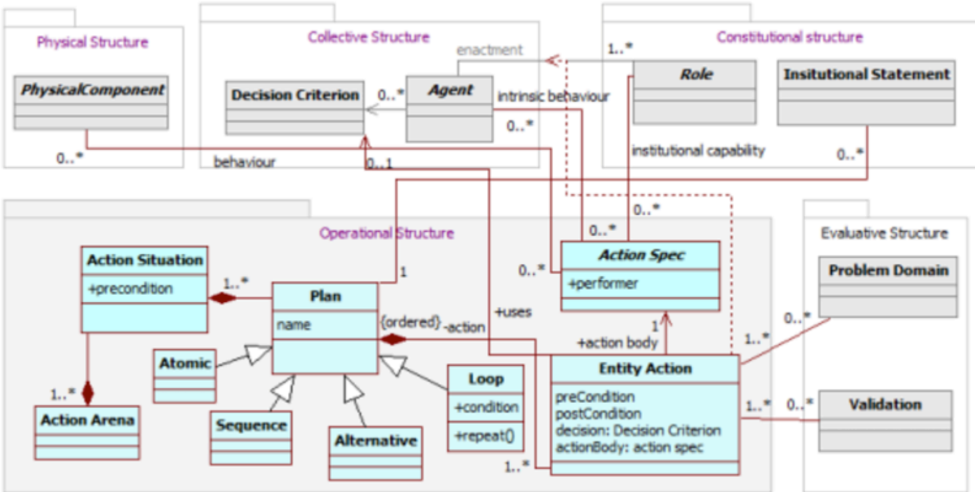


Figure 2.5 _ The Operational Structure in MAIA (Ghorbani et al., 2013).

The Evaluative Structure

In the Evaluative Structure are included and described the concepts that will be used to evaluate the outcomes of the system. It is strongly based on the right-hand side of the IAD framework, and it's the place that will help the modeller answering the two fundamental question concerning the validity and usability of the model.
First of all, in order to validate the whole model its variables need to be validated. This can be done firstly defining variable-specific constraints; secondly defining the type of influence that an entity action has on that variable, it can be either *direct* or *indirect*. Afterwards, in order to verify the usability of the model the modeller can specify what variables, among the variety that have been modelled, can be defined as useful indicators for the problem domain.

The MAIA framework has been selected to proceed with the conceptualization of the model for this thesis and its case study. The main consideration leading to this choice is that it represents a suitable bridge between the two chosen methodologies (CM and ABM). MAIA constitutes both a guide for the researcher when developing the choice experiment and collecting data on its target sample as well as when developing the agent-based simulation. Furthermore MAIA framework has been already applied to several case studies in which its effectiveness has been confirmed. A complete explanation on how the methodological combination is suggested and performed is given in chapters 6 and 7.

2.2 Research Framework

In order to answer to the main research question several research steps were undertaken. A schematic representation of them is given in the research framework below (figure 2.6).

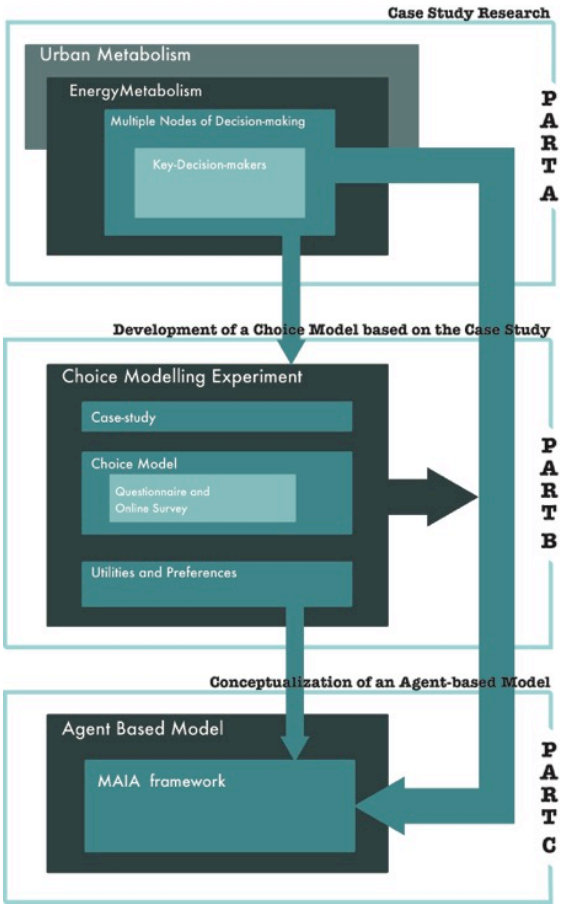


Figure2.6 _ Research framework

Three stages, or parts as they are defined in the framework above, compose the core of this research process, which is developed in the second part of the thesis. For each part a different methodology has been used.

In **Part A** literature review, case study and desk research are the methods employed. The outcomes of this part are firstly and manly used in the Choice Model (Part B) but also later on for the conceptualization of an ABM (Part C), as shown by the arrows. In **Part B** the methods used are (1) Choice Modelling, intended as the method on which is based the development of an experiment to investigate preferences and choices of decision-makers; and (2) the creation of an online survey, based on the questionnaire developed as part of the CM experiment. As shown by the arrows in the research framework, input from the case study investigation are here used to develop a Choice Model, the results of which will be used later in the conceptual ABM (Part C). **Part C** consists of a methodological investigation, aimed at providing an added value to the whole research. For this investigation the combination of CM and ABM is suggested and developed in the form of a conceptual model through the use of MAIA framework. This framework has been chosen as considered the most suitable bridge between the two methods. Results from both the previous parts will be used here.

In the following sections the 3 Parts of the research framework will be individually thoroughly described. Firstly we present below a list of all the steps taken during our research process.

2.2.1 Research steps

The steps are listed in chronological order whenever possible, considering that several steps were iterative.

- Review of literature on Urban Metabolism and Energy Metabolism, especially on the literature focusing on the social aspect of it and the multiple nodes of decision making that are enclosed in it; literature review on the combination of ABM and CM.
- Desk research to investigate and define the concept of Energy Metabolism and the case study (the energy metabolism in Amsterdam). This step was divided into several sub-steps:
  Research on the city of Amsterdam;
    - Research and informal interviews on the City-zen project;
    - Research on municipal, governmental and international projects for the sustainable development of the city of Amsterdam;
    - Analysis (through colour coding) of the plans and projects related to Amsterdam's energy system to individuate the common themes;
    - Research and definition of the main characteristics and components of Amsterdam's Energy system;
    - Development of a map representing Amsterdam's Energy system as intended and defined within this research.
- Development of a choice model experiment, following the stages defined in the book by Henser et al. (2007).
- Desk research to adapt the case study to the requirements of the choice modelling experiment among which:
    - Reduction of the research scope to a smaller area of the energy system. Definition of this area and research on its characteristics and criticality;
    - Research on the technological systems, already in place in Amsterdam, to improve the efficiency and sustainability of the energy system;
    - Research to define the Alternatives, Attributes and Attributes levels for the Choice sets.
- Definition of the type of actors to be involved in the research for the choice experiment, first, and for the conceptual ABM at a later stage.

- Desk research on the key-decision-makers actors to be involved in the choice experiment. Definition of categories to group these actors and development of an excel database with contacts' details. Part of this research has been based on the previous system analysis developed by the City-zen project.
- Creation of the Choice-sets' combinations with the software *Ngene*.
- Creation of a formal questionnaire containing the choice experiment (choice sets), socio-demographic questions and follow-up questions related to the overall research.
- Development of an online survey through the online platform *Collector*.
- Contacting the decision-makers to answer to the survey in order to gather information on their preferences and choices. In order to meet the statistical requirements for the choice experiment to be valid and significant, new key-actors (complying with the definition) to include in the experiment have been found and contacted while the survey was already online and the data collection already started.
- Collection of data regarding key-actors preferences and choices through the online survey and a few face-to face informal interviews.
- Analysis of the choice experiment results with the software *Biogeme*.
- Interpretation of the Choice Model's results.
- Use of the MAIA framework to conceptualize an Agent-based Model in which the results from the Choice model were used.
- Analysis of the methodological combination of ABM, MAIA meta-model and CM.
- Discussions of the research's results, and suggestions for future research.
- Conclusions on the research answering to the research questions.

We now proceed individually describing each of the three parts composing the research framework.

2.2.2 PART A – Case study and Desk research

Desk research it is firstly used to review the literature regarding urban metabolism and to define the sub-concept 'energy metabolism' and then to review literature concerning it. Following, desk research is used to investigate and describe the selected case study, the city of Amsterdam, and its current energy system. This exploration is driven by the first and second sub-questions:

What are the components, characteristics and boundaries of an urban energy metabolism?

Who are the key-decision-makers involved in the urban energy metabolism?

Through desk research several sources, reports, websites and other materials were used to define not only the status quo of the energy system, with its socio-technological components, but also the prospects for its future state and especially for its sustainable development. Results and materials gathered from the City-zen project have been used in this stage to contribute to the analysis and description of the Amsterdam's energy system. To make sense out of all this research on the case study we performed a simple analysis, through colour coding, to identify the common themes. At a later stage the same resources together with new relevant materials were used (1) to define the components, characteristics and margins of the urban energy system, which resulted in the creation of a map of such energy system; and then (2) to identify the key actors, defined as key-decision-makers, involved in the energy system, which resulted in the creation of a map of the nodes of decision-making. These nodes here individuated have been used, later on, to identify the individual key-decision-makers to include in the CM experiment.

2.2.3 PART B – Choice Modelling

The second methodology, which is at the core of Part B and of the whole thesis, is Choice Modelling, which through the design of a specific experiment, the data collection and the statistical analysis of the data collected, allowed gathering insights on preferences and choice mechanisms of the key-decision-makers involved in the Amsterdam's energy system. This exploration is driven by the third sub-question:

What are the preferences of the different key-decision-makers involved in the urban energy system?

Henser at al. (2005) in their book on choice analysis develop a schematic representation of all the required steps for the development of an experimental design. The scheme is presented in figure 2.7. These are the stages we followed to design the choice experiment.

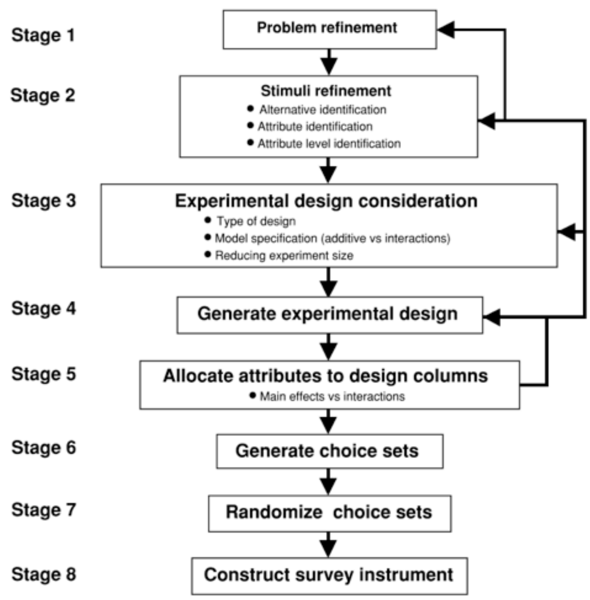


Figure 2.7 _ Stages of the Experimental design process (Henser et al., 2005)

The first two stages required the most work and time, as preannounced by Henser et al. (2005), due to their fundamental importance for the whole design process. Problem and Stimuli refinement lead to a redefinition of the focus of the choice model, since the investigation of choices to be made considering the whole energy system would have led to vague and therefore statistically weak choice sets. In order to refine the problem and the stimuli, report and researches on the current state and the future development of the Amsterdam's energy system were used to identify a suitable problem to be at the core of the choice analysis.
To give a practical and simple example of this two fundamental steps let's suppose that our problem consists in finding out consumers' preferences concerning their eating habits. For practical reasons and for the choice model to be statistically relevant we need to be more specific. We decide, then, to look into their breakfast eating habits. At this point, even with such a narrow scope, we have thousands of options available among which we can choose to define our alternatives. We could select as alternatives only beverages,

or only foods, or we could select some combinations of food and beverages. Once we decide on a set of alternatives we need to select a limited amount of alternatives from that set, mostly for feasibility and practical reasons. Assuming that we ended up having three alternatives (coffee and toasted bread; milk and cereals; tea and biscuits), we now have to define the attributes describing them. The same screening process that has been done for the alternatives need to be done for the attributes. Assuming that we choose three attributes (preparation time, nutritional values, cost) we now have to specify some levels for each of them. The first, preparation time, will have three levels (5 min, 7 min, 10 min); the second, nutritional values, will have four levels (50 kcal, 70 kcal, 90 kcal, 110 kcal); the third, cost, will have again three levels (0,50 cents, 1 €, 2€). At this point we have enough information to proceed with the experiment design. A similar path was taken for our research, in a less linear and simplistic way, as explained below.

Hence, once the problem has been refined several types of alternatives were evaluated before the final decision on which alternative typology to use. Afterwards four alternatives were selected and described. It followed the individuation of several attributes, common to all alternatives, which were grouped according to the type of information on the alternatives they were able to describe.

In order to get to the final list of alternatives and attributes, and start looking into the attributes' levels, some consideration about the design of the experiment had to be made (Stage 3). Driving the considerations on the design of the experiment were principally the constraints of the research, such as the time-availability, the lack of any type of financial resources, the typology of respondents selected, the expected amount of participants and the required brevity of the final questionnaire. At the end of stage 3, we were able to define the final three alternatives and the four attributes, as well as some other important features of the choice experiment design (e.g., unlabelled alternatives, sequential orthogonal factorial design, number of levels per attribute, main-effects design).

Before moving forward to stage 4, the attributes levels had to be defined. Defining the attributes levels is another fundamental task since, in simple terms, it is what gives statistical validity to the choice experiment. The levels have to be as realistic as possible, while also being consistent and with values that are not too distant from each other to avoid too large ranges that would lead to biased choices (i.e., one alternative results more favourable than the others).

Once the attributes levels were defined we proceeded to the generation of the experimental design (stage 4) through the software Ngene (ChoiceMetrics, 2011a). In this stage, considering the firsts results given by the software, i.e. choice experiments composed by a very large number of choice sets (over 100), we had to made some adjustments to the previous choice-sets concerning the attribute levels. Originally three attribute levels were defined for each attribute and this led to an extremely large experiment, too large for the current research and its constraints. In the end the number of levels were drastically reduced to two for each attributes except for one attribute that maintained the original three levels. Afterwards we were able to repeat stage 4 and simultaneously perform stage 5, mainly done by the software.

At this point we were able to generate the choice sets (Stage 6) and consequently to construct the questionnaire and the online survey (Stage 8). Stage 7, the randomization of the choice sets, was not performed as considered not relevant considering the reduced dimensions and simplicity of the experiment.

2.2.4 PART B – Questionnaire

Once the choice sets were defined, we proceeded developing the questionnaire. An appropriate questionnaire, as different sources (Henser et al., 2005; Lee, 2013) suggested, requires an introduction to explain the context and the purpose of the study, but also to explain what will be asked and to give all the specifications if and where necessary. It usually contains a group (of varying sizes) of socio-demographic questions, meant to gather information on the population sample reached by it. Afterwards it is followed by the core of the enquiry, which is represented by the choice sets in our specific case. We developed all these three parts and we added also a final section, composed by three follow-up questions, to look into the perception the respondents have on Amsterdam's energy metabolism. One last open question was added, before the conclusion of the questionnaire, to offer the respondents the chance to give an opinion on the questionnaire itself and specifically to specify whether the information included in the choice sets was or not sufficient.

Once the questionnaire was ready, we proceeded with the development of an online survey instrument, using the TUDelft online platform Collector ("Collector," 2011). Before starting the actual data collection and distributing the survey link to the selected participants, we performed a small trial session to gather feedbacks on the questionnaire and the survey, and therefore to be able to do the appropriate adjustments. We distributed a paper-version of the questionnaire to two participants and we sent the link for the online survey to three participants. It must be noted that the participants involved in the trial session are not part of the population sample selected for the study. This is due to practical reasons such as time constraint and most importantly to the attempt of avoiding the chance that any of the respondents would not fill-in the final and real questionnaire having already participated in the trial session. This last reason is the result of some considerations like the fact that the respondents selected for the research (key-decision-makers) are a small sample per se, which do not have much time to spend on the questionnaire; furthermore the percentage of the population from the defined sample who actually decide to undertake the questionnaire is assumed to be low, considering general statistics on surveys' attendance. Nevertheless the trial session resulted in a few minor feedbacks on questionnaire and survey that were implemented in the final version of the questionnaire, which is included in Appendix E.

At this point we were able to proceed with the distribution of the survey's link to the defined sample. The link was sent personally to each respondent via private e-mail. The e-mails shared the structure and the main content but each of them was personalized, in order to specify to each respondent the reasons why they were contacted and selected as participants. The standard version of the e-mail can be found in Appendix F.

2.2.5 PART C – ABM and the MAIA framework

One final part is included in the core of this research; it consists of an exploration of a combination of two methodologies: Agent-based Modelling and Choice Modelling. The combination of the two tools consist basically in using the research and the results from the choice experiment to model the behaviour of the actors studied within the ABM. This combination provides for a level of uncertainty connected to ABM. In fact, using real-life data resulted from the choice analysis to model the individuals' behaviour parameters gives a realistic value to the assumptions made to model agents' behaviour. The combination of the two modelling tools have been already applied by several authors

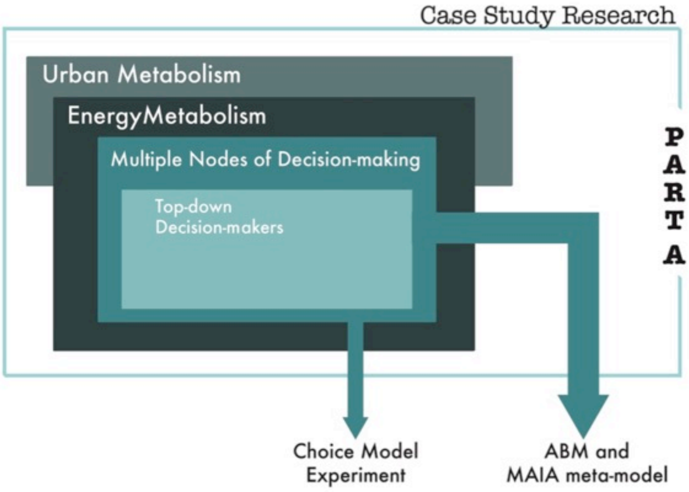
(Brown, 2013; Cui et al., 2010; Dia, 2002; Vag, 2007) successfully, demonstrating the feasibility and potential of this combination. For this specific research this combination translates into using the information gathered with the questionnaire and especially the values of utility and preference resulted from the choice experiment as the input values, in the meta-model, describing agents characteristics and preferences.
This exploration has been performed with the aim to give a value added to the whole research as well as to explore, and possibly to suggest, a method to gather further insights on the main topic, the direct influence of decision-makers on the urban energy metabolism. This exploration is driven by the last sub-question:

How can the interactions dynamics between key-decision-makers' preferences and the energy system be observed?

In order to perform the methodological combination a specific framework, or meta-model, was chosen. As introduced in the first part of the chapter, the MAIA framework has been developed by Ghorbani (2013) as a tool for the conceptualization of ABM of complex social system building up on the Institutional Analysis and Development framework by Ostrom (2005). As such, MAIA perfectly responds to the aim of this methodological exploration, which is specifically intended to be conceptual leaving the model development out for further research.
We make use of the MAIA framework as explained by Ghorbani et al. (2013) and as presented in the MAIA web-tool application (http://maia-tool.github.io/#/list/agent). Therefore we developed the five structures composing the meta-model through five tables. Each table represents one structure (e.g., collective structure, institutional structure…); for each structure all its main components (e.g., roles, institutions, dependencies as part of the institutional structure) were listed; for each component were listed all the characteristics describing it, required for the general model (e.g., properties, personal values, information, capabilities, decision-making criteria).
Specific numeric values were assigned to those parameters that were investigated in the choice experiment, while for the parameters that were not investigated by the choice experiment the numeric values have been excluded. Using the MAIA framework gave us the chance to look at the case study differently, mostly taking several aspects that were not being taken into account before. This was a very interesting and important feature of the methodological combination that allowed us to extract further information from the case study research, from the choice experiment as well as from the questionnaire. Some data have been, in fact, reconsidered thanks to the application of MAIA framework. This assessment, as will be discussed later on in this report, suggested that, whenever the combination of a Choice Model and an Agent-Based Model is planned, the use of MAIA framework is preferable during the first two stages (i.e., problem refinement, stimuli refinement) of the choice experiment design. This should allow the researcher to investigate all the agents' characteristics (as well as the environment's characteristics) the she will include in the ABM, in particular those that did not seem important in the first place.

PART TWO

PART A



"As the main site of energy consumption, cities have become the focus of considerable attention, with the goal of adopting concrete measures to reduce urban energy consumption. At present, the most effective way to identify weak links in an urban energy system is to study energy consumption from the perspective of energy metabolism" (Fath et al., 2010, p. 2)

Chapter 3
CASE STUDY INVESTIGATION: THE ENERGY SYSTEM IN AMSTERDAM AND ITS KEY-DECISION-MAKERS

In order to fulfil the aim of this research and look into an energy system to investigate the multiple nodes of decision-making and their influence on that system, we decided to focus on a specific case study. The explorative character of this research made sufficient the selection of a single case study, and we selected the city of Amsterdam and its energy system. The justifications for this choice are mostly practical such as: data availability, geographical vicinity and linked possibility to frequent visits on site, the possibility to interview and meet decision-makers, and, finally, the chance to gather information on the related energy system through existing projects (i.e. City-zen project) and the AMS research centre.

In the first part of this chapter a definition of the concept of energy metabolism, as its intended in this research, is proposed. In the second part the basic features of the city of Amsterdam are briefly introduced as a starting point; following we present the investigation of three municipal plans and one project concerning the development of a sustainable energy system in Amsterdam. To conclude this investigation we analysed the plans to highlight the common themes.

In the third part we present and discuss the energy map, first result of the case study investigation, describing the main elements of energy consumption. In the fourth and final part of the chapter we present the second result of the case-study investigation: the nodes of decision-making and the related key-decision-makers involved in Amsterdam's Urban Energy Metabolism, and more specifically those related to the Energy in the Built Environment.

3.1 Proposing a definition of "Urban Energy Metabolism"

Before proceeding with the core of this section, let us begin enunciating the definition that has been developed, in this research, for the concept of energy metabolism.

Considering the initial problem statement and the research framework adopted, Amsterdam's energy system has been observed and analysed through a metabolic perspective. This led to a specific definition of what is intended as energy metabolism:

> **A complex adaptive system of energetic flows that cross throughout an urban environment. When looking at such system several dimensions are taken into consideration (environmental, social, economical, technical) and accounted for their role in shaping the system's metabolism; both the production, supply and use levels are taken into account; and lastly, the boundaries of such system are flexible**

and loosely defined as energy in-flows and out-flows go beyond the urban perimeter.

The concepts of energy system and energy metabolism are considered identical in this research, and used interchangeably.

3.2 Case study investigation

To fulfil the research's goal we make use of a case-study investigation both as a reference and starting point in order to be able to investigate in depth a specific urban energy metabolism and the preferences of the decision-makers involved. Here we present our case study investigation: firstly introducing some key features of Amsterdam, the chosen case study, and secondly presenting and then analysing three municipal plans and one project concerning the future development of Amsterdam's energy system.

3.2.1 Amsterdam Metropolitan Area – Key features

The city of Amsterdam is the capital as well as the most highly populated city of The Netherlands. In table 3.1 are illustrated some basic descriptive data regarding the city and its metropolitan area. Amsterdam Metropolitan Area (AMA), or Metropoolregio Amsterdam (MRA) in Dutch, as shown in figure 3.1, includes the city of Amsterdam together with 32 other municipalities, and it is comprised between two regions (Noord Holland and Flevoland). AMA hosts more than 14% of the country's population and it is the most robust economic region of The Netherlands (Geemente Amsterdam, 2016).

Table 3.1 _ Basic descriptive data on Amsterdam. (Blok et al., 2015; CBS, 2016; "iAmsterdam, fatti e cifre," 2016, "World Population Review," 2016, Municipality of Amsterdam, 2015a, 2015b;)

Amsterdam city region's inhabitants	**813,562**
AMA's inhabitants	2,332,773
Amsterdam's population density	4,908 $\boldsymbol{people/km^2}$
Households in Amsterdam	417,096
Average m^2 per household	74 $\boldsymbol{m^2/dwelling}$
Average household size	2.2 $persons$
Average energy requirement per household per year	58 GJ
Current CO_2 emissions in Amsterdam	4437 $kTon/year$
Bikes	881,000 $ca.$
Parks	40
Electric vehicles charging stations	650
Shops	6,159
Bridges	80
Historical Buildings (XVI, XVII e XVIII centuries)	8,863

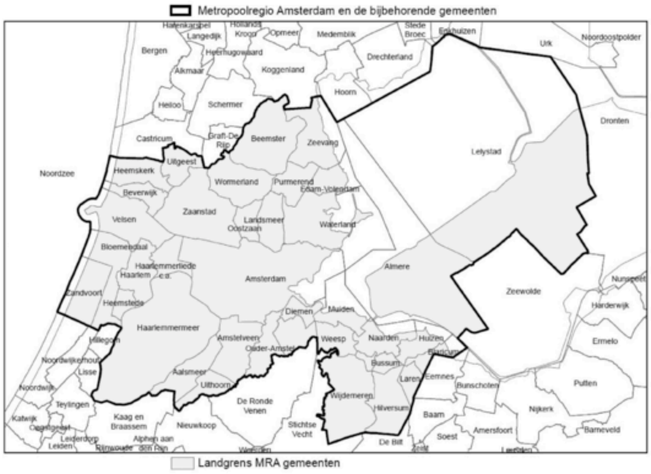


Figure 3.1 _ The perimeter of AMA (Savini et al., 2015)

The key features concerning the social environment are the extreme ethnic diversity, as shown in figure 3.2, to the extent that in 2015 Amsterdam has been recognized as "*the city with the greatest number of different nationalities in the world*" (Gemeente Amsterdam, 2015)*;* and the positive trend of population growth in the past decade as well as in the projected future (Geemente Amsterdam, 2013), which is, interestingly, caused by "*young and higher educated households*"(Savini et al., 2015).

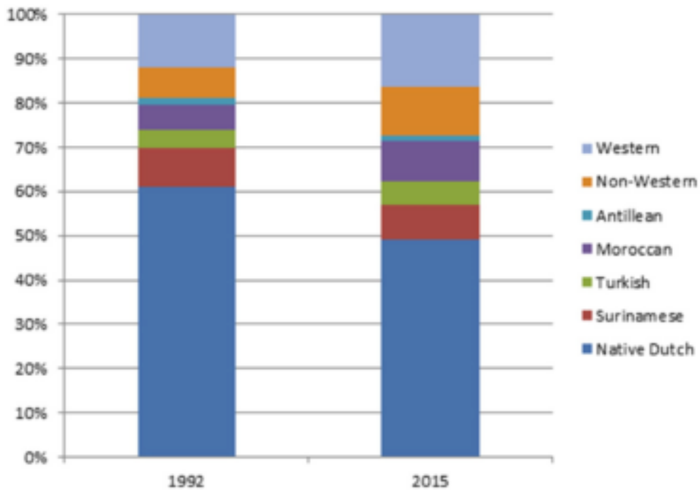


Figure 3.2 _ Ethnic shares of Amsterdam's population (Savini et al., 2015)

Concerning the energy consumption in general terms, the Netherlands has a high level of energy consumption per capita: 4,16 kg of oil equivalent, 1 point over the European average (IEA statistics, 2014). The average energy consumption per households, in the Amsterdam area, is of 58 GJ (Blok et al., 2015). The country imports a substantive amount of energy, which sells abroad for the two thirds in different forms, mostly crude oil and oil products; and it still has a large reserve of fossil energy, which is worth, based on the current consume trends, twenty years of energy reserves (*Monitor Duurzam Nederland*, 2011).

3.2.2 Plans and Projects for the development of Amsterdam's energy system

Three programs and one project, concerning the development of a sustainable energy system in Amsterdam, are here described and analysed with the purpose of assessing the current political and administrative directions about the energy system. Almost all of these programs have scopes that go beyond the energy system. However we attained to our research scope and investigated only those aspects clearly relevant for the energy system. The three plans are: 1) Amsterdam's Structural Vision, 2) Sustainable Amsterdam Agenda, 3) The Energy Agreement; the project is: The City-zen project.

3.2.2.1 Amsterdam's Structural Vision

The Amsterdam's Structural Vision is defined as "*a visionary scenario for the future*" (Lauwers et al., 2011) and it encloses the ambitions set by the City Council according to the Sustainability Plan for the period 2010-2040 (Lauwers et al., 2011).
Seven spatial tasks are defined to steer the sustainable development of the city:

1) Densify
2) Transform
3) Public transport on the regional scale
4) High-quality layout of public space
5) Invest on the recreational use of green space and water
6) **Converting to sustainable energy**
7) Olympic Games Amsterdam 2028

In the Structural Vision, the objective for the future of the energy system, given in the sixth spatial task, is ambitious and broad. The city council aims, in fact, at reaching a sustainable energy system, prioritizing renewable sources with the aim of self-sufficiency, but it aims also at working on the efficiency of the energy flows in the existing housing stock. The details of the seven spatial tasks with their focuses are given in Appendix G.

3.2.2.2 Sustainable Amsterdam Agenda

The Agenda for a sustainable Amsterdam outlines 5 transition pathways for the near future. The main ambition of the Agenda is indeed to set achievable goals to be reached and carried out now by this generation, giving for granted the importance and urgency of a global change towards sustainability. The five pathways are: 1) **Renewable Energy**, 2) Clean air, 3) Circular Economy, 4) Climate-resilient city, 5) Sustainability of the Municipality's operational environment.
A table summarizing goals and ambitions of all seven pathways is included in Appendix G together with and info-graphic representing them.

The pathway concerning Amsterdam's energy system, the first one, is defined by two comprehensive sets of goals and ambitions:

- 20% increase of renewable energy per capita by 2020, to be achieved through the increase of solar and wind energy production, and through the use of renewable heating (district heating).

- 20% decrease of energy consumption per capita by 2020, to be achieved through the implementation of the housing stock's sustainability, the reduction of the energy use by corporate and private real estate, and the promotion of energy-neutral new constructions.

Within the Renewable Energy pathway four main components can be identified. They represent the main areas of interest for the specific actions to be taken in order to fulfil the goals. These four components, with their targets, are:

1) **Wind energy**: the target is **18 MW** extra (from 67 MW at present to 85 MW by 2020);
2) **Solar energy**: **t**he target is **150 MW** extra (from 9MW in 2013 to 160MW by 2020), around 950,000 m^2 of PV panels;
3) **Renewable heating**: the target for the expansion of the district heating (DH) grid is around **102,000** connections;
4) **Existing housing stock**: improving the current sustainability and energy efficiency levels.

Further information about the specific approaches proposed by the council in order to tackle each of the four components and fulfil the main goals is given in Appendix G.

3.2.2.3 Energy Agreement for a sustainable growth

The Energy Agreement for a Sustainable Growth or "Energieakkoord voor duurzame groei" in Dutch, is the result of a joint collaboration among more than 40 heterogeneous organizations, both private and public, facilitated by the Social and Economic Council of the Netherlands (SER). The main purpose was to create a long-term prospect, with concrete intermediate goals, towards a completely sustainable energy supply by 2050. The agreement constitutes of 10 basic components, for which are defined specific objectives and measures. Together these components constitute a coherent framework to guide and give directions to work towards, for all the organizations and parties involved (SER, 2013). The 10 components are:

1) Saving Energy
2) Scaling up Renewable Energy generation
3) Decentralized Energy generation
4) Energy transmission network
5) EU Emissions Trading System (ETS)
6) Energy generation from fossil fuels and coal-fired power stations
7) Mobility and Transport
8) Employment opportunities
9) Energy innovation and Energy exports
10) Funding programme

In table 3.2 are briefly presented some specifics for each component. A fully comprehensive version of the same table is included in Appendix G.

Table 3.2 _ Summary of the 10 components of the Energy Agreement. (SER, 2013)

Saving Energy	1.5% saving on energy consumption; Expected generation of 100PJ of energy savings through the proposed measures; The measures are directed towards the built environment and towards the commercial sectors, agriculture and industry.
Scaling up renewables energy generation	Generate 16% of the national energy through renewable sources by 2023 the latest; Offshore wind power scaled up to 4450 MW by 2023; Onshore wind power scaled up to 6000 MW by 2020; The use of biomass by coal-fired power plant is promoted but limited to 25 PJ; Substantial reduction of energy costs; Construction of a more efficient offshore network.
Decentralized energy generation	Encouragement of private initiatives of decentralized energy generation; Economic promotion of private initiatives for local energy generation and consume; Increase of the generation options, when needed.
Energy transmission network	Measures to make the transmission network more flexible, such as: smart-grids, demand-side management, storage capacity; Measures concerning European cooperation such as: closer collaboration with the Energy forum and specific countries in geographical proximity, promotion of an EU framework and approach for the integration of gas and electricity markets;
EU Emissions Trading System (ETS)	The parties involved agreed upon four requirements for an efficient ETS, and formed a lobby to strive the implementation of a package of improvements.
Energy generation from fossil fuels and coal-fired power stations	Minimising the capacity of the existing coal-fired power plants; The use of CCS (Carbon Capture and Storage) technology is defined as unavoidable to be applied by both industry and coal-fired power plants.
Mobility and transport	60% CO_2 reduction in the mobility and transport sector by 2050.
Employment opportunities	Creation of 90,000 full-time jobs, by 2020, by all these investments in the energy sector.
Energy innovation and energy export	Becoming an international frontrunner for clean technology expertise, by quadrupling, by 2020, the economic value of clean energy technology chain.
Funding programme	Creation of a funding programme, arranged by several parties, that will focus on large-scale and small-scale decentralized investment projects.

3.2.2.4 City-zen project

The City-zen project, which stands for City zero (carbon) energy, is a EU funded project in the FP7 context. It consists of a consortium of 23 partners from 5 European countries, coordinated by the Belgian company VITO. The consortium represents a rich synergy of industry, network operators, municipal representatives, housing corporations and research institutes. The City-zen project has three main objectives ("City-zen Objectives," 2016):

1) Showcase ambitious pilot demonstration projects related to energy efficient retrofitting, innovative district heating and cooling networks, and smart grids at districts level;
2) Link cities and citizens needs with industries, so they can develop innovative technology for the benefit of smart cities and citizens;

3) Demonstrate effective planning methodologies and collaboration models between city and stakeholders for the development of smart cities.

In Amsterdam, seven projects are currently being implemented (Amsterdam Smart City, 2016):

1) Intelligent net
1) Sustainable heat network (District Heating)
2) Drinking Water used for cooling of business area
3) Energy saving by residents, or Residential Retrofit
4) Testing Living Lab
5) Serious Gaming
6) Roadmap to City Zero Energy

The retrofitting of the residential stock is one of the City-zen projects currently active in Amsterdam. The aim is to renovate more than 700 dwellings (around 52,000 m^2 of residential buildings) and save 3000 tonnes of $\boldsymbol{CO_2}$ / $year$. Among the technologies and saving measures that are being implemented there are: heat pumps, PV panels, air insulation and smart ventilation systems, glazing, smart meters and smart grid connections, connections to the district heating network.

3.2.2.5 Analysis of the plans and project for the development of Amsterdam's energy system

In this part of the chapter are presented the conclusions of the previously presented investigation. Analysing and comparing (through colour coding) the previously presented project and plans it was possible to identify some recurring themes among them:

1) The increasing of the energy share derived from renewable energy sources and the promotion of decentralized energy generation, in which it is included the increase in transmission's network flexibility (in light green);
2) The promotion and implementation of energy saving and energy efficiency measures of various type (or as otherwise stated the decrease of energy consumption) in the built environment (in celeste);
3) The promotion and implementation of the district heating network (in yellow);
4) The importance of clean and innovative technologies' development and smart grid connections (in grey).

In table 3.3 this analysis is shown by presenting a short list of the main objectives of the various plans and projects and the colour coding to show the recurring elements.

Table 3.3 – Comparison of the plans and projects for the development of Amsterdam's energy system with colour coding to identify the recurring themes.

Amsterdam's Structural Vision	Improvement of the Energy efficiency of the existing housing stock; Solar-energy on rooftops; Wind-turbines; Closed heat-transfer systems (District heating).	**1** **2** **3**
Sustainable Amsterdam Agenda	Wind Energy; Solar Energy; Renewable Heating; Improvement of the Energy efficiency levels of the existing housing stock.	**1** **2** **3**

The Energy Agreement (national scale; it looks at the energy supply level)	Saving energy in the built environment and in the commercial sector; Scaling-up renewable energy generation; Decentralized energy generation, funds and subsidies to promote and support it on different scales; Flexibility of the energy transmission network, at the national and international level; Efficient European ETS; Use of CCS technology and reduction of the share of fossil-fuel based energy generation; Increase the value of Clean-tech;	**1** **2** **4**
The City-zen Project	Increase energy efficiency of built environment through retrofitting; Implementing district heating and cooling networks as well as smart grid connections; Link cities and citizens with industries for the development of innovative technologies; Bottom-up initiatives for the development of a smart-city.	**2** **3** **4**

Looking more in depth in the results of the analysis we identified the one theme that always recurs: the second. That is the promotion and implementation of **energy saving and energy efficiency measures in the built environment**.

This theme resulted as important both in this analysis as well as in the following investigation on the energy system. The built environment, in which we can include households as well as public buildings, offices & retails and industries & enterprises, is in fact the energy system's component with the most energy requirements.

3.2.3 Concluding remarks

Through our case study investigation we identified some key features describing Amsterdam, such as the number of households, their average size and energy consumption, the energy consumption pro capita and the population's ethnic composition. The analysis of some of the current municipal programs and projects lead to an assessment of the most recurring themes describing the current political and administrative directions concerning the development of Amsterdam's energy system. These themes are: (1) the increasing of: share of energy from renewable sources, decentralized generation and flexibility of the transmission's system; (2) the promotion and implementation of energy savings and efficiency measures to reduce energy consumption especially in the built environment; (3) the promotion and implementation of the district heating network; and (4) the development of innovative clean technologies and of smart grid's connections. The second theme, in particular, is the one recurring in all the analysed sources. We therefore concluded that the built environment, and the implementation of energy saving measures related to it, is a focal point for the development of a sustainable energy system in Amsterdam, where lots of work and improvement need to be done.

The results of this first case study investigation confirmed the importance of our research scope: the energy consumption in the built environment.

3.3 Components and characteristics of an Urban Energy Metabolism

In this section we explore the previously defined concept of energy metabolism by applying it to our case study, the city of Amsterdam, and give an answer to the first research sub-question:

What are the components, characteristics and boundaries of an urban energy metabolism?

In order to identify the main components of an urban energy system we searched for those elements (1) where the energy flows pass through and (2) that define the requirements for the whole energy system. In other words we looked for the nerve centres of the urban energy demand. The reasoning behind this choice started with the basic notion that demand drives production. This notion led us then to the understanding that what we needed to look at, considering our research scope and question, were exactly those elements driving the energy consumption. In this way we would have been able to identify the key elements that, being the driving forces of the overall energy system, are the objects of the decision-making processes concerning the energy flows in the urban environment.

As a result of this exploration[1], we identified and defined, as driving forces, **7 components**:

1) **Households** (social housing, apartments, houses…);
2) **Public Buildings** (schools, municipalities, hospitals, government's offices…);
3) **Industries and Enterprises**;
4) **Offices and retails' buildings**;
5) **Public areas** (open spaces to be of use for the community);
6) **Streets** (open space of public transfers).
7) **Infrastructures** (for communication, transport, and energy carriers)

These components were found to have different energy requirements according to their own characteristics and functions. Three types of **energy requirements** have been defined: (1) Heating and Cooling, (2) Electricity, (3) Fuel (Gas and Oil).

As a side note, it must be pointed out that, even though the question is formulated on a general level, for this research step we considered Amsterdam energy system. Nevertheless, in the authors' opinion this description of energy metabolism can be generalized to (almost) any other urban context, especially in OECD countries.

[1] This exploration was performed through desk research and literature review. The sources for the definition of the first 4 and the 7th components have been the municipal plans related to the sustainable development of Amsterdam's energy system, in particular 'Amsterdam Sustainable Agenda' (Municipality of Amsterdam, 2015a) and the 'Energieakkoord voor duurzame groei' (SER, 2013), but also the Amsterdam Smart City online platform (Amsterdam Smart City, 2016)(Amsterdam Smart City, 2016). The 5th and 6th components have been specifically added in this research, because identified as important to be taken into account.

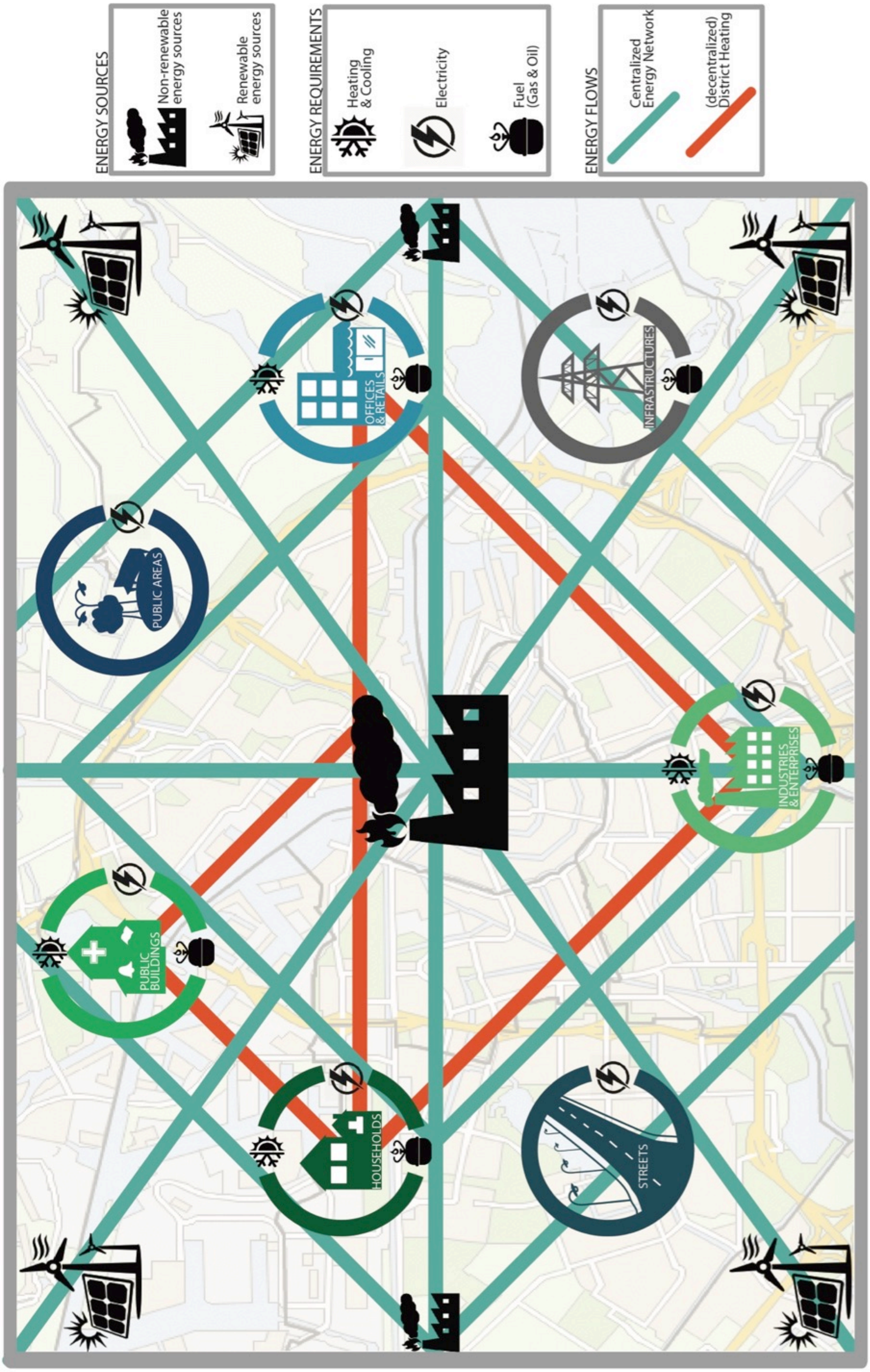


Figure 3.3 _ Info-graphic Map of the Energy system under study.

Furthermore, we briefly looked into some **characteristics** of the urban energy system. Power plants, or other energy production facilities, can be centralized or decentralized and their geographical location influences their distribution networks. The types of resources used to generate energy in the city of Amsterdam are several. Among the non-renewable sources there is: coal, methane, and other similar types of fossil fuels. Among the renewables sources there are mostly wind and solar, municipal waste, and district heating. As expected, especially considering the population density of the city and the low concentration of heavy industries within its boundaries, the majority of the required energy is produced outside of the main urban area.

These results have been graphically translated into the map of Amsterdam's energy metabolism shown in figure 3.3. All the elements above listed are there included and presented. The figure also contains a key on the side.

As an aside, it must be noted that the magnitude of the energy flows, as well as the magnitude of the demand weight of the seven elements have not been investigated. We acknowledge that the vast majority of Urban Metabolism and Energy Metabolism's studies focus on the quantitative assessment of the resources flows that go throughout the urban environment. However this is outside of the scope of this research.

In Appendix H the details of the energy requirements of each components of the energy system are presented to understand what the energy needs are due to.

3.3.1 Concluding remarks

Combining the Energy Metabolism definition to the city of Amsterdam and to the case study investigation we have been able to answer to the first research sub-question and we include here a full answer to it.

An urban energy metabolism is principally defined by its nodes of energy consumption. Those represent its main components, of which we identified 7: Households, Public areas, Streets, Public Buildings, Offices and Retails, Industries and Enterprises, Infrastructures. The characteristics of an urban energy metabolism are: the types of energy requirements that need to be addressed (Heating and Cooling, Electricity, Fuel), the types of energy flows that connect the nodes of energy requirement (centralized or decentralized), and finally the types of productions and sources used to generate the required energy (locally generated or imported; non-renewable or renewable sources). The characteristics of the energy system define its margins, which might be vague considering that a great amount of energy required by the urban area comes from outside its perimeter.

3.4 Key-Decision-Makers

The energy flows that pass throughout the urban environment are determined primarily by the above social system and its energy requirements. We described this social influence as 'multiple nodes of decision-making', which are, intuitively, composed by groups of decision-makers, or stakeholders.

There are several types of decision-making nodes and consequently there are several types of decision-makers. Within this broad variety, as already introduced, we decided to investigate a specific type of stakeholder, here named key-decision-makers. In the first chapter we presented a specific definition of such stakeholders. In this section is instead presented the answer to the second sub-question:

Who are the key-decision-makers involved in the urban energy system?

Therefore, here, we will present the investigation, within our case study, performed to identify the key-decision-makers that are involved in the Amsterdam's energy metabolism, and that can be included in our research. In order to do identify them we firstly defined and described the main nodes of decision-making composing an urban energy metabolism.

3.4.1 The Nodes of Decision-making in the urban energy system (based on the City-zen project)[2]

There are six nodes of decision-making composed by the key-decision-makers of an urban energy system, where are included different types of actors with similar characteristics, the most important of which is their similar decision-making extent. As part of a system, they give shape to a network of formal and informal relations among them and with the demand-side of the energy system.
In table 3.4 we present these six nodes including a brief description of their role in the energy system, as well as a list of their main formal, and some informal, relations. These relations are based on laws, regulations, well-established practices when formal, and on less-established practices, assumptions and hypothesis when informal. These elements are graphically shown in figure 3.4. In table 3.5 instead, for each node of decision-making we list the different types of actors that are included in it.

Table 3.4 – The multiple nodes of decision-making and their main formal and informal relationships.

Nodes Of Decision-Making	Role Description	Formal And Informal Relationships
Governments	It represents the highest level of authority within the urban energy system.	They have the power: to regulate the overall system, to issue permits, to institute and enforce rules and laws, to give subsidies, to supervise.
Energy Producers	They manage and have the control over the energy sources (unique control over non-renewable energy sources) and the main processes of energy conversion.	They receive (and need) permits; they might receive subsidies; they establish contracts with energy service providers and network operators; they might cooperate with other actors inside or outside of their group.
Network Operators	They are the main operators of the energy transmission system for which they develop and manage the appropriate infrastructure.	They receive (and need) permits; they build the infrastructures, they establish contracts with energy producers and energy providers, they transport energy in different forms to the energy requirements locations.
Energy	They act as intermediary between	They establish contracts with energy

[2] This part of our analysis is based on the preliminary results of the actors analysis developed by the City-zen project's research group for the "City-zen Serious Role Playing Game" ('System Analysis *City-zen serious role playing game*'). The document was given to us with confidentiality. Therefore no direct information from it will be shared here (and it is not possible to share the direct source). City-zen is and EU funded project, more information in section 3.2.2.4.

Service Providers	the energy producers and the energy consumers, they might be also energy producers and this is particularly the case for small and local sustainable energy production.	producers, network operators as well as with the nodes of energy requirements; they receive (and need) permits; they might receive subsidies; they might cooperate with other actors inside or outside of their group; they might support and favour specific energy producers.
Knowledge Developers	They develop knowledge about the energy systems, technologies, innovations and efficiency measures, they can be either impartial or partial;	They provide knowledge; they look for innovative solutions; they (publicly) share information and knowledge; they provide consultation.
Others	They are very different types of actors but, in general, they all provide services or act as mediators.	They establish contracts with energy suppliers and the nodes of energy requirements; they might promote or demote specific types of energy or specific companies; they can invest (and/or develop) in infrastructure related to the energy requirements nodes and therefore they might steer energy demands.

Table 3.5 – The multiple nodes of decision-making and their type of actors.

NODES OF DECISION-MAKING	TYPES OF ACTORS
Governments	Local, Regional and National government
Energy Producers	Central power plants, Heat 'producers', Natural gas and Biogas producers, Energy companies
Network Operators	Energy companies, Transition System Operator, Heat Infrastructure Operators, Distribution System Operator
Energy Service Providers	Energy companies, Energy suppliers (Heat, Electricity, Gas), Local sustainable energy suppliers
Knowledge Developers	Research centres, Universities, Consultancies, Corporate R&D, Sustainability consultancies
Others	ICT companies, Renovation companies, Architecture studios, Building Owners and Real Estate companies, Business developers, NGOs

Considering our refined scope, the urban energy system and its built environment, to these 6 nodes one addition is required: the Building Owners. When talking about the energy in the Built Environment, building owners represent an important node of decision-making, which have the same decisional strength as the key-decision-makers, and their influence on any energy savings implementation on the built environment is substantial. Nevertheless we decided to not include this node for one significant reason: it is extremely difficult to categorize and to pinpoint Building Owners as they may be very different types of stakeholders, ranging from local government and banks, to cooperatives and house associations, to single individuals.

In conclusion we acknowledge their role and influence in shaping the urban energy metabolism, especially considering the Built Environment, nonetheless we decided to not include them in our research because it was above of our knowledge extent.

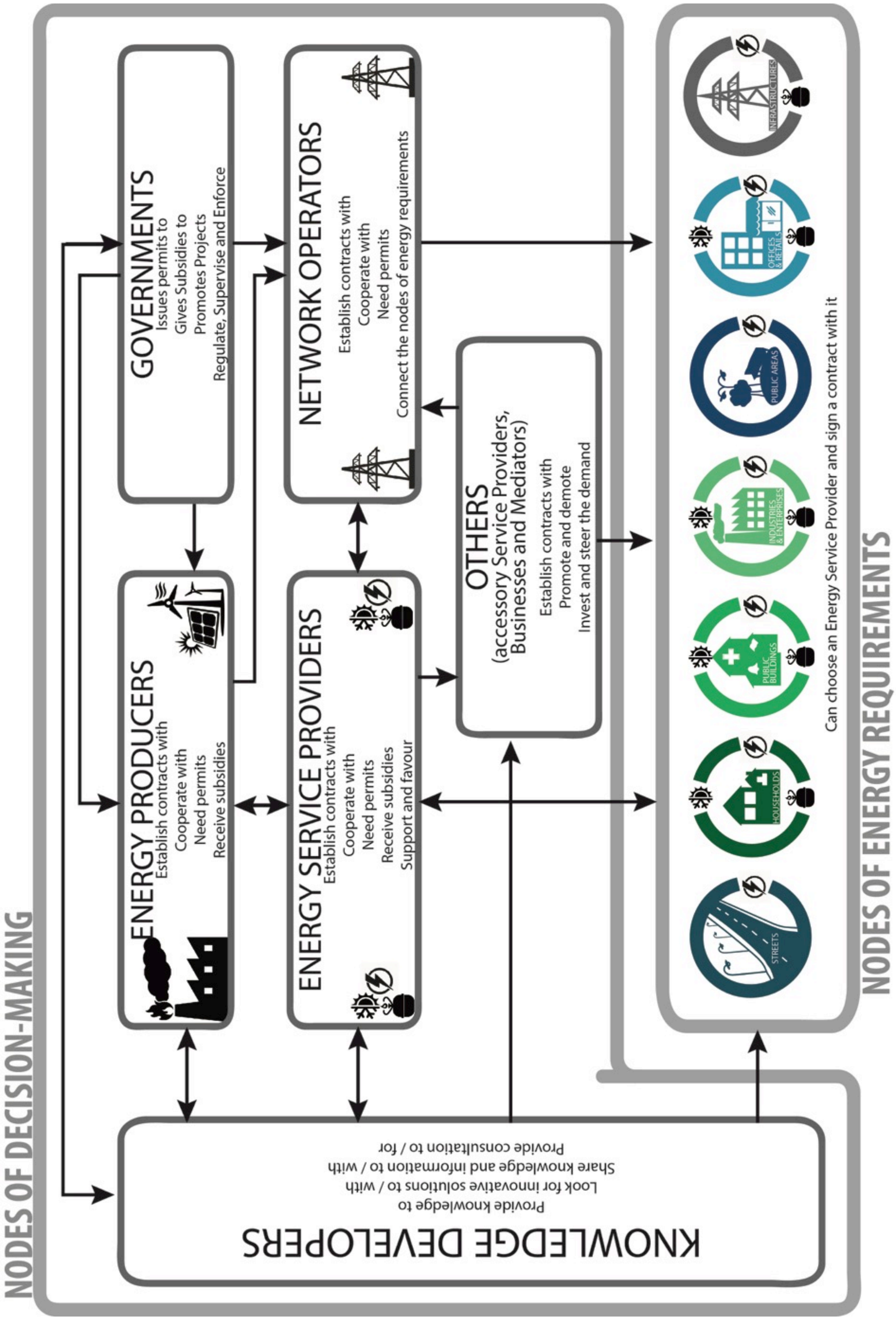


Figure 3.4 – Map of the nodes of decision-making with the main network of formal (and informal) relations among them and also month the nodes of energy requirement.

3.4.2 Key-decision-makers in Amsterdam's energy system

Once the multiple nodes of decision-making were defined we looked for specific companies, organizations, entities, institutions within Amsterdam's energy system, who could comply with the given definition and fit in the above presented partition.
In order to do so we gathered specific information and names of companies from the preliminary system-analysis developed within the City-zen project ('System Analysis *City-zen serious role playing game*'). We also had already gathered specific information from the case-study investigation, in particular from the plans and project about the development of Amsterdam's energy system, and additional reports on energy and energy companies (Netherlands Enterprise Agency, 2014; Nijpels, 2014). Further information on interesting and suitable stakeholders was gathered through informal interviews within Amsterdam's research centre for Advanced Metropolitan Solutions (AMS), and with energy experts within TU Delft. Lastly some more information was gathered through online research (e.g., company's websites, LinkedIn,…).
The result from this investigation was the development of a database where the nodes of decision-making, the typology of actors within them, and specific companies and organizations have been included and organized accordingly. In table 3.6 a concise list of the key-decision-makers individuated is given through the organizations or companies they are part of.

Table 3.6 – Some organizations and companies composing the Nodes of Decision-making in Amsterdam's energy system.

NODES OF DECISION-MAKING	ORGANIZATIONS or COMPANIES
Governments	Geemente Amsterdam, Amsterdam Smart City, Ministry of Economic Affair, DCMR (Environmental Protection Agency), RVO (Rijksdienst voor Ondernemens).
Energy Producers	AEB, Nieuwe Stroom, ENECO, Nuon, Essent, E.On.
Network Operators	Sympower, APX - Epex Spot, Delta Netwerkgroep (DNWG), Alliander, TenneT, ENECO.
Energy Service Providers	Waternet, Nieuwe Stroom, ENECO, Sympower.
Knowledge Developers	Eurbanlab, PBL (Environmental Assessment Agency), ECN (Energy research Center of the Netherlands), TNO, DNV GL, Accenture, Ecofys, EVOLV, IEE (Industrial Energy Expert), Utrecht University, Small (and Local) Conulting Companies.
Others	City-zen, Amsterdam Smart City, GreenIT, AFWC (Amsterdamse Federatie van Woningcorporaties), UNICA Ecopower, Ugenda, Posad, Valstar-Simonis, Sustainable Amsterdam, Resourcefully, De Groene Grachten, Spectral.

It is important to mention already what emerged from this investigation, which is the existence, within each node, of key-decision-makers with different levels of influence. This is important to take into account for the second and third part of our research process, when we will investigate their preferences and their influence on the energy system, considering all of them as influential people, with the awareness of differences in influence levels among them.

3.4.3 Concluding remarks

Having defined the Urban Energy Metabolism we have been able to look into the nodes of decision-making, which constitute the categorization of key-decision-makers, and therefore answer to the second sub-question, of which we report here a complete answer. In an urban energy metabolism there are 6 main nodes of decision-making ('System Analysis *City-zen serious role playing game*'): Governments, Energy Producers, Energy Service Providers, Network Operators, Knowledge Developers and Others. Each node is composed by a great variety of individual-decision makers. The extent of their knowledge and decisional power is considered greater than that of the general collective because of the influence it has on the energy metabolism. These decision-makers are, among others, aldermen, urban planners and policy makers, managers and CEO, but also architects and designers, consultants and professors, building contractors and influencers. An overview of the organizations in which these key-decision-makers have been found in Amsterdam's energy system is given in table 3.7.

3.5 Conclusions on the Case Study Investigation

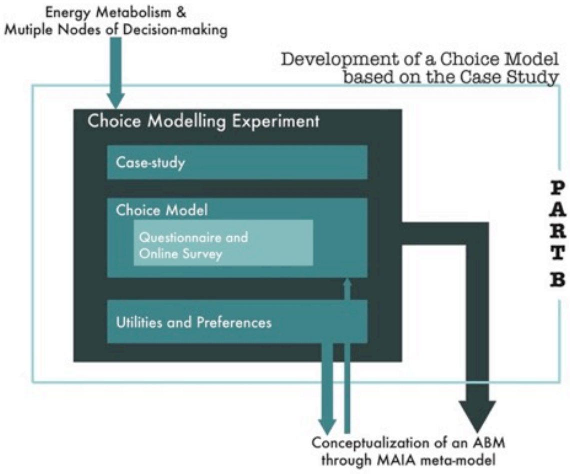
In this first part of our research we proposed a definition for the concept of Urban Energy Metabolism suitable to our scope. In the second part, through desk research, we investigated our case study: Amsterdam's energy system. We did so by firstly defining some key-features and secondly by analysing the current political and administrative direction concerning the development of Amsterdam's energy system. This resulted in a confirmation of the relevance of our scope: the energy consumption in the built environment.

In the third part, we described the main components and characteristics of an urban energy system and developed an energy map representing them. The main components are the nodes of energy-consumption of which we identified 7: Households, Public areas, Streets, Public Buildings, Offices and Retails, Industries and Enterprises, Infrastructures. The main characteristics are instead the types of energy requirements that need to be addressed, the types of energy flows that connect the nodes of energy requirement and finally the types of productions and sources used to generate the required energy.

In the fourth and last part, we performed an investigation to identify the key-decision-makers involved in Amsterdam's energy metabolism. In order to do so we firstly identified the 6 nodes of decision-making: Governments, Energy Producers, Energy Service Poviders, Network Operators, Knowledge Developers and Others (accessory service providers, businesses and mediators). Each node is composed by a variety of organizations and companies, which in turn are the ones composed by a variety of individual key-decision-makers. We then were able to identify some specific names of organizations and companies that compose these decision-making's nodes in Amsterdam's energy system.

At this point we had developed the required knowledge to proceed with the creation of a choice model to investigate the preferences of the key-decision-makers, involved in the Amsterdam's energy system, in regards to policies and municipal plans to reduce the energy consumption in the built environment.

PART B



"An experiment defined in scientific terms involves the observation of the effect upon one variable, a response variable, given the manipulation of the levels of one or more other variables" (Henser et al., 2005, p. 100).

"For policy scientists, the decision process remains a useful tool for analyzing policy issues" (Sabatier & Weible, 2014, p. 7)

Chapter 4
CHOICE MODELLING EXPERIMENT

Individuals are constantly facing tasks that require making choices. We repeatedly take decisions such as where to go out for dinner, which cereal's brand to buy, what movie to watch and so forth. Every time we must take a similar choice we actively perform a reasoning process comparing the available options and deciding which one to select according to our perception of the satisfaction (or utility) we could get from it.

When we look at a group of individuals, a sample, which are asked to make a contextualized choice among a limited number of alternatives we will observe different choice outcomes. Each individual within the sample will, in fact, associate different levels of satisfaction to different alternatives, from which we can reveal their preferences. Choice modelling is basically about this: trying to explain this variability among the choice outcomes looking at individual's preferences (Henser et al., 2005). This understanding of the decision-making process is based on the microeconomic concept of Random Utility, which define individuals as utility maximizers (Devinney & Lin, 2011; Henser et al., 2005; Louviere et al., 2000).

In this chapter we go through the steps and the main components of the *stated preference*[3] *choice model experiment* we designed as part of our research process in order to answer to our third research sub-question:

What are the preferences of the different key-decision-makers involved in the urban energy system?

To construct our choice experiment we went through the 8 stages defined by Henser et al. (2005)[4]. However here we will not retrace this process stage by stage. Instead we will present the main components of our choice model and choice experiment (i.e., alternative, attributes, attributes' levels, choice set, experimental design and questionnaire), and the most important steps to obtain them.

4.1 Problem Refinement

To properly begin the design of a choice experiment we needed to refine our understanding of the problem under study and of the scope of the research. Going back to our own problem definition and research question (chapter 1) we did the first refinement process. The reason why this research has been undertaken is to explore the choice preferences of specific decision-makers involved in the Amsterdam's energy metabolism so to gather insights on the influence they exert, through their choices and preferences, on the urban energy metabolism, more specifically considering the energy consumption in the built environment.

In order to further refine and confirm the problem to be studied through the choice model we also went back to the case study investigation, Amsterdam's energy system. Studying choices being made on issues concerning the overall energy metabolism would not have

[3] The definitions of Stated Preference and Revealed Preference are given in chapter 2.
[4] The 8 stages are presented in chapter 2, particularly in figure 2.9.

been a feasible or a statistically advisable solution. In the case study investigation, especially from the analysis of the municipal programs and projects for the development of Amsterdam's energy metabolism, we were able to highlight one theme, the most recurring. This theme is **energy** (specifically energy savings and energy efficiency measures) **in the built environment**. This theme, already highlighted in the problem definition, represents a suitable and feasible scope for our choice experiment. The investigation of choices made by key-decision-makers concerning energy savings and energy efficiency measures in the built environment is therefore the extent of our choice experiment.

After this first refinement, we further narrowed down the scope to a context, specific and practical enough, to be translated in a choice task to propose to our decision-makers. This step, the stimuli refinement, is presented in the following section.

4.2 Stimuli refinement

Having refined the problem under study and its scope we went on to refine the stimuli, that is the choice task or choice input to give to the decision-makers. A choice task is constituted by a context for the choice, followed by a finite set of alternatives described by a limited number of attributes. Each attribute has at least two levels describing it.

As context for the choice we decided to look into **policy plans**, at municipal level, **for the implementation of specific technologies** suitable **to reduce the energy consumption** in the built environment, more precisely **at the households level**. This choice has been made primarily considering the decision-makers that are at the centre of the investigation. The key-decision-makers, as previously defined, are personalities from different sectors and operating at different levels. Nevertheless, looking at their common features, we could assume that all of them would have been able to evaluate and compare any implementation plans, for the municipality of Amsterdam, concerning different technologies (but not focused on technical details) that could increase the energy efficiency and reduce energy consumption in the built environment, and at the households level.

4.2.1 Alternatives

Having the choice context clearly defined we listed nine possible alternatives, emerged from our case-study investigation (see Appendix I). All those alternatives were based on technological systems that are already implemented in Amsterdam; which are positively considered and still included as suitable solutions for future plans about the sustainable development of city. From this preliminary list we selected 4 alternatives:

1. Solar Roofs = implementation of solar energy production by installing PV panels on households roofs;
2. Smart grid = implementation of connections to the smart grid and diffusion of smart meters;
3. District Heating = implementation of the connection to the district heating network;
4. Energy Retrofits = improvement of the current conditions of buildings through refurbishment, better insulation measures, upgrade of the households' energy label.

For practical reason we anticipate the final result of the total stimuli refinement step. In fact, eventually we selected only three of the four listed alternatives. While defining the attributes level for the **Smart grid** alternative, we encountered some practical barriers principally due to the loose definition of smart grid and smart meters, which made it prone to different interpretation of what a policy plan related to it could include. We therefore finalized our list of alternatives to the following three:

1) **Residential PV system**
2) **District Heating**
3) **Energy retrofit – thermal insulation**

It is important to start mentioning that, during the third stage of the choice experiment design, we decided to have **unlabelled alternatives**. This means that the decision-makers will not know which technological system is related to the policy plan that he or she is choosing. Two main reasons led to this choice. First and more important, to avoid bias that might exist for different respondents and that would compromise the results of our experiment. Decision-makers might have personal interests, opinions, or misconceptions about any of the three technological systems, and we need to avoid these factors to take part in their final decision. Second, to have a choice experiment of reduced size. In fact, the amount of choice sets that needs to be included and the amount of respondents that needs to answer to the questionnaire vary in combination to the composition of the choice experiment. Labelled alternatives require a more complex and larger experiment, which was not a feasible option for our research.

4.2.2 Attributes

The preliminary list of attributes to be possibly used to describe the three final alternatives was very large, it included more than 20 possible attributes (see Appendix I). This list was initially reduced by firstly eliminating the redundancies; secondly by removing the attributes with subjective interpretation (e.g. affordance, consumer's comfort); thirdly by grouping the attributes describing similar alternatives' characteristics; and finally by eliminating also those that were found not significant. We eventually had a list with six possible attributes, presented in table 4.1 with a short description.

Table 4.1 – First reduced list of attributes with their description

ATTRIBUTES	Attributes' description
Ease of implementation for the municipality	According to the different levels of infrastructure to be implemented in order for the technological system to be operative and effective.
Energy savings	Thanks to the implementation of that specific technological system this represents the amount of energy that can be saved per year, when the implementation is fully achieved.
Energy label upgrade	Thanks to the implementation of that specific technology the house can increase its energy label.
Effect on the environment (environmental Improvement)	Amount of CO_2 that can be saved (not emitted) with the implementation of that specific technological system (CO_2 in metric tons per year).
Cost for the policy	Cost to be undertaken by the municipality promoting the implementation of a specific technological system. The money is

	to be invested in subsidy for citizen or for the establishment of the appropriate infrastructure.
Competence area / Energy-problem addressed	To describe which energy-use the technology is going to address. For instance: electricity, electricity and heating, electricity and hot water, heating, (heating and hot water), heat loss.

This first set of attributes was further reduced to the smaller and final set of 4 attributes. This has been done mainly for one important reason: the information about decision-makers' preferences that we would have been able to obtain from it. Looking critically at our initial attributes' list we noticed that the attributes *Energy savings, Energy label upgrade* and *Effect on the environment* were all aiming at gathering the same information: the importance of energy efficiency (and the relative impact on the environment) for the decision-maker. Eventually from these three attributes we only kept one, *Energy savings*. The name of the first attribute also changed in the final set, where it is named *Difficulty of implementation for the municipality*. This has been done after a final review of the choice set's settings with a choice modelling expert. The reasoning is, also in this case, linked to the perception the final decision-makers might have of an ill-defined attribute.
In table 4.2 the final list of attributes with their description and units is presented. The same table was given to the respondents of the questionnaire.

Table 4.2 – Final Attributes' list with description and measurement units.

ATTRIBUTE NAME	DEFINITION	UNITS
Difficulty of implementation for the municipality	Describes the different levels of complexity of the infrastructure that is required to be implemented, in order for the technological system to be operative and effective.	Low, Medium
Energy savings	As a result of the implementation of that specific technological system this represents the percentage of energy that can be saved by 2020, if the implementation is fully achieved.	%
Cost of policy implementation	Cost to be undertaken by the municipality supporting the implementation of a specific technological system. This cost is intended to describe the investments in subsidy for citizen or for the establishment of the appropriate infrastructure.	€
Competence area addressed	Describes which types of energy consumption the technology is going to tackle.	Electricity, Heating…

4.2.3 Attributes' Levels

With the final list of attributes defined, the next step consisted in the identification of the levels of each attribute, that is all the possible values they can assume within the choice experiment. Solid attributes' levels are of great importance for the statistical validity of the model. As a matter of fact they need to be realistic, balanced, and all within a valid range to avoid the creation of most preferable alternatives. In our case this task was particularly tricky for the *Energy savings* and *Cost of policy implementation* attributes. This is because the different alternatives, described by those attributes, were representing a technological system implementation on a municipal level. Therefore we needed to define the requirement of such system, the size of the implementation plan and the characteristics of the technologies so to be able to have a solid base to make the calculation to obtain the levels of energy savings and to calculate accordingly the policy costs.

4.2.3.1 Energy Savings' Levels

After initial attempts of making valid assumptions based on literature concerning the percentages of energy savings, we came across a tool perfectly fitting our requirement. Blok et al. (2015) in their report '*The Energy Productivity and Economic Prosperity Index*', measure the current energy consumption and energy efficiency levels of existing technologies and show how an efficient use of the current technological systems could already significantly increase the energy productivity performances (Blok et al., 2015). To do so they compared a Business-as-Usual scenario and a High Energy Productivity Growth scenario, which were modelled using a web-tool developed by Quintel Intelligence: the Energy Transition Model (https://pro.energytransitionmodel.com/).

With this modelling tool we were able to develop a basic scenario describing the energy system in 2020 with the current technological system and a few general efficiency measures implemented. From this basic setting we developed three scenarios each one corresponding to the implementation of one of the three technological-systems represented in the three Alternatives. All the scenarios shared the common settings, beside those included in the basic scenario, such as: the end-year for which all the values are calculated is 2020; the selected country is The Netherlands; the region of interest is scaled to the number of households in Amsterdam (417,096). The features that were chosen as main settings for the Basic scenario are shown in table 4.3

Table 4.3 – Settings of the Basic scenario for Amsterdam's energy system in 2020

BASIC SCENARIO https://pro.energytransitionmodel.com/scenarios/302783	
Residences built before 1992	300 k
Residences built after 1991	117 k
COOKING:	
- Gas	20%
- Electric	30%
- Halogen	20%
- Induction	30%
- Biomass	0%
Appliances	20 % efficiency increase for all appliances
LIGHTING	
- Incandescent	20%
- LED	40%
- Low-energy Bulb	40%
Behaviours	50% increase in all behaviours
FINAL ENERGY USE	**-10%**

For all the following scenarios these settings remain the same. Hereafter are included the tables presenting the settings that were specifically changed for the other scenarios, each one representing one of our three alternatives. Moreover in each table the three levels of implementation assumed for that specific technological system are shown. In the last raw of each table it is shown the final-energy-use calculated by the model with those specific input settings. Those are the final values of the three levels of the *Energy saving* attribute for the corresponding alternative. It must be noted that the values reported in the tables are the results of the actual value of energy use calculated by the model with the different scenario's settings, minus the final-energy-use value calculated for the basic scenario (-10%).

Table 4.4 – Settings of the Solar panels' scenario for Amsterdam's energy system in 2020

SOLAR PANEL SCENARIO https://pro.energytransitionmodel.com/scenarios/302786			
ATTRIBUTES' LEVELS	Level 1	Level 2	Level 3
SOLAR PANELS			
PV panels	50%	75%	100%
Solar Thermal Collector	25%	50%	75%
FINAL ENERGY USE	**- 3.2%**	**- 5.2%**	**- 6.9%**

Table 4.5 – Settings of the District Heating's scenario for Amsterdam's energy system in 2020

DISTRICT HEATING SCENARIO https://pro.energytransitionmodel.com/scenarios/302788			
ATTRIBUTES' LEVELS	Level 1	Level 2	Level 3
DISTRICT HEATING			
Gas CHP	20%	10%	10%
Biomass CHP	10%	20%	25%
Biogas CHP	20%	25%	20%
Geothermal	0%	5%	5%
Centralized	50%	40%	30%
SPACE HEATING			
District Heating	100%	100%	100%
FINAL ENERGY USE	**- 3.3%**	**- 4.8%**	**- 6.5%**

Table 4.6 – Settings of the Energy Retrofits' scenario for Amsterdam's energy system in 2020

ENERGY RETROFITS (thermal insulation) SCENARIO https://pro.energytransitionmodel.com/scenarios/302791			
ATTRIBUTES' LEVELS	Level 1	Level 2	Level 3
CONSTRUCTION & INSULATION			
Insulation level OLD residences (m2 K/W)	0.8	1.0	1.2
Insulation level NEW residences (m2 K/W)	2	2	2
FINAL ENERGY USE	**- 4.7%**	**- 6.4%**	**- 7.7%**

4.2.3.2 Cost for the policy's Levels

The *Cost of the policy* attribute, as previously defined, consists in the expense to be undertaken by the municipality supporting the implementation of a specific technological system. More precisely this cost is intended to describe the investments in subsidies for citizen or for the establishment of the appropriate infrastructure. In order to calculate the possible values we made two main assumptions:

1) The technological system would be implemented in the totality of the households in Amsterdam (417,096);
2) The municipality would grant, for each household, a standard economic contribution of 5% of the total investment costs necessary to fully implement the technological system.

To estimate the investment cost of each technological system we looked into the literature. In table 4.7 are shown the raw cost data, for each technology, gathered.
Eventually to obtain the final values of the levels of this attribute, we multiplied the investment cost for one technology, times the number of households in Amsterdam obtaining the total cost. From this we calculated the 5% having assumed this being the percentage the municipality would invest through subsidies.

Table 4.7 – Primary data to calculate the levels of the Cost for the policy attribute

	Level 1	Level 2	Level 3	Source
Residential PV system	1750 $/kw	2200 $/kw	2400 $/kw	(IEA-ETSAP & IRENA, 2013) Conversion $ to made with(Yahoo Finance, n.d.)
District Heating	1448.8 €	2151,3 €	/	(Blok et al., 2015; Ecofys, n.d.)
Energy retrofits	2100 €	4000 €	4500 €	Agenshap NL (2011) and Arcadis (2013) retrieved from (Quintel, 2014)

4.2.3.3 Difficulty of Implementation for the municipality's Levels

For the *Difficulty of Implementation* attribute, which aims at describing the complexity level of a possible system implementation, we decided to have qualitative levels. *Low, Medium* and *High* are the three levels defined to measure this attribute. According to our case study research, even though a district heating system is already in place in Amsterdam, a large implementation of such system will necessarily require more complexity and infrastructure than would be needed for the other two alternatives. For this reason we choose to only have two levels (*Medium* and *High*) for the District Heating's alternative.

4.2.3.4 Levels of Competence Area Addressed

The *Competence Area Addressed* attribute was included in the final list with the aim of assessing whether decision-makers prioritize certain type of energy requirements rather than others, as well as assessing whether it takes any part in the decision-making process. In the literature there isn't a final position on the matter concerning which type of energy is dissipated the most, however a large consensus agrees on heating being the most wasted at the households levels (Blok et al., 2015; Boermans et al., 2015; van Bueren et al., 2012).
Therefore we suggested for this attribute two (for the first alternative) and three (for the second and third alternatives) descriptive levels.

4.2.3.5 The Choice set matrix

At this point we had gathered all the necessary information to create a complete choice set matrix. The full matrix is shown in table 4.8, together with the corresponding coding syntax (included in the squared brackets). Once again we must anticipate the narration of the design process to make the reader aware of the fact that the final choice sets did not contain all the attributes' levels that were previously defined. The preliminary complete choice-set matrix can be found in Appendix I. Here it is instead presented the final choice-set matrix used for the choice experiment. The significant reduction was done during the process of choice set generation with the specific software tool. It was a reduction determined by practical reasons: to have a choice experiment of restrained dimensions so to be able to actually gather a sufficient amount of choice data, and, more importantly to maintain the *orthogonality* [5]. More levels mean high response variability taken into account and therefore high accuracy of results. Nevertheless the amount of levels given for each attribute has a large impact on the process of choice set generation. A high amount of levels leads to a high amount of choice sets, which in the end leads to a large experiment and a to a large number of respondents needed to fulfil the statistical requirements.

Table 4.8 – Complete Choice set matrix with coding.

	OPTION A	OPTION B	OPTION C
Difficulty of implementation for the municipality	Medium [1]	Medium [1]	Medium [1]
	High [2]	High[2]	High [2]
Energy savings	3.2% [1]	3.3% [1]	4.7% [1]
	5.2% [2]	4.8 % [2]	6.4% [2]
	6.9% [3]	6.5% [3]	7.7% [3]
Cost for the policy	39,000,000 € [1]	37,500,000 € [1]	55,800,000 € [1]
	42,700,000 € [2]	55,700,000 € [2]	62,800,000 € [2]
Competence area addressed	Electricity [1]	Heat loss prevention [1]	Heat loss prevention [1]
	Electricity and Hot water [2]	Heating and hot water [2]	Electricity and Heating [2]

4.3 Experiment

Having defined all the stimuli to be included in the choice tasks we could proceed with the next step: the generation of the choice experiment. We were able to create an experimental design with the guidance of a CM expert, and the use of *Ngene* (ChoiceMetrics, 2011a), a specific software for the generation of experimental design to be used in stated choice experiments with the aim of estimating choice models (ChoiceMetrics, 2011b).

The code used for the generation of the experimental design is included in Appendix I. Herby we discuss the design choices that have been made. First of all, we decided to have a **Fractional Factorial Design**. It consists of a design of the experiment where only a limited amount of all the possible attribute-level combinations is included. Its opposite is

[5] The concept of Orthogonality is explained in the following section.

the Full Factorial Design and includes all the possible attribute-level combinations; therefore it easily results in a very large number of choice sets.
Secondly, we wanted our experiment to be **Orthogonal**: "*An orthogonal design is said to be orthogonal if it satisfies attribute level balance and all parameters are independently estimable. This translates into the definition that the attribute levels for each attribute column in the design need to be uncorrelated*" (ChoiceMetrics, 2011b, p. 64). There are several important reasons supporting the use of orthogonal design. The most important are: (1) that it allows estimating the influence of each attribute on the choice outcome independently from the other attributes; and (2) that, considering the relation between choice experiments and linear regression models, orthogonality is fundamental as it serves to avoid multicollinearity and to minimize the variances in the parameters that will be estimated, or in other words to "*maximize the power of the design to detect statistically significant relationships (i.e., maximize the t-ratios at any given sample size)*" (ChoiceMetrics, 2011b, p. 66). Lastly, orthogonal designs are generally easier to obtain even through software packages.
Thirdly, we decided to have a **main effects** design only, without looking into the interaction effects. An effect is the impact a particular combination attribute-levels has on the choice outcome. A main effect is defined as the direct impact that each attribute has on the response variable independently from the others. An interaction effect is the impact that a combination of two or more attributes has on the response variable (Henser et al., 2005).
Furthermore, as previously anticipated, with all the attribute levels we originally wanted to include, the first attempt in generating an experimental design resulted in a too large experiment (around 100 choice sets). Therefore we had to minimize the initial attribute levels considered. We decided to maintain three levels for the *Energy Savings* attribute and to only have two levels for every other attribute. Eventually we made the necessary modification in the code (see Appendix I) to generate a **Sequential Orthogonal Fractional Factorial Design** with **twelve rows** (i.e., attribute-level combinations and therefore 12 choice-sets). More specifically the syntax `'rows = 12'` indicates to the software to choose only 12 choices sets out of all the possible choice sets. The following line `'orth = seq'` indicates that the property of orthogonality must held only among attributes within the same alternative. The 12 choice sets, then, will be chosen accordingly. Furthermore, the absence in our code syntax of the `'fact'` property/line implies that the MNL model will be later used to analyse the results and therefore Ngene will optimize the design of the experiment accordingly.
At this point the design of the experiment was completely defined and the software generated the attribute-level combinations as specified in the code. In figure 4.1 the first choice set generated by the software is presented. In Appendix I all the choice sets are included together with the table synthetizing all the treatment combinations.

Scenario 1

	alt1	alt2	alt3
a	1	2	1
b	1	2	3
c	1	1	2
d	1	2	2
Choice question:			

Figure 4.1 – First of the choice set as generated by the Ngene software.

4.4 Questionnaire & Online Survey

The questionnaire we developed for our choice experiment is composed of three parts plus an extensive introduction. Before going into details on these parts we want to clarify that what is shown here is the final result following several attempts and a trial session in which a preliminary version of the questionnaire was given to five respondents (not part of the actual target group). The feedbacks received from it were implemented in the final version. Eventually, once the questionnaire was finalized the online version for the Internet survey was developed as well, using the online platform Collector ("Collector," 2011).
In the following sections we will present all the parts composing the questionnaire and the survey, which are identical in all their features.
The final version of the questionnaire is included in Appendix E. The survey, originally accessible with through the link (http://tbm.collector-survey.tudelft.nl/nq.cfm?q=11F7BE6B-C697-4973-88A9-CAAC07746FC8), cannot be accessed anymore as it expired when the timeframe given for the data collection ended. The survey has been online from the 10th October 2016 to the 15th December 2016.

4.4.1 Introduction

The aim of the introduction is to briefly introduce the research, to give an overview of what is included and the time it will require to complete it, as well as to guarantee the privacy protection of the information given by the respondents.
We didn't include any details on the scope of the overall research as this was individually explained to each respondent in the personalised email they received, where his or her participation to the study was being request.

4.4.2 Part 1 – Background Information

In the first part the specific context of the questionnaire is explained, giving to the respondent some useful information and data about it as well as the setting within which they are asked to undertake the rest of the questionnaire, particularly the choice sets.
More specifically a table is given with data about Amsterdam, among which the energy consumption of households and the national goal for energy savings. Following, a fictitious context is given to the respondent: a discussion concerning the improvement of energy efficiency in the residential stock by 2020. Then, it is asked to the respondent, in order to answer to the questionnaire, to imagine him-/herself in the position of a policy-analyst or a decision-maker for the city of Amsterdam, whose opinion has been asked for his or her personal knowledge and expertise in the energy sector and/or in the built environment.
Following this introduction to the context, some socio-demographic questions are included. From this type of data the only ones we considered useful for our research scope are the gender, the education level, the type of organization or company the respondent works for, his or her role in it, the duration of such role, and finally his or her possible participation in projects related to some of the topic investigated by our research (e.g., energy system in Amsterdam, residential stock in Amsterdam, energy metabolism, urban metabolism…). We also asked for the name of the participants, but only to checkout from the list of participants the decision-makers who already had fill-in the questionnaire.

4.4.3 Part 2 – Choice Experiment

The second part of the questionnaire is composed by the actual choice experiment. The 12 choice sets, estimated through Ngene, were recreated substituting the coding with the actual values and names defined for the attributes and attributes levels. In table 4.9 it is shown the first choice-set given in the final questionnaire and online survey. It is also included the main question driving the choice task. A short introduction to explain the choice task and the data included in the choice set was also given together with a table in which every attribute is individually explained (table 4.2).

Table 4.9 – First choice set as given in the questionnaire.

The three policy options to reduce residential energy consumption are here described according to the values assumed by the four attributes in this specific case. According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	High	Medium
Energy savings	3.2%	4.8 %	7.7%
Cost of policy implementation	39,000,000 €	37,500,000 €	62,800,000 €
Competence area addressed	Electricity	Heating and hot water	Electricity and Heating
Which option do you prefer?	A	B	C

4.4.4 Part 3 – Follow-up questions

To conclude the questionnaire we included five more questions. In the first three questions the respondents were asked to express their opinion, on a Likert scale (from 1 to 7), about: their perception on the sustainability of the energy metabolism in Amsterdam, in the first; on their perception of the importance that efficiency improvements, of the whole Amsterdam's energy system and of the residential stock, have on the municipal agenda, respectively in the second and third questions. The aim of these questions is to gather insights on the decision-makers' perception of the current status of Amsterdam's energy system. The fourth is an open question where respondents are asked to indicate whether and what type of information they felt was missing in the description of the policy-plans (i.e., the choice sets). This question represents a mean, for us, to individuate possible important attributes that were not considered as well as possible information missing in the description of the choice's context or in the attributes' explanation; but also to have some space for the respondents to give feedbacks. The final question asks the respondents whether they would like to receive the results of the study.

4.5 Collecting Preference Data

The process of collecting preference data was performed, mostly, through the survey method using the online platform Collector ("Collector," 2011).

From the decision-makers database we selected 135 respondents complying with the set requisites. We then contacted each one of the selected respondents individually via email, with a few exceptions. The emails were composed by a standardized text introducing the researcher, the research institutes and the partnerships (City-zen project, www.amsterdamsmartcity.com, AMS research centre); the aim of the research and of the questionnaire; the time required to complete the questionnaire and the timeframe during which it would have been possible. It included the link to the survey and the proposal of answering to the questionnaire through a face-to-face interview, if preferred. Towards the end it included a sentence highlighting the importance of the respondent's participation to the research, the willingness to share the results of the research, and the assurance of privacy guarantee for the respondents. The full text of the standardized email can be found in Appendix F.

For each respondent we personalized the email's text explaining why we included him or her in the research and occasionally how we came across to him or her name. We proceeded sending a follow-up email, also personalized, after some time had passed from the first contact only if we didn't receive any answer from them, nor to the email or to the survey.

As already mentioned there are a few exceptions of decision-makers that were contacted differently, precisely in two other ways. The first is by mean of word of mouth. During the data collection stage, in fact, we had the chance to have a few people forwarding the survey's link to third contacts who fitted our definition of key-decision-makers. The second is through the Amsterdam Smart City platform. Considering our collaboration (as little as it is) with the City-zen project we were given the chance to share the scope of our research and to advertise the participation to the survey through their community based website to a larger group of people, among which there could have been some decision-makers fitting our definition. Nevertheless the decision-makers reached through these two methods, who actually answered to the questionnaire, are a large minority (less then 5).

We carried out our choice experiment from the 10th October to the 15th December 2016. We contacted over 134 key-decision-makers asking them to participate to our enquiry. Among these, 17 decision-makers were excluded for technical reasons such as the correct email address was untraceable, the subject was retired or not working for the same company anymore or out of the office for a longer period than the survey's timeframe. A few of these decision-makers instead replied to our email explaining why they did not find themselves to be the appropriate respondents for our research. We managed to get in contact, properly, with 117 key-decision-makers. Out of those only 69 started the online survey, of which: 10 completed only the first part (i.e., the socio-demographic questions) of the survey; 1 completed the survey up to the second part (i.e., the choice sets); 2 completed the survey up to end without properly submitting their answers; instead 45 properly completed the survey. Besides, 1 decision-maker filled-in the questionnaire during a face-to face interview; 1 decision-maker was contacted telephonically on request, in addition to the reception of the email, but didn't complete the survey; 2 decision-makers asked for additional information via email concerning the scope of the research and the guarantee of their privacy, nevertheless neither of them completed the survey after the required information was given to them; finally we had the chance to meet personally one decision-maker after he filled-in the online survey to discuss the research. In total we have been able to gather 49 responses to our choice experiment and only 48 complete responses to the whole questionnaire. As a side fact, 33 respondents said to be interested in our research and left their email address to receive the final results.

4.6 Conclusions on the Choice Modelling Experiment

In this chapter we described how we developed the choice experiment, the questionnaire, how we collected the choice data and the final sample of respondents.

We firstly refined the problem narrowing it down to the high level of energy consumption in the built environment. More specifically, as context for the choice we decided to look into policy plans, at municipal level, for the implementation of specific technologies suitable to reduce the energy consumption in the built environment, more precisely at the households level. Afterwards we refined the stimuli (alternatives, attributes and attributes' levels) that compose the choice sets. We selected 3 technological systems as alternatives: (1) Residential PV system, (2) District Heating, (3) Energy Retrofit – thermal insulation. Four attributes are used to describe them: (1) Difficulty of Implementation, (2) Energy savings, (3) Cost of policy implementation, and (4) Competence area addressed. Two qualitative levels describe the first and the last attributes. The three levels describing the second attribute have been calculated through the development of 3 different scenarios, one per alternative, through on online model (The Energy Transition Model). The two levels of the third attribute have been calculated according to cost data from literature adapted to Amsterdam's energy system.

Once the choice-set matrix was defined we proceeded with the generation of the experimental design. The defined settings for our design are: Orthogonal Fractional Factorial Design with unlabelled alternatives and considering only the main effects.

Afterwards we developed a questionnaire and translated into an online survey format, which we used to collect the choice data. The data collection process lasted for more than a month and a half during which we have been able to engage 49 key-decision-makers. The result of the data collection and our choice model are presented in the next chapter.

Chapter 5
CHOICE MODEL'S RESULTS, AN INTERPRETATION

In this chapter we will now look into the actual results of the choice modelling experiment, firstly and most importantly, and into the rest of the questionnaire.
One clarification is due before proceeding with the analysis and interpretation of the results. It must be made clear that the authors have a limited knowledge of the statistical tools that are used in CM estimations, such as MNL, MLE, Hypothesis testing. Considering our research scope we can say that the CM is a mean to gather insights on decision-makers' preferences and not the focal point of the research. We therefore spent a fair amount of time and effort in investigating the above mentioned statistical tools to be able to fully understand the results of the choice experiment. Nevertheless the final analysis and interpretation of the result has been done with the guidance of a CM expert; instead the theory behind some statistical concepts and parameters intervals (e.g., log-likelihood, t-test, p-value) has been given for granted, since their complete investigation would have been outside the scope and timeframe of our research.
Before moving to the core results of the choice model, we present a description of the respondents' sample. In this first part are included the information we were able to gather through our questionnaire, the sample's socio-demographic characteristics and perception of Amsterdam's energy system.

5.1 Description of the Respondents' Sample

We present here the sample of key-decision-makers that we were able to engage in our experiment. We contacted decision-makers from all the 6 Nodes of Decision-Making (see Chapter 3.4) but not in the same amount. Decision-makers from the Government and from the three Energy-supply groups were the most difficult to contact. Difficulties were found firstly in individuating the appropriate decision-makers, and secondly in finding the contact's information to actually engage them. The information about individuals performing high-level roles in such institutions is very little, and there is not much transparency about the internal hierarchy. On the contrary, information about individuals performing high-level roles in the Knowledge Developers' group and in private and smaller companies, the one included in the Others group, was easier to find. Nevertheless we made as much effort as possible to contact a similar amount of decision-makers for each of the 6 Nodes. In the end we contacted over 134 decision-makers but only 49 fully responded to our survey with a response percentage of 36.6%.
In table 5.1 it is shown the amount of respondents we were able to engage for our choice model. For privacy guarantee we cannot include the name of the respondents, therefore we only present the name of the companies or organization they are part of.

Table 5.1 – Sample of Respondents grouped into the 6 Nodes of Decision-Making.

NODES OF DECISION-MAKING	ORGANIZATIONS or COMPANIES	N° of RESPONDENTS
Government	Geemente Amsterdam, Amsterdam Smart City, Ministry of Economic Affair, DCMR (Environmental Protection Agency), RVO (Rijksdienst voor Ondernemens).	6
Energy Producers	AEB (Nieuwe Stroom, ENECO).	3
Network Operators	Sympower, APX - Epex Spot, Delta Netwerkgroep (DNWG), Alliander, TenneT.	5
Energy Service Providers	Waternet, Nieuwe Stroom, ENECO (Sympower).	3
Knowledge Development	Eurbanlab, ECN (Energy research Center of the Netherlands), TNO, PBL (Environmental Assessment Agency), DNV GL, Accenture, Ecofys, EVOLV, IEE (Industrial Energy Expert), Utrecht University, Small (and Local) Conulting Companies.	19
Others	City-zen, Amsterdam Smart City, GreenIT, AFWC (Amsterdamse Federatie van Woningcorporaties), UNICA Ecopower, Ugenda, Posad, Valstar-Simonis, Sustainable Amsterdam, Resourcefully, De Groene Grachten, Spectral.	13

At the end of our experiment our sample results not fully balanced. In fact the key-decision-makers from the Knowledge Development and Others groups are over-represented in the sample. It must be noted, though, that within these two groups there is a higher variety of single organizations represented. On the contrary the key-decision-makers from the Energy Producers, Network Operators and Energy Service Providers groups are slightly under-represented in the sample, considering that they do not include a large variety of individual organizations within them. In our opinion also the decision-makers from the Government are only slightly under-sampled. The variety included in this group is in fact much inferior compared to all the others group, nonetheless a larger participation of key-decision-makers from the government would have been appreciated as they can be considered as the most influential among the key-decision-makers.

5.1.1 Socio-demographic characteristics of the Sample

In the first part of our Questionnaire we asked a few socio-demographic questions to the respondents in order to be able to better describe the final sample of key-decision-makers that we were able to engage in our research. These characteristics are here presented and their distribution is graphically shown.

The key-decision-makers' sample is prevalently composed by men (figure 5.1), only 10% are women, with a high level of education (figure 5.2), 73% posses a Master degree and 10% has a PhD degree. These sample's characteristics intuitively fit the totality of the population investigated. The presence of women performing high-level roles in both private and public institutions is still lower compared to the opposite gender's presence, and this is shown also in our sample.

Figure 5.1 _ Gender of the Respondents' Sample.

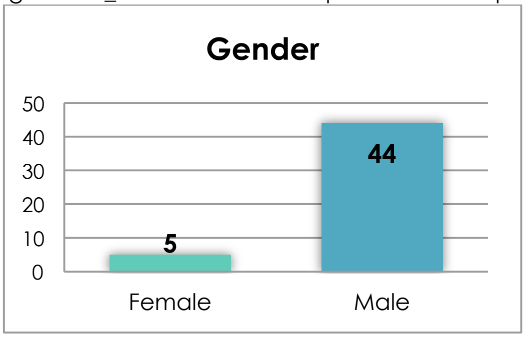
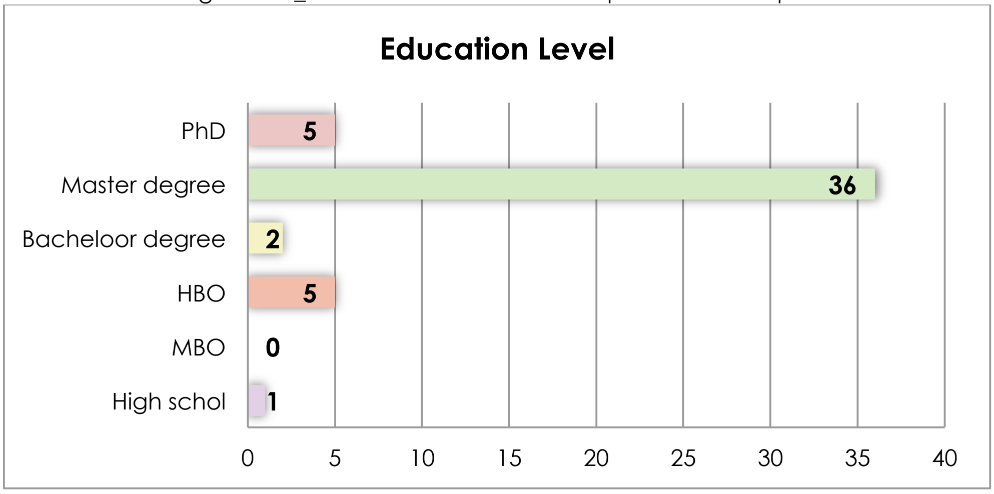


Figure 5.2 _ Education Level of the Respondents' Sample.



Afterwards we asked a few questions concerning the type of organizations or companies the respondents were working for, in that moment, their role in it (figure 5.3) and the duration of that role (figure 5.4). The first two questions were used to verify our information on each respondent.

As represented in our sample, and shown in the graphs, the key-decision-makers operating in the context of our research have managerial and leading roles, which they have been holding for a long period of time (61% for 4 years or more, 18% of which for 10 years or more).

Figure 5.3 _ Current roles as indicated by the Respondents.

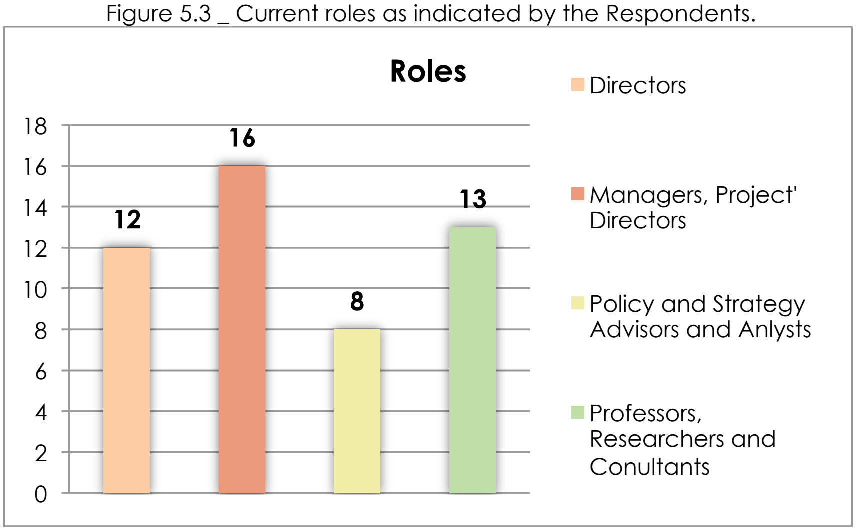
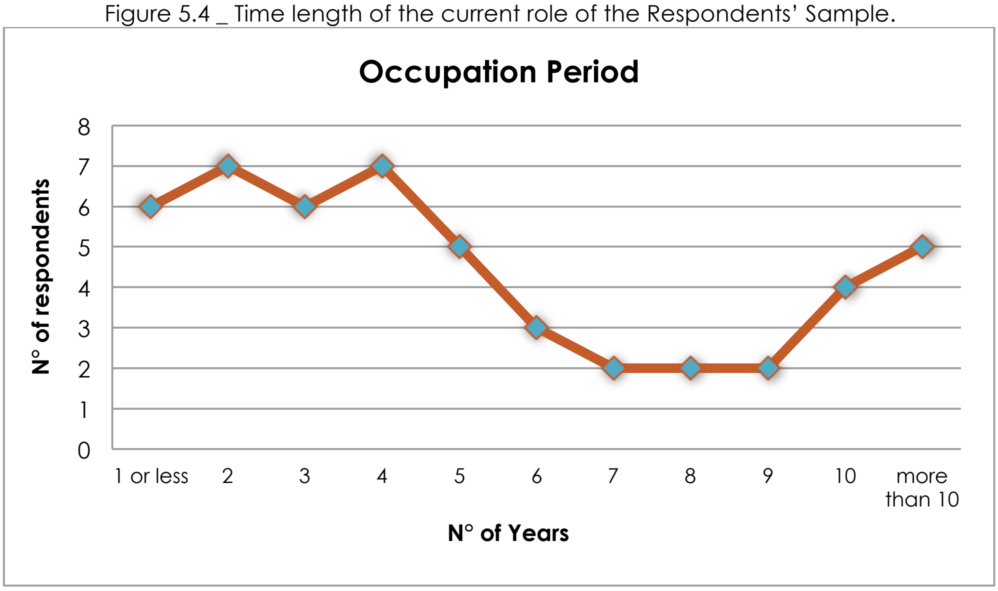


Figure 5.4 _ Time length of the current role of the Respondents' Sample.



5.1.2 Previous experience of the Sample

The last introductory question aimed at investigating the previous experiences and participations in projects related to some of the topics touched upon by our research. From the gathered answers we are able to extrapolate different types of information.

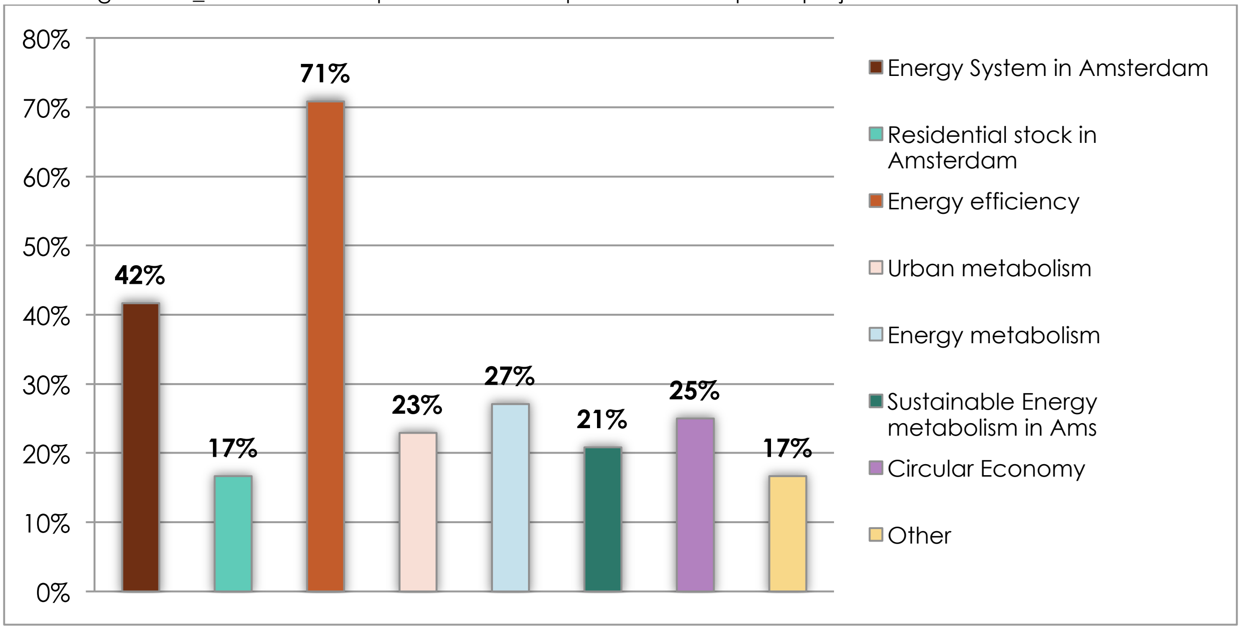
First, it represents an insight on the level of engagement of key-decision-makers in Amsterdam. In this regard, the 31% of the respondent had at least one previous experience, and the 39% had more than three previous experiences. Only one key-decision-maker didn't have any previous experience in the listed areas.

Second, it represents a source of information on the research areas and projects that are most investigated and active (figure 5.5). In this regard projects related to Energy Efficiency, not specifically for the city of Amsterdam, are the large majority, followed by projects on the Amsterdam's energy system.

Third, it also gave us a grasp of the most common terminology used and shared by key-decision-makers. In fact, outside of the academic field the concept of Urban Metabolism or Energy Metabolism are hardly used or even known. Therefore we wanted to verify this assumption by seeing how many decision-makers actually would define their previous experience using those 'labels'. As shown in the graph 27% of the respondents said to have previous experience in Energy Metabolism, and 23% in Urban Metabolism.

Among the projects' areas indicated within the 'Others' option there are: "*Urban Renewal Nation Wide*", "*Energy Strategy in the Built environment*", "*Energy Policy*", "*Telecommunication sector*", "*Resilient Infrastructure*", "*Cleantech industry*", "*Innovation system analysis built environment*". In the same line of reasoning used before, looking at the answers given by respondents to define their others experiences, we concluded that they used a different terminology to define very similar concepts to the one proposed by us (i.e.: "Energy Strategy in the Built environment", "Resilient Infrastructure", and "Innovation system analysis built environment", which are similar to our broader Residential stock in Amsterdam); also that they don't feel at ease with the concept of Energy Metabolism and Urban Metabolism, which could have been used, even though in a more general way, to describe the others project's areas indicated.

Figure 5.5 _ Previous Participation of the Respondents' Sample in projects related to this research.



5.1.3 Respondents' perception of Amsterdam's energy system

In the third and last part of the questionnaire we included three follow up questions to investigate the key-decision-makers perception of Amsterdam's energy system.

The first question (table 5.2) inquired the perception among key-decision-makers toward the energy metabolism. The results, considering the average score of 2.83 on a growing scale from 1 to 7, showed a strongly shared perception of an urban energy metabolism far from being sustainable and efficient. Almost 73% of the respondents express a vote equal or lower than 3 (i.e., below average).

Table 5.2 – First follow-up question, votes and average score.

To what extent do you perceive the energy metabolism* in Amsterdam to be sustainable and efficient? (*taking into consideration the circulation of energy inflows and outflows within the geographical boundaries)				
1 (Not at all)	**5**	**10%**		
2	**20**	**42%**	**Most common vote**	**2**
3	**10**	**21%**		
4	**7**	**15%**	**Average score**	**2,83**
5	**4**	**8%**		
6	**1**	**2%**		
7 (Completely)	**1**	**2%**		
NULL	**1**			
TOT	**49**	**100%**		

The second question (table 5.3) inquired the perception among key-decision-makers of the relevance, in the municipal agenda, given to the improvement of the residential stock's energy efficiency. In this case the votes were more evenly distributed with a slight

prevalence of the lower values, 31% of the votes are comprised between 1 and 3, compared to the 28% of the votes comprised between 5 and 7. The large majority of the respondents, more than 40%, chose the average vote.
In this regard we can conclude that the, considering the balanced votes' distribution, key-decision-makers have different perceptions of the importance the improvement of residential stock's energy efficiency has on the municipal agenda, or they don't have an opinion on the matter.

Table 5.3 – Second follow-up question, votes and average score.

To what extent do you think the improvement of the energy efficiency of the residential stock in Amsterdam is high on the municipal agenda?				
1 (Not at all)	**1**	**2%**		
2	**2**	**4%**	**Most common vote**	**4**
3	**12**	**25%**		
4	**21**	**44%**	**Average vote**	**3,94**
5	**8**	**17%**		
6	**4**	**8%**		
7 (Completely)	**0**	**0%**		
NULL	**1**			
TOT	**49**	**100%**		

The third question (table 5.4), similarly to the second, inquired the perception among key-decision-makers of the relevance the improvement of the total energy system has on the municipal agenda. The results are also similar to the previous question, in fact the votes are again evenly distributed and the average score is 4. Therefore we can one more time conclude that key-decision-makers have different perceptions, or they don't have an actual opinion on the matter.

Table 5.4 – Third follow-up question, votes and average score.

To what extent do you think the improvement of Amsterdam's energy system is high on the municipal agenda?				
1 (Not at all)	**0**	**0%**		
2	**1**	**2%**	**Most common vote**	**4**
3	**14**	**29%**		
4	**17**	**35%**	**Average vote**	**4,10**
5	**12**	**25%**		
6	**3**	**6%**		
7 (Completely)	**1**	**2%**		
NULL	**1**			
TOT	**49**	**100%**		

5.2 Results of the Choice Model

The analysis of the result of a choice experiment consists mainly of two parts: (1) the analysis of the data validating the model itself, and (2) the analysis of the values[6] concerning the validity of the utility coefficients or parameters (i.e., the β in our utility function[7]), to which follows the analysis of the coefficients themselves.
To analyse the results of the choice experiment we used a specific software for choice models estimation: BIOGEME 2.2 (Bierlaire, 2012).In order to do so we firstly downloaded the dataset from the survey platform and cleaned it by removing the data relative to the uncompleted choice sets. Afterwards, starting from this we created a new dataset complying with the software requirements. With the guidance of a CM expert we developed a suitable code in order for the program to run according to our requirements: the utility functions describing our alternatives and the use of MNL as regression model to be used to process the data. This code is included in Appendix J.
We run the code, with two different datasets, and performed the analysis twice. After the analysis of the first results, obtained with BIOGEME, we observed one unexpected value among our coefficients. We made a simple modification to our dataset (specifically we standardized the attributes levels values of one attribute) and obtained new results. These two analyses, even though similar, will both be explained in the following sections.

5.2.1 Analysis of the 1st results

As previously mentioned, the results' analysis is divided into two parts: the first is model validation, and the second is the analysis of the coefficients. We will explain our first analysis accordingly. The results that will be analysed here can be found, as given by BIOGEME, in the Appendix J.

5.2.1.1 Model validation – 1st results

The first series of values regard the model description and model validation. Describing the model there are values such as: the number of parameters estimated (i.e., the attributes' coefficients, 4 in our case), the number of observation (i.e., the choice sets times the amount of respondents), and the type of regression model used for the assessment (MNL in our case). The most important data related to the model validation are presented in table 5.5.

Table 5.5 – Main values for the model validation – 1st results.

Log-likelihood	Null log-likelihood	- 644.885
	Final log-likelihood	- 420.126
Rho-square	Rho-square	0.349
	Adjusted rho-square	0.342

The two log-likelihood values[8] indicate respectively the likelihood value at the starting point and at the end point of our model. For the model to be valid the likelihood value at

[6] T-test and p-value
[7] For the Utility function see chapter 2.1.1.1.
[8] These values are based on the Maximum likelihood estimation (MLE) model. This is based on the simple concept that any observed sample could be generated by different populations,

the end point (i.e. Final log-likelihood) needs to consistently decrease from its initial value. This is exactly what we observe in our values.
The two rho-square values, the most important of which is the adjusted rho-square, give a measure of the accuracy of the overall regression. Particularly they represent the percentage of the variance in the output (i.e., the β coefficients) that is explained by the variance in the input. As shown in the table, in our case this percentage is about 34%. In CM experiments this is considered a good value.
We can therefore say that our model has been validated.

5.2.1.2 Coefficients validation and interpretation – 1st results

The set of values describing the utility parameters obtained by the model is presented in table 5.6. Some of the values have been excluded as not relevant.

Table 5.6 – Information describing the Utility parameters, the β coefficients of the Utility functions – 1st results.

Attribute name	Utility parameter's label	Value	Standard error	t-test	p-value
Difficulty of implementation	EASE_IMPL	- 1.28	0.125	- 10.19	0.00
Energy savings	EN_SAVING	0.815	0.0541	15.05	0.00
Cost of the policy	COST_POLICY	- 7.58 e^{-8}	7.47e^{-9}	- 10.15	0.00
Competence area	EN_AREA	-0.0832	0.115	- 0.72	0.47

First of all, we have to look at the values given for ***t-test*** and ***p-value*** of each attribute. They are both related to the Hypothesis testing method[9] performed on samples.
The *t-test* value concerns the statistical significance of the β coefficients. In particular it is used to test whether a specific β is significantly different from 0. In CM experiments it is commonly recognised that when the *t-test* value of a utility parameter is either higher than 1.96 or lower than -1.96, then we can conclude that that parameter has an influence on the choice outcome (Bierlaire, 2009, 2012). Otherwise the utility parameter is defined as not significant. To the *t-test* is directly connected the *p-value*. The *p-value* measures the reliability of the coefficient's value. The closer to 0 the *p-value* is, the higher is the probability that the coefficient's value is not obtained by chance. Vice versa the farer from 0, and closer to 1, the *p-value* is, the higher is the probability that the coefficient's value is obtained by chance.
We have now explained how to read the two values' columns describing the validity of the coefficients and therefore we can proceed with the description of our results.
In our case the *t-test* values for the first three parameters are all significantly different from zero and therefore indicate that the relative attribute might have an influence on the

nevertheless one population is more likely to generate that sample than others. MLE are "that set of population parameters that generate the observed sample most often" (Louviere et al., 2000).
[9] In Hypothesis testing, patterns of observed data are compared to hypothesised data. It is tested whether the population means underlying the two samples are reliably different form one another, assuming a normal distribution for both samples. In Hypothesis testing there are two possible results: to reject or not reject the null alternative. We can reject the null alternative when the t-test value is significantly different from 0. Consequently this means that the parameter has an influence on the choice outcome. (Henser et al., 2005; Louviere et al., 2000)

choice outcome. The *t-test* value for fourth parameter, instead, is close to 0, which means that is not significant.
The same trend is observed in the *p-values*. The first three parameters have a *p-value* that is close to zero, which means that the values of the coefficient are not obtained by chance and therefore they actually represent the population preferences. Vice versa the fourth parameters' *p-value* is 0.47, meaning that there is 47% probability that the related coefficient's value is obtained by chance.
To complete the validation of the coefficients we can conclude that **the first three attributes might play a role in the choice outcome and they all have a utility coefficient that is not obtained by chance**. The magnitude and direction of their impact is given by the value of the parameter itself. The last attribute instead is found not being significant or statistically valid. We therefore can already conclude that, for reasons that will be investigated at a later stage, **the *Competence area* attribute does not play a significant role in the decision-making process in the observed sample**.
With these conclusions in mind we can now proceed interpreting the values of the three significant utility parameters.

The β coefficient of the ***Difficulty of Implementation***'s parameter is estimated being – 1.28. The minus sign represents the direction of the influence of this attribute on the choice outcome. In this case the direction is negative, which means that as the value of this attributes decreases, its influence on the choice outcome increases. Taking a step back from the technical interpretation, if we look at our choice experiment we can see how, intuitively, this result makes sense. That is: **when the level of difficulty for the implementation related to a specific technological system decreases, then the likelihood that the decision-maker will choose that alternative** (i.e., the technological system) **increases**. The magnitude (1.28) of this parameter is quite substantial, especially when compared to the magnitude of the other two significant parameters (0.815 and 7.58$\boldsymbol{e^{-8}}$).

The β coefficient of the ***Energy Savings***' parameter is estimated being 0.815. The positive sign means that it has a positive direction of influence. Looking at our choice experiment this means that: **with the increasing of the levels of energy savings related to a specific technological system, the likelihood that a decision-maker will choose that alternative increases as well**. The magnitude (0.815) of this parameter is also quite substantial, although less than the first parameter.

The β coefficient of the ***Cost of the policy***'s parameter is estimated being – 7.58$\boldsymbol{e^{-8}}$. The negative sign means that it has a negative direction of influence. Looking at our choice experiment this means that: **with the decreasing of the cost related to the implementation of a specific technological system, the likelihood that a decision-maker will choose that alternative increases**. The magnitude (7.58e^{-8}) of this parameter is extremely little, which can be translated in a very small contribution of this attribute to the final choice outcome.

Now that we have individually interpreted the three valid parameters we could conclude our results' description saying that: considering our sample of decision-makers and the settings of our choice experiment it has been found that the two aspects that play a major role in the decision-making process of key-decision-makers are the Difficulty of implementation, first of all, followed by the Energy savings.

However we were not convinced by the extremely small influence played by the *Cost of the policy* attribute in the decision-making process. Therefore we took a step back looking for possible interpretations and reasons behind this, and as a result we realized that the order of magnitude of the levels of this attribute was 10^7 times higher than the order of magnitude of the other parameters' levels (i.e., 39,000,000 compared to levels such as 3.3% and 1 or 2). With this in mind we standardized [10]the dataset used to calculate the model's result and then we run again the model with BIOGEME. These second results and the final interpretation of our choice experiment are given in the following sections.

5.2.2 Analysis of the 2nd results

With the standardized dataset we run again the model with BIOGEME and obtained the following results about the model validity and about the parameters' coefficients. The results that will be analysed here can be found, as given by BIOGEME, in the Appendix J.

5.2.2.1 Model validation – 2nd results

The data related to the model validation, with the 2nd dataset, are presented in table 5.7. As we can see the value of the initial likelihood is the same as we had the first time. This is correct since the experiment is the same and the main features of the dataset have not been changed. The value of the final likelihood is almost the same but slightly smaller than the one we obtained before. Therefore we still observe a decreasing from the initial to the final value and therefore our model can be considered valid up to this point.
The rho-square values are exactly the same as in the first set of results. Also in this case we have 34% of the variance in the output that is explained by the variance of the input, which is generally considered a good value in CM experiments.

Table 5.7 – Main values for the model validation – 2nd results.

Log-likelihood	Null log-likelihood	- 644.885
	Final log-likelihood	- 420.112
Rho-square	Rho-square	0.349
	Adjusted rho-square	0.342

From the data related to the model validation we can positive conclude that our choice model is abundantly valid, also with the standardized dataset.

5.2.2.2 Coefficients validation and interpretation – 2nd results

The set of values describing the utility parameters obtained by the new model is presented in table 5.8. Some of the values have been excluded as not relevant.

Table 5.8 – Information describing the Utility parameters, the β coefficients of the Utility functions – 2nd results.

Attribute name	Utility parameter's label	Value	Standard error	t-test	p-value
Difficulty of implementation	EASE_IMPL	- 1.29	0.125	- 10.29	0.00
Energy savings	EN_SAVING	0.814	0.0541	15.04	0.00
Cost of the policy	COST_POLICY	-0.759	0.0748	- 10.14	0.00

[10] We changed the order of magnitude of the levels of the cost of the policy attribute so that it was standardized to the order of magnitude of the levels of the other attributes, 10^{-1}.

Competence area	EN_AREA	- 0.0706	0.116	- 0.61	0.54

The first thing we need to look at, once again, are the parameters' values obtained for the ***t-test*** and the ***p-value***, in order to see whether the relative coefficient's value can be validated or not. Just as for the first results, also in this case the *t-test* and *p-value* for the first three coefficients are respectively significantly different from zero and very close to zero. This can be translated as: the first three parameters might have an impact on the choice outcome, and it is very unlikely that their coefficients' values have been obtained by chance and therefore they actually represent the population preferences.
Vice versa the opposite is estimated for the fourth parameter. Its *t-test* and *p-value* are, in fact, respectively very close to zero and very far from zero. Which means that the parameter does not have an impact on the choice outcome and especially that is likely (54%) that the value has been obtained by chance.

Once again we can complete the validation of the coefficients concluding that **the first three attributes might play a role in the choice outcome and they all have a utility coefficient that is not obtained by chance**. The last attribute, instead, is found being not significant or statistically valid. We therefore can already conclude that, for reasons that will be investigated at a later stage, **the *Competence area* attribute does not play a significant role in the decision-making process in the observed sample**.

This time, in analysing the value of the parameters' coefficients, we have expectations derived by the first set of results. We expect the coefficients of *Difficulty of Implementation* and the *Energy Savings* to be respectively negative and positive, but both significant. Though, going back to the motivation for the second run of the model, we want to know whether the *Cost of the Policy*'s coefficient, that we expect to be negative, actually has a significant impact on the choice output; or whether, even with the standardized dataset, the coefficient remains too small to be taken into consideration. We can now look at them individually.

The new β coefficient of the ***Difficulty of Implementation***'s parameter is estimated being – 1.29. As we expected the parameter is again negative, and its magnitude is basically the same as the previous result (which was - 1.28).

The new β coefficient of the ***Energy Savings***' parameter is estimated being 0.814. As we expected the parameter is again positive, and in this case its magnitude is again basically the same as the previous result (which was 0.815).

The new β coefficient of the ***Cost of the policy***'s parameter is estimated being – 0.759. Also in this case the parameter is again negative, as expected. What is most interesting to observe is that, with the standardized dataset, this parameter, and the related attribute, seems now to actually play a role in the choice outcome, considering its magnitude. Nevertheless, compared to the other two parameters this is still the less relevant, as slightly smaller than the Energy savings' coefficient.

To conclude the description of the three valid parameters, obtained in our second model, we can say that: considering our sample of decision-makers and the settings of our choice experiment it has been found that **the three aspects playing a role in the decision-making process of key-decision-makers are the *Difficulty of implementation*, first of all, followed by the *Energy savings* and finally by the *Cost of the policy* attributes**.

5.3 Interpretation of the Choice Model results

Before unravel our discussion and interpretation of the results of our choice model we first want to recall the research sub-question guiding this part of our research, and secondly the conceptual heart of CM, the RUT and the Utility function in particular.
The research question guiding us in the development of the choice model experiment and in the results' interpretation is:
What are the preferences of the different key-decision-makers involved in the urban energy system?

The Utility function, instead, is the mathematical expression of the "utility maximizing behaviour" (Henser et al., 2005) rule, which states that individuals, when facing different choice alternatives, will supposedly choose the one that provides them with the highest utility or satisfaction (Devinney & Lin, 2011; Henser et al., 2005).

$$U_i = \beta_{0i} + \beta_{1i} f(X_{1i}) + \beta_{2i} f(X_{2i}) + \beta_{3i} f(X_{3i}) + \cdots + \beta_{ki} f(X_{ki}) + \varepsilon_i$$

The various $\beta_{\mathrm{k}i}$ in the Utility formula are the parameters representing the weight each attribute will have on the total utility perceived for a specific alternative.

With our choice model we have been able to individuate the values assumed by the various $\beta_{\mathrm{k}i}$, that is the weight, or better, the importance each attribute has for the sample of key-decision-makers inquired. Consequently, knowing the importance each attribute has on the choice outcome gives us an understanding of what is taken into account the most and in what direction (negative or positive) when choosing among different alternatives, in our case, concerning the reduction of energy consumption in the built environment. In other words we have been able to gather insights about the preferences of the sample of key-decision-makers investigated.
In the rest of the section we will individually look at the three valid coefficients and discuss what they represent in terms of decision-makers' preferences. In table 5.9 it is presented a summary of this discussion.

Table 5.9 – Summary of the attributes, their coefficient and their interpretation.

ATTRIBUTES NAME	Description	Levels	β Coeff.	Coefficients' interpretation
Difficulty of implementation for the municipality	Describes the different levels of complexity of the infrastructure that is required to be implemented, in order for the technological system to be operative and effective.	Medium High	**- 1.29**	**Negative and strong influence**. When the level of difficulty for the implementation of the policy-plan decreases (only 2 levels were considered) the utility perceived for that policy-plan increases. Intuitively it means that key-decision-makers prefer technological-systems that are relatively easy (or easier) to implement. In our choice model this happens to be the attribute with the highest influence on the choice outcome.

Energy savings	As a result of the implementation of that specific technological system this represents the percentage of energy that can be saved by 2020, if the implementation is fully achieved.	3.2% 5.2% 6.9%	**0.814**	**Positive and relatively strong influence**. When the percentage of energy savings related to a technological-system increases it also increases the utility perceived for that alternative. Intuitively it means that key-decision-makers prefer technological-systems that entail higher energy savings results. Nevertheless, in our choice model, it results that this is not the first aspect that is taken into account when evaluating different policy-plans.
Cost of policy implementation	Cost to be undertaken by the municipality supporting the implementation of a specific technological system. It describes the investments in subsidy for citizen or for the establishment of the infrastructure.	3.90 (10^7) € 4.27 (10^7) €	**-0.759**	**Negative and relatively strong influence**. When the total cost to be undertaken by the municipality to implement a policy-plan decreases the interest toward that option increases. Intuitively it means that key-decision-makers prefer technological-systems that are less expensive. Nevertheless, in our choice model, this attribute happens to be the third one to be considered when evaluating different policy-plans, contrarily to our expectations.
Competence area addressed	Describes which types of energy consumption the technology is going to tackle.	Electricity Electricity and hot water	/	This attribute, in our choice model, resulted to be **not significant for the choice outcome** and not reliable (56% chances to be obtained by chance). We can say that this attribute does not play any role in the evaluation of different policy-plans.

5.3.1 Difficulty of Implementation for the Municipality - Interpretation

The *Difficulty of Implementation* attribute, in our choice model, is the most important, the attribute that exert the higher influence on the choice outcome. According to our results we can say that key-decision-makers clearly **prefer technological systems requiring the lowest level of complexity for their implementation**. The level of disturbance on the energy system linked to a specific technological system is of great importance for key-decision-makers and **they are willing to undertake and support low levels of disruption**. In more technical terms, when the level of difficulty for the implementation of the proposed policy-plan decreases the perceived utility increases.

One of the assumption we made while including this attribute in the final list was the fact that key-decision-makers, considering their position and role in the energy system, might be influenced in their choice by the strive for legitimacy or in general by the fact that they care about the public opinion and the return specific decisions might have on their public image. As many scholars, in the field of policy and politicians' preferences analysis suggest (Chorus, 2015; Chorus et al., 2011; Sabatier & Weible, 2014) the perceived public and political acceptability related to specific policy plans usually take part in the decision-making process. Nevertheless, even if we strongly believe that this aspect played an actual role, this remains a personal interpretation and speculation since in the description of the attribute, as given to the decision-makers, the element of public acceptability was not clearly mentioned.

Our expectation on this attribute was confirmed and exceeded, since we intuitively assumed the ease of implementation would have played an important role but we did not foresee it would have been the most impacting attribute. Nonetheless, interestingly enough, during one of the 5 trial sessions of the questionnaire, we were able to ask to the respondent how she perceived the attributes and which in her opinion was the most significant one in her final choice. In this particular case her feedback completely comply with the choice model results since the Difficulty of Implementation was exactly the first attribute she took into consideration for every choice-set.

Two more aspects should be taken into account in the interpretation of this attribute. Firstly the qualitative labels used to describe the attribute's levels: *Medium* and *High*. These levels' labels are indeed open to interpretation and they might have played a bigger impact than expected. For instance, it is possible that whenever the respondents were faced with a choice-set where one alternative was described with a High Difficulty of Implementation, the rest of the attributes for the same alternative were not considered at all as the personal expectancy and interpretation connected to the *High* label acted as a shield towards the rest of the characteristics describing that alternative.
Secondly, this attribute was always the first one presented to describe the alternatives. The static order of the attributes throughout the choice model might therefore have played a role in the decision-making process, consequently on the choice outcome and on the parameter estimate.

5.3.2 Energy Savings - Interpretation

The *Energy Savings* attribute, in our choice model, is the only positive attribute. The implication of the positive direction is that: **as the level of energy savings increases so does the utility perceived for that alternative**. Intuitively this means that key-decision-makers prefer technological-systems that entail higher energy savings results.

In our choice model, this attributes is the second in order of importance, meaning that that this is not the first aspect that is taken into account when evaluating different policy-plans. One interpretation behind this might be given in addition to the interpretations given for the first and most impacting attribute (*Difficulty of Implementation*). Although it is possible that there is a lack of knowledge and awareness concerning the burden carried by urban areas and more specifically the built environment on the overall energy system, in our opinion, this is note actually the motivation behind the estimate of this parameter. In fact, more than to a real lack of knowledge, the lower estimate of this parameter might be due to the fact that in reality, even though the benefits of a technological implementation are abundant and significant, key-decision-makers, as such, need to take other aspects much more into account, as it is the case for the *Difficulty of Implementation*. This might result in a trade-off among alternatives where a technological system with a lower level of *Energy Saving* and a low *Difficulty of Implementation* is preferred to a technological system with higher levels of *Energy Savings* and higher *Difficulty of Implementation*.
For instance, in our specific case, the implementation of thermal insulation measures, on the totality of the residential stock in Amsterdam, could bring over 7% of energy savings. Nevertheless the implementation of such plan would require a great deal of effort from the municipality, but mostly it would require the consumers to accept and be willing to

take upon the implementation themselves. The result of these considerations might be the trade-off of the above alternative for one that has less energy savings but that is easier to implement or less expensive.

5.3.3 Cost of Policy Implementation - Interpretation

The *Cost of Policy Implementation* attribute, in our choice model, has basically the same impact on the choice outcome as the *Energy Savings* attribute, but with a negative influence's direction. This means that **as the cost to be undertaken by the municipality** to implement a policy-plan **decreases the utility perceived for that alternative increases** instead. Intuitively this means that key-decision-makers prefer technological-systems that have a lower economical burden.

Even though the impact of the Cost of Policy Implementation and the Energy Savings attributes are similar, the actual magnitude of this parameter estimate is the lowest of the three valid attributes. This result was very surprising as we expected this to be the most impacting factor in the choice outcome, considering the typology of decision-makers investigated.

5.3.4 Competence Area Addressed - Interpretation

As already mentioned this attribute **has not been validated** by the results of our choice model. The motivations might be several: a poor definition of the attribute and of its levels; compared to every other attribute, this could have been easily perceived as unrelated and irrelevant; the levels labels given for each alternative were different and, most importantly, difficult to compare (e.g., 'Heating and Hot water' compared to 'Electricity and Heating').

Furthermore, the lacking of validation also implicates that the attribute is found to have **no effect on the choice outcome** of the respondents' sample. We decided to include this attribute since there are some areas of energy consumption, in the built environment, which are more impacting and problematic than others (i.e., the great amount of heat losses due to poorly insulated dwellings). The CM's results have shown that, considering the settings of our experiment and the selected respondents' sample this aspect related to the implementation of a technological system does not play any role in the decision-making process. When comparing different technological alternatives, the energy area that is been tackled the most, being the reduction of heat loss or the lower electricity consumption, does not have any influence on the key-decision-makers' choice outcome and they do not have any specific preference in this regard.

5.4 Insights from the Questionnaire's results

In our questionnaire we included three final questions, the first of which investigates the respondents' perception on the current state of the energy system. Reinterpreting now the results, both of the choice model and of the first question they actually correspond. In fact, in the first question the respondents shared a very low and negative perception of the current state of the energy system's efficiency. In our CM's results we discovered that the actual efficiency increase is not the main decisional criteria for key-decision-makers. Therefore, interpreting these results in a very simplistic and linear way, we can say that the same key-decision-makers who perceive the energy system as inefficient and unsustainable are still taking actions, influencing the system, based more on other criteria, such as the level of disruption, than on the actual increase of efficiency to be brought to the system.

Finally, we included in Appendix K a table listing the information that, according to the respondents, was missing, in the questionnaire, for the completion of the Choice Model. We want to present and discuss here a few of the received feedbacks.

The *Difficulty of Implementation* attribute and its levels (i.e., High or Medium) were not clearly defined and not enough information was given. According to one of the response: "*Insight into the difficulty factor is hard to judge. If the costs are given I assume that for that money the policy plan is executable and the relevant resources can be attracted. But if not more information is needed to judge that*". The openness to interpretation and the interrelation between attributes, which might have been performed by more than one respondent, might have influenced their individual choice outcomes and the overall CM's results. This element should be addressed by further research, through the analysis of the correlation of the coefficients.

Different feedbacks were given that concerned the *Competence Area Addressed* attribute, which confirm our interpretation of its non-valid β coefficient. In fact they stress both the poor quality of the attributes' levels, the lacking of information within the questionnaire to concerning the actual shares of energy consumption so to be able to compare them and choose, and also the broadness and vagueness of the individual energy area included.

One feedback clearly stated that "*terms like energy metabolism might not be clear to everyone*" as we also assessed from the responses gathered in the first part of the questionnaire.

Furthermore some feedbacks were given concerning the lacking of information considered important or even fundamental to make decisions concerning policy-plans implementations. The spatial component, the possibility for companies to profit from the implementation, the relation between the energy savings and emissions, possible lock-ins connected to the technologies, specifics technical information, the ownership of the solution and of the actual implementation (i.e., who is going to do it) are some of the information that some respondents perceived as missing although important.

5.5 Conclusions and discussions on the Choice Model's results

Considering the defined settings of our choice experiment we can conclude by saying that, as resulted from our choice model, the *Difficulty of Implementation* is **the key factor** considered by key-decision-makers, when asked to express their preference and support on a policy plan promoting the implementation of different technological system to reduce the burden carried by the built environment upon the energy system. The *Energy Savings* and the *Cost of Policy Implementation* are respectively **the other two relevant factors** in their choice outcome.

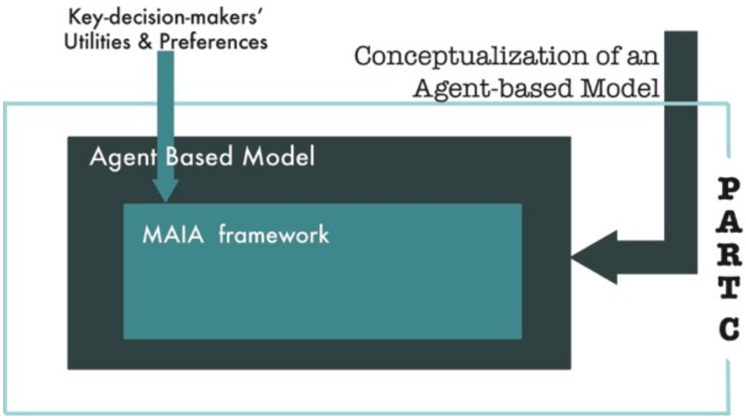
Going a step further and connecting the attributes to the actual preferences of key-decision-makers we can also conclude that they prefer implementations that are as little

disruptive as possible, rather than implementations that entail high levels of energy savings or rather than implementations that require low investment costs for the municipality.
When choosing among different technological systems, key-decision-makers prefer the ones with the lowest levels of disturbance even if those might entail higher cost for the municipality or lower levels of energy savings.

5.5.1 Limitations of the CM

The final design of our experiment, for reasons given in chapter 4, included only 2 of the 3 previously defined attributes' levels except for the *Energy Savings* attribute. This discrepancy of levels might also have played a role in the final results. In our opinion, it would be interesting to run another choice experiment with the original design (i.e., 3 levels for each attribute).
The greatest limitation of our CM is, nevertheless, the limited amount of respondents we were able to engage and therefore the limited amount of preference data we gathered. We did foresee this issue from the very beginning of our research process, and, as repeatedly mentioned in previous chapters, we developed our experiment accordingly. Nonetheless we must acknowledge that a bigger respondents' sample would significantly increase the statistical validity of our experiment as well as the strength of the insights gathered through the whole CM.

PART C



"A growing realization across the social sciences is that one of the best ways to build useful theories of group phenomena is to create computational models of social units (e.g., individuals, households, firms, or nations) and their interactions, and observe the global structures produced by their interactions. ABM and its computer simulation of human behavioral and social phenomena is a successful and rapidly growing interdisciplinary area." (Cui et al., 2010)

"with the appropriate methodologies one could learn more from the information currently available." (Vag, 2007)

Chapter 6
A METHOD TO COMBINE CM AND ABM

In this third part of our research investigation we propose and conceptually develop a methodological combination to answer to the 4th and last sub-question:
How can the interactions dynamics between key-decision-makers' preferences and the energy system be observed?

The complete answer to this question will be given at the end of the next chapter. In fact here we will only explain the method we proposed, and later on used, to combine the results from the Choice Model with a conceptual Agent-based Model.
In fact, in order to answer to the main research question we acknowledged that the combination of Choice Modelling with another modelling tool, such as ABM, would have been able to look into the pattern outcomes of the influence dynamics previously identified. In this chapter we propose a method for this combination.

6.1 Combination of CM and ABM in the Literature

In order to understand how the two methods can be combined we investigated in the literature existing approach to such methodological combination.

Cui et al. (2010), in their research, estimate the future ownership distribution of electric vehicles by developing an agent-based model where a consumer choice model is integrated. In particular the ORNEL model is used to estimates the probability of consumers' choices according to consumers' attributes and some vehicles characteristics. After the development of an ABM describing the system under study, Cui et al. (2010) combine the two modelling tools by implementing the consumer choice model working as the decision-making criteria for individual households when choosing among the available vehicles. It is highlighted by the authors that the biggest strength of this models' combination lay in the use of "*high fidelity input data for agent-based simulation*" (Cui et al., 2010) which guarantee the results of the simulation to be useful.

In Han et al. (2008) the models' combination is conceptually different. The scope of their study is, indeed, to use the ABM tool to explore the dynamism of choice mechanisms, investigated with CM. In their research, about travel behaviour, the individual choices' mechanisms are the main focus. They investigate the decision-making process of individuals, starting from the assumptions that individuals act according to internal criteria such as: behavioural principles and mechanisms, preferences and needs. From these they derive plans and schedule for their actions. Occasionally or in response to specific events, individuals will explore their environment and will possibly modify their internal criteria, which will in response lead to different actions. Furthermore individuals might also be influenced by the social interactions with other individuals with different beliefs, preferences and needs. Therefore, being the individuals' decision-making process the heart of their research, the application of ABM represents the perfect match to explore the dynamism of individual choice behaviours when faced with social interaction, changes in the environment or different alternatives' availability (Han et al., 2008).

Our approach, instead, is a sort of combination of the previous two. In our research, as in Han et al. (2008), the core is the investigation of the preferences of key-decision-makers, which we explored through a choice model. On the other hand we do not investigate the choice mechanisms and we also do not want to explore the dynamism of choice mechanisms as, instead, Han et al. (2008) do. Rather we need the ABM to observe the interaction dynamics between the preferences of key-decision-makers, the discussions among them and the energy metabolism in which they are embedded. This will allow us to study the influence key-decision-makers' preferences have on the energy metabolism, similarly as it is done by Cui et al., (2010).

Considering the social context of our research and the fact that we only aim at conceptualizing an agent-based model, we decided to make use of the MAIA framework as considered the bridge appropriate for the research context and suitable to guide us through a structured conceptualization of an agent-based model.

6.2 Combining CM and ABM through MAIA

A complete description of the ABM method and MAIA framework have been given in chapter 2, here we will now explain how we intend to perform the combination between CM and ABM through MAIA.

In figure 6.1 we clearly show the bridging role of MAIA framework connecting the Choice Model to the Agent-based Model.
The 4 components of a CM are allocated through the 5 MAIA's structures. Specifically the information describing the decision-makers is included and deepened in the Collective and Constitutional Structures. The results of the Problem and Stimuli Refinements, two of the fundamental steps in CM's development, are allocated in the Constitutional, Physical, Operational and Evaluative Structures. The information gathered through the questionnaire is instead allocated in the Collective, Physical and Operational Structures. Preferences and Utilities of key-decision-makers, main results of the CM, are included in the Collective Structure but utilized also in the Operational and Evaluative Structures.

The information stored in MAIA, both new and from the CM, can then easily be translated into the 3 main components of an ABM: (1) Agents, with their states and rules, (2) Actions, on other agents, on self and on the environment, and finally (3) Environment, with the physical elements and the information included, but also into its static or dynamic structure. The specific individual connections between the MAIA and ABM are shown in figure 6.1

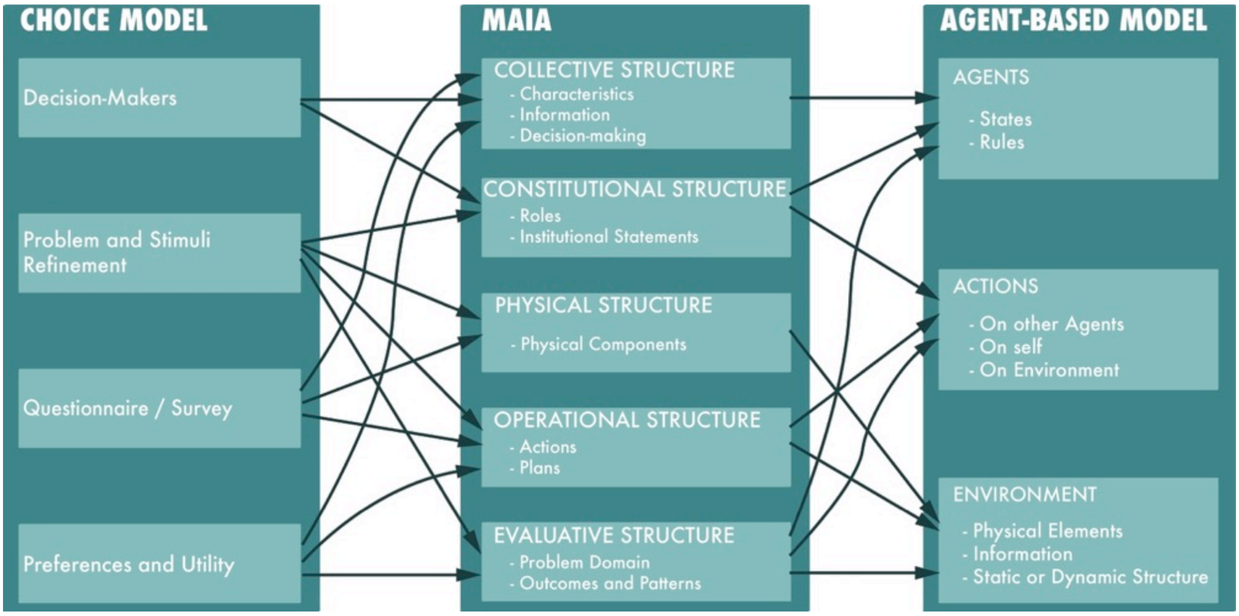


Figure 6.1 _ Combination of Choice Model and ABM through MAIA framework

6.3 Applying the combination of CM and MAIA

The previously presented combination is here, and specifically in figure 6.2, unravelled and applied to our research. Therefore we only focus on the CM and MAIA as, at this point, showing the connections with ABM is not necessary anymore.

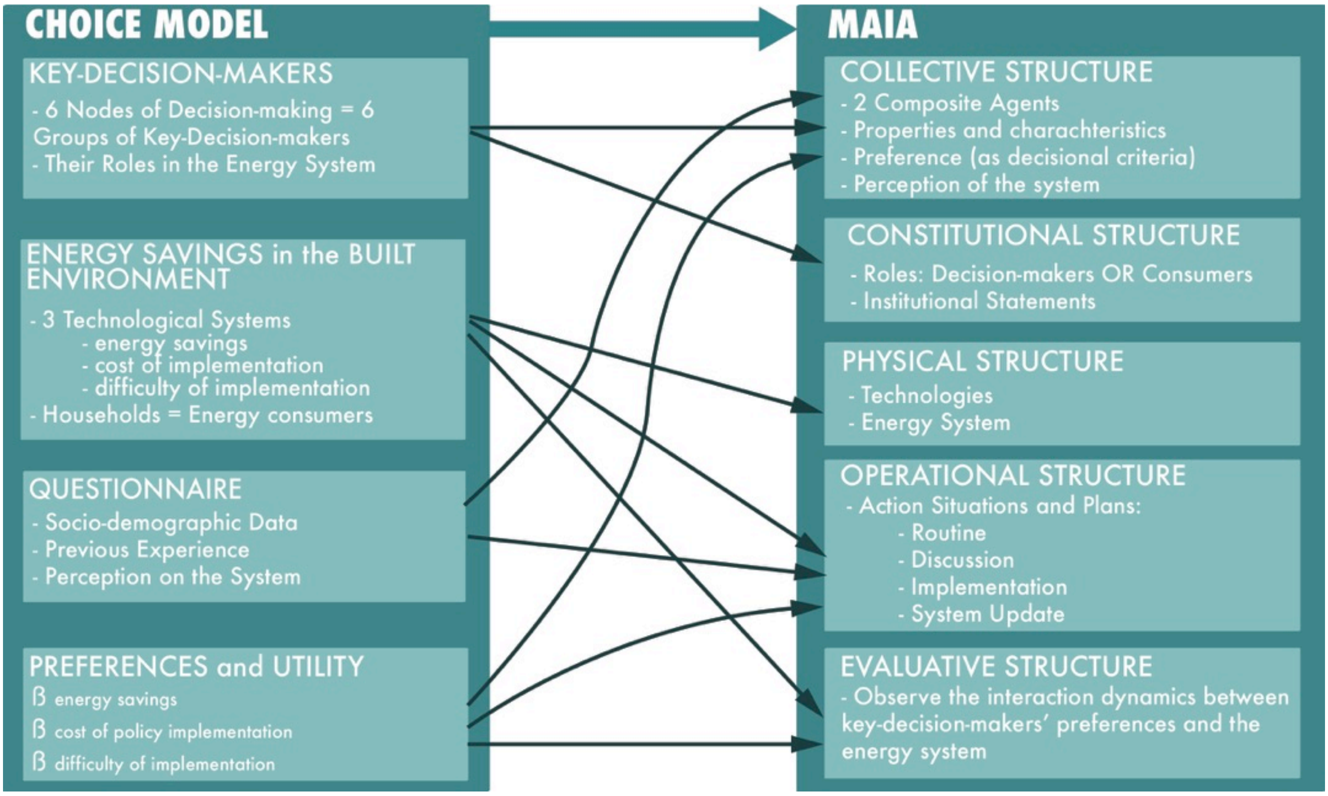


Figure 6.2 _ Applied combination of Choice Model and MAIA framework.

The complete methodological combination with the resulting conceptual agent-based model is presented in the next chapter (chapter 7). However we here anticipate the rest of the description for the sake of the discussion. In fact, the most important lesson learnt through the combination of CM and MAIA is the importance of performing such combination at a much previous stage of the research process than it was done in this thesis and with an iterative approach. Several results gathered through the CM were not useful for the conceptual model, which in return was lacking of other types of information that we did not gather as we did not foresee to be of any use, and for which we had to make assumptions. Therefore we suggest avoiding such sequential combination of the methodologies in favour of an iterative one so that MAIA can also be of use to develop the CM itself. In figure 6.3 this concept is presented through the addition of bi-directional arrows (thick dark green arrows), and of unidirectional arrows from MAIA toward the CM (light green arrows) whenever it is assumed such combinations are possible.

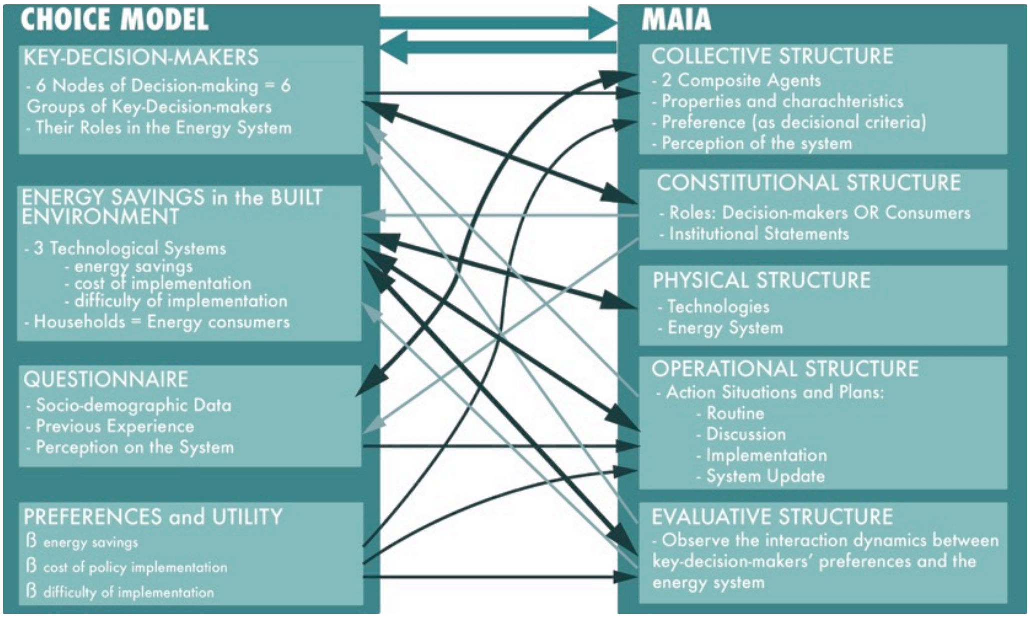


Figure 6.3 _ Suggestion for the improved and iterative combination of CM and MAIA.

To further strengthen our claim and clearly show the benefits of it, we provide some examples of the suggested iterative process.

Using MAIA when developing the questionnaire would have guided us in the formulation of the socio-demographic and follow-up questions. Indeed, to fill-in the Collective Structure we require information about the personal values, characteristics and information. From our questionnaire we were able to gather only a few personal characteristics (gender and education) and information about their perception of the system. No information about their personal values or the type of information available to them was gathered.

To fill-in the Constitutional Structure we had to make assumptions about the institutional implications of their roles. Instead if we had used MAIA iteratively we would have preformed specific research on the matter, and we could have also explored the key-decision-makers' response to their roles' institutional statements, objectives and capabilities.

These being just a few examples, we strongly believe the benefits of a two-way and iterative methodological combination are many and significant.

Chapter 7
CONCEPTUALIZED ABM

In this chapter the final part of the research investigation is presented. This part aims at completing the answer to the 4th and last sub-question:
How can the interactions dynamics between key-decision-makers' preferences and the energy system be observed?

In this chapter we conceptualize the previously explained combination using MAIA framework. We firstly present a narrative of what the model is expected to look like and to perform. Afterwards we give shape to the conceptual model using the five structures of MAIA framework. The last structure, the Evaluative Structure, is used to define the variables and elements in the model that will be observed, after the model's implementation, as they are the "*useful indicators for the problem domain*" (Ghorbani, 2013) that can be used to gather insights and answer the research question.

7.1 Model Narrative

Our model will represent a simplified urban energy system. The narrative of the actions that will take place in the model is represented in the flowchart in figure 7.1. We will use the number of the flow chart's blocks to guide the reader through the model narrative.

The agents in this energy system are of two types: 1) Households and 2) Key-decision-makers. They all have specific characteristics and properties. We decided to focus on households in the conceptual model, out of all the elements in the Built Environment, since they are the one that it has been investigated more in depth for the CM, and especially because the technological implementation as presented to the key-decision-makers in the Choice Experiment were specifically directed towards households.

Households

The amount of households is initially corresponding to the current amount of households in Amsterdam divided by 10^{-3} (for practical reason), which is 417. The user of the model can change this initial number before starting the simulation, according to the system being studied. Each household, considering 2.2 persons each, and an average $74m^2$size, has similar *Initial Energy Requirements* of 58GJ plus or minus 5GJ per year (this is to make the model more realistic by adding some variability); this energy requirement value may change with time as an effect of possible implementation of technological systems that involve energy savings **[block 13]**.
Each household has an *Energy Bill* in which are considered the cost related to its energy requirements (energy cost*energy requirement); whenever an actual technological-system is being implemented the costs related to the installation are added for as long as it is required by that specific implementation **[block 13]**.
Furthermore, each household also has a *Satisfaction* value representing its perception of the energy system.

The number of households will increase during the simulation of 0.36% per year **[block 15]**, nevertheless the *Energy Requirement* for the new households will steadily decrease of 1% each year (considering the average initial value of 58GJ). The average *Initial Energy Requirement* value will be updated every year, so that the decrease of energy requirements for the new households is incremental.

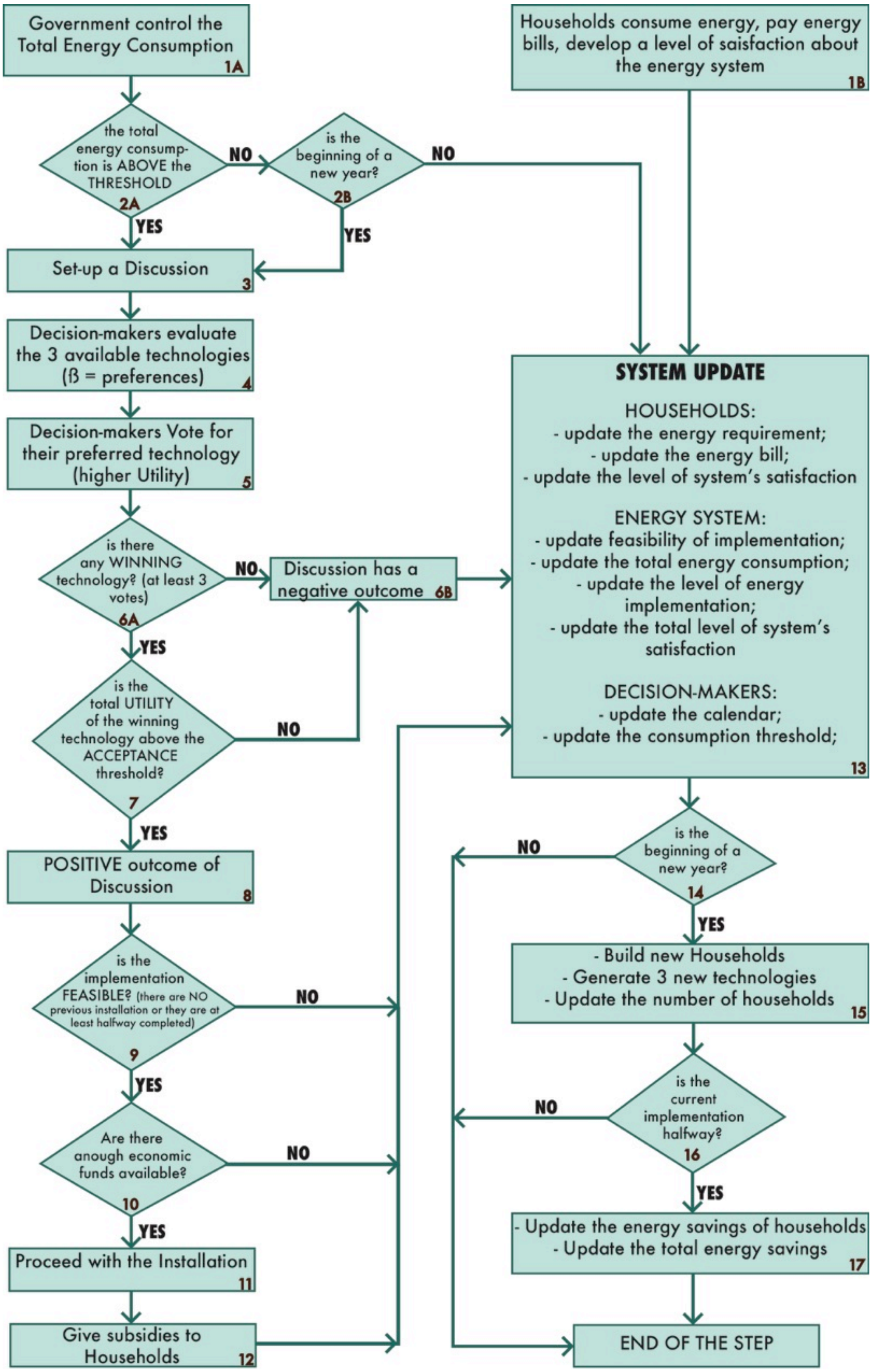


Figure 7.1 _ Flow chart of the model narrative.

Key-decision-makers

The amount of key-decision-makers is fixed at 6 (Governments, Energy Producers, Energy Providers, Network Operators, Knowledge Developers and Others). They all are part of the same composite agent (Key-decision-makers), but each of them has different characteristics and properties.

They all have three preferences' values: the *Difficulty of Implementation*, *Energy Savings* and *Cost of Policy Implementation*. These are the β values resulted from our choice model. If, as it currently is in our case, only one preference value (one β) is given for all the key-decision-makers, then a variation will be added to those β values making use of a normal distribution curve. Their preference will influence their decision-making processes when asked to take part in a discussion about the possible implementation of technological systems to decrease the overall energy consumptions **[block 4]**.

All the key-decision-makers have access to the *Implementation Funds*, where are collected all the money paid by the households for their *Energy Bill*. The actual money availability, both for households and for the governmental funds, is not modelled, as it is not important for the outcomes and patterns that are of interest for our research.

Energy System

The energy system, modelled as a **physical component** and not as an agent, has several properties, or else variables in which will be registered useful information about the system that need to be accessible to all the key-decision-makers and to the model's user: *Total Energy Consumption*, *Total Energy Savings*, *Number of Households*, the overall *System Satisfaction* (it includes the average level of satisfaction of the Households), the *Implementation Feasibility* (where it is registered whether there is an implementation already underway, and therefore no other implementation can be initiated), the *Total Implementations* (the total number of implementation that took place during the simulation), the *Total Discussions* (the number of times the key-decision-makers where asked to be Decision-Makers and vote for a technological-system), and finally the *Total Positive Discussion* (the number of Discussion where a technological implementation for the system was agreed upon).

Actions and Dynamics

In their routine Households consume the energy they require, pay for it, and have a perception of the system that influences their system satisfaction **[block 1B]**. Instead the key-decision-makers, in their routine, only control the Energy System's status; in particular the Governments look at the *Total Energy Consumption* and the *overall System Satisfaction* **[block 1A]**. Whenever the *Total Energy Consumption* will exceed a certain threshold (this value can be defined and changed by the model's user) **[blocks 2A and 2B]** all the key-decision-makers are asked to have a *Discussion* on which would be the best technological-system to implement to decrease the overall energy consumption. When participating to the *Discussion* each key-decision-maker enact the role of *Decision-Maker* and, as such, will calculate the *Utility* value associated with the *3 technological-systems*, available in that moment, according to their own preferences and will consequently *Vote* for their preferred alternative **[blocks 3, 4, 5]**. The alternative that will result as the most preferred (at least 3 votes required) ***and if*** its cumulative *Utility* value will be above a defined threshold (it represents a *margin of acceptance* for technology below which it is assumed to be too "unpopular" to be implemented) **[blocks 6A and 7]**

then it will be implemented **[block 11]** ***if*** it is feasible in that moment. ***If*** there is no *preferred alternative* ***or*** the *Utility* value associated to that alternative is below the threshold, ***then*** no technology will be implemented in that moment **[blocks 9 and 10]**.
Nevertheless, ***even if*** the *Total Energy Consumption* does not exceed the set threshold, ***every year*** the *key-decision-makers* will have a *Discussion* **[block 2B]**, and possibly proceed with the implementation of a technological system for energy saving **[block 11]**.
Every year 3 different *technologies* are made available in the system to the key-decision-makers **[blocks 14 and 15]**. Each technology, when available, has 4 characteristics: the *Cost for the Implementation* (to be undertaken by the municipality through subsidies), the *Installation Cost* (to be undertaken by the households), the *Difficulty of Implementation* and the *Energy savings* (% related to each household). These characteristics have different values for each of the 3 technologies available each year.
When a final decision is taken by the key-decision-makers on the technology to implement in the system, then the implementation process starts right away **[blocks 11 and 12]**. It lasts accordingly to its *Difficulty of Implementation* value (Low = 1 year; Medium = 2 years; High = 3 years). The *Installation Cost* is paid by each household, subtracting the governmental subsidies to the cost of the technology (cost for 1 household = cost of 1 technology – 5% of subsidy) **[blocks 12 and 13]**. The *Difficulty of Implementation* value of the technology also affects the *Satisfaction* value of each household (the higher is *Difficulty* level, the more negative is the effect that it has on households). The *Energy Savings* due to the implementation of the technology are completely effective only after its full implementation or, if preferred, half *Energy Savings* could already be available halfway through the overall implementation **[blocks 16 and 17]**. While one technological-system is being implemented, no other implementations are allowed until the one underway is halfway completed.
One step in the simulation corresponds to 1 month. After 10 years (120 time steps) the simulation will stop. It can be restarted again and it will again stop after other 10 years (240 time steps total).

This being the outline of what the model will contain and the events that will take place in it, what we want to observe are the dynamics of the **Discussion** (*Total Discussions, Total Discussions with Positive Outcome*), the actual **Number of Implementations** that have occurred (*Total Implementations*), the **Total Energy Savings** level reached and the **Overall System Satisfaction**.

7.2 The Collective Structure

In the Collective Structure are represented the Agents that are included in the system and the most important aspects, attributes and properties of each agent (Ghorbani, 2013; Ghorbani et al., 2013). In our model we have two main composite agents: the **Built Environment** and the **Key-decision-makers**.
The first is a collection of Households, which have all the same characteristics and properties but with different values. The second is a collection of 6 semi-individual agents, which have different labels but the same properties even though with different values. In theory this 6 agents are very different from each other, but they have all been investigated in the same way during our previous research. Therefore here they all are

described by the same attributes and properties. This is also because we are mostly interested in their role as decision-makers for the energy system.
In table 7.1 these agents are defined and generally described, in table 7.2a, instead, the agents' properties are defined and described. Table 7.2b include all the agents' properties that have been previously researched for the choice model but that currently are not useful for our conceptual ABM.

Table 7.1 – The Collective Structure: Agents.

Composite Agents	AGENTS	Specifics	Possible Roles
The Built ENVIRONMENT	Households	Initial amount: 417 (it can be changed by the model's user). Every year the number of households increase of 0.36% [Value calculated considering the estimation made by World Population Review ("World Population Review," 2016) for which the population in The Netherlands is expected to grow of about 0.8% per year (up to 2030) and considering the average household size of 2.2 persons].	CONSUMERS
Key decision-makers	Governments	These are the 6 nodes of key-decision-makers that have been identified through the choice model and case study research. They are grouped under the same Composite Agent and they all can enact the role of Decision-Makers. BUT they have different characteristics: preferences, education, types of influence, knowledge, and values.	DECISION-MAKERS
	Energy Producers		
	Energy Suppliers		
	Network Operators		
	Knowledge Developers		
	Others		

Table 7.2a – The Collective Structure: Agents and their Properties relevant for the ABM.

Properties	Agents	Values	Description
Initial Energy Requirement	Households	58 GJ +/- 5GJ (randomly assigned)	Average Energy consumption per household per year - based on the case study (Basic Scenario in 2020 developed with the Energy Transition Model).
Energy Requirement	Households	Initial Energy Requirement – Energy Savings	The Energy consumption might decrease as result of the implementation of technological systems.
Energy Bill	Households	Energy Requirement * Energy cost	Cost of Energy per household per year, according to their requirements.
Energy cost	All agents	42.97 €/GJ	Based on the case study. The model's user can change this cost. The value is based on the Basic Scenario for 2020 that we developed for our choice model. Considering 58GJ as the average energy consumption per household per year (based in 2012 in (Blok et al. (2015); based in 2020 in our scenario) and 2,492€ as the yearly energy cost per household, we calculated a standard cost per 1 GJ (2,492€ / 58 GJ) = 42.97 €/GJ
Energy savings	All agents	Energy savings + Energy Savings of Technology	It represents the total % of energy savings that have been implemented in that households since the beginning of the simulation
System satisfaction	Households	From 0.1 to 1 with an incremental interval of 0.05	This property represents the households' satisfaction in relation to their perception of the energy system. It is influenced by the increase or decrease of the energy bill, the total energy consumption and by the difficulty of implementation of technological systems. It is initially randomly assigned.
β Difficulty of Implementation	Key-decision-makers	β value from the choice model (-1.29) +/- variation on a normal distribution	The weight of their preference is given by the results of the choice model. If only a unique value for all the key-decision-makers is available, a standard deviation for each preference of each agent is automatically inserted in the model. If, instead, different values are available then there is no standard deviation. The model's user could instead insert these values as static inputs before the simulation.
β Energy Savings		β value from the choice model (0.814) +/- variation on a normal distribution	
β Cost of Policy Implementation		β value from the choice model (- 0.759) +/- variation on a normal distribution	

Money		TOTAL SUM of Energy Bill – Cost of Implementation of Technology	Here are summed all the money spent by the Households to pay their Energy Bills. To this amount is detracted, whenever necessary, the Cost for technology Implementation that is undertaken by the Decision-makers through Subsidies.

Table 7.2b – The Collective Structure: Agents and their Properties, resulting from the CM but irrelevant for the conceptual ABM.

Properties	Agents	Values	Description
Size-person	Households	2.2 persons	Average amount of persons per households considered - based on the case study
Size-m^2	Households	74 m^2	Average size of households considered - based on the case study
Gender	Key-decision-makers	{1,Female}{2,Male}	
Education Level		{1,High school} {2,MBO} {3,HBO} {4,Bachelor degree} {5,Master degree} {6,PhD}	
Role in the Company / Organization		{Leading role = High Influence} {Managerial role = Medium influence} {Regular role = Medium-Low influence}	It is assumed that this information could be used as a parameter of the influence level of that particular decision-maker.
Duration of the role		{up to 1; 2; 3; 4; 5; 6; 7; 8;9; 10; more than 10}	
Participation in related projects		{Energy; Residential Stock and Infrastructure; Urban metabolism; Sustainability; Circular Economy; Urban development; Energy Policy; Cleantech industry}	It is assumed that this information could be used as a parameter for the Expertise level of that particular decision-maker → the more projects he/she previously participated to, the more expertise he/she has.
Perception of the current Energy System		{1, 2, 3, 4, 5, 6, 7}	

7.3 The Constitutional Structure

In the Constitutional Structure it is represented the social context of the system that is being modelled. Specifically here are described the **Roles** that agents may enact. Each role is defined by a set of **entry conditions, objectives, capabilities**, and the **set of actions** that can be performed according to some rules. These rules are here defined as Institutional Statements and are expressed using the ADICO syntax (Ghorbani, 2013).
In our conceptual model there are two possible roles that can be enacted by the agents: the **Consumer** role or the **Decision-maker** role. In our model settings each agent can interpret only one role. More specifically the Consumer role can only be enacted by Households, and the Decision-maker role can only be enacted by Key-decision-makers. These settings are based on the scope of the research, the type of choice model previously developed and the results gathered from it. In table 7.3 the two roles are presented and described with their features; in table 7.4 instead, the Institutional Statements included in our model are defined through the ADICO syntax.

Table 7.3 – The Constitutional Structure: Roles.

Entry Condition(s)	ROLES	Objectives	Capabilities	Institutions
Being Households agent	CONSUMER	Consume and Pay for Energy; Reduce the Energy Requirements.	Consume and pay for energy requirements; install energy technologies; perception of the system.	C1, C2
Being an agent form the Key-decision-makers group	DECISION-MAKER	Supervise the energy system and increase its efficiency by selecting and implementing the preferred technological system.	Control the total Energy Consumption of the Energy System; evaluate different technological-systems; having preferences on the technologies; participate in the discussion; vote for the preferred alternative; promote and initiate its implementation.	DM1, DM2, DM3, DM4

Table 7.4 – The Constitutional Structure: Institutional Statements.

Label	A Attribute	D Deontic	I Aim	C Conditional	O Or else	Type
C1	**Consumer**	must	Pay for their energy requirement.		They will be in debt with the Energy Providers	Rule
C2	**Consumer**	must	Install the technological system when the Decision-makers initiate the implementation.			Norm
DM1	**Decision-maker**	must	Control that the total energy consumption doesn't exceed the fixed threshold.			Norm
DM2	**Decision-maker**	must	Take part in the discussion.	If the energy consumption is above the threshold OR once a year.	The Energy System will require too much energy (especially with households increment).	Rule
DM3	**Decision-maker**	must	Vote for one technology	If they are asked to take part in the discussion as key-decision-maker for the energy system.		Norm
DM4	**Decision-makers**		Choose one technology	If there are at least 3 votes for the same technology AND the cumulative Utility value associated to the winning technology, in that moment, is above the margin of acceptance threshold		Shared Strategy

We must explain why so little institutions have been included in our conceptual model. Considering our research question what we want to observe are the outcomes of the decision-making processes of key-decision-makers, in particular we want to observe how these outcomes might influence the energy system in terms of the total energy consumption and savings and of the amount of implementation that actually get completed. In order to do so without adding too much complexity to our model we conceptualized a rather simplified energy system. Therefore we are not interested, up to this point, in modelling all the institutions that exist in the energy system. We have only modelled the few that are important for our observation.
For future research, once the simplified model has been developed it could be interested adding some complexity and therefore also more institutions.

7.4 The Physical Structure

In the Physical Structure are represented the physical components that are included in the system. Each physical component might have specific properties and functions, and they might be open to be used by all agents or restricted.
In our conceptual model there are two groups of objects: the **Energy System** and the **Technologies**. We decided to model the Energy System as a physical component, even though it is a system resulting from the interaction of the agents within, because this allowed assigning updatable properties to it, which could be accessed by all the agents in the model. These properties are: the *Total Consumption*, the *Total Energy Savings*, the *Total amount of Households*, the *Total System Satisfaction* and the *Feasibility of Implementation*. Within the same group there is also the **Calendar**, which will be used to keep track of the time. The Technologies, instead, are three and they are defined by 4 properties: *Cost of Policy Implementation*, the *Energy Savings*, the *Difficulty of Implementation* and the *Installation Cost*. The first three of them are the technology

attributes over which the key-decision-makers have preferences that will determine their favourite alternatives, and therefore their vote in the discussion.
In table 7.5 the physical components are presented and described with their properties, affordances and behaviours.

Table 7.5 – The Physical Structure.

Category	Physical Components	Properties	Affordance	Behaviours	Open or Fenced
Technologies	Technology A	Cost of Policy Implementation; Energy Savings of Technology; Difficulty of Implementation; Installation Cost.	Can be used; Can be voted; Can be implemented	Cost money to the government in subsidies; Provide energy savings households' consumption; Involve a change in the Households' System Satisfaction.	Open
	Technology B				Open
	Technology C				Open
Energy System	Energy System	Feasibility of Implementation; Total Consumption; Total Energy Savings; Total Households; System Satisfaction; Economic Funds; N° of Discussions with positive outcome; N° of Implementation.	Can be observed; Its efficiency can be improved by technologies' implementation.	Increase or decrease its consumption; Increase the number of Households existing in it; Increase or decrease the level of satisfaction perceived by its costumer.	Open
Calendar	Calendar	Months, Number of Years	Can be updated and accessed	Every 12 months (steps) count 1 year.	Open

7.5 The Operational Structure

In the Operational Structure are represented the dynamics and the actions that take place in the system and their partial order. In every simulation there is only one Action Arena, where are listed all the Action Situations that the agents can perform. Each Action Situation includes a variety of singular Entity Actions and a Plan for their execution. Every Entity Action has a subject performing it (either agent, role or physical component), some preconditions and post-conditions. It has an Action Body that describes the actual events taking place, which might be related to some Institutional Statements or to some Capabilities available to agents enacting Roles. It is possible that in order to actually execute an Entity Action, the subject needs to perform a decision-making process.

In our conceptual model, 4 Action Situations compose the Action Arena: **Routine**, **Discussion**, **Implementation** and **System Update**. This is presented in figure 7.2 on the side.

7.5.1 Routine

In this first Action Situation agents enacting the role of Households perform their routine activities such as consuming energy and paying for their energy requirement, as well as expressing their perception of the Energy System in their Satisfaction level. Meanwhile the Government control the Total Energy Consumption of the Energy System so that if it is above a set threshold it will ask the Decision-makers to participate in the Discussion.

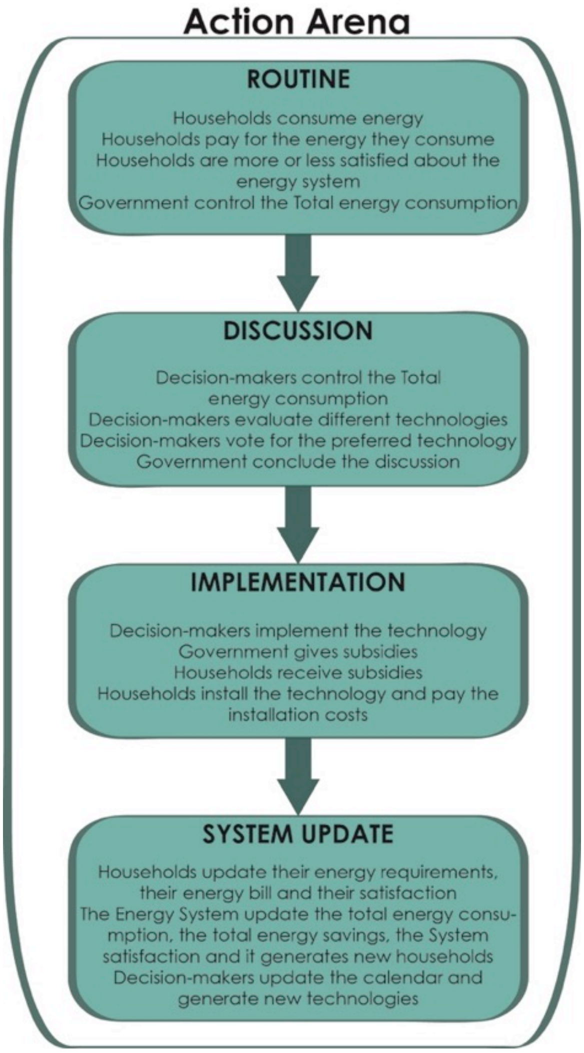


Figure7.2 – The Action Arena.

7.5.2 Discussion

In this Action Situation different Entity Actions take place depending on two variables: the result of the previous Government's action and the Calendar status. In fact **if** the Government, in its observation of the *Total Energy Consumption*, performed in the Routine situation, registered a value exceeding the set threshold **then** it will proceed with the rest of the *Discussion* and all the agents enacting the Decision-maker role will be asked to evaluate different technologies and vote for the preferred alternative. **Otherwise** the Decision-makers will look into the *Calendar*. **If** it is the second month of a new year **then**, independently from the current level of *Total Energy Consumption*, the Decision-makers will proceed with a Discussion evaluating and voting for one of the 3 technologies currently available. **Otherwise** no *Discussion* will take place. **If** one of the two possibilities resulted in a *Discussion*, **then** the Government will close it by registering its outcome. The outcome will be positive **if** one alternative will gain the majority (3 out of 6 votes) **and** the total *Utility* value associated to it will be above a set threshold (the margin of acceptance). **Otherwise** the outcome will be negative.

7.5.3 Implementation

If a *Discussion* took place in the previous Action situation **and if** its result was positive **than** the preferred technological system will actually be implemented by the Decision-makers. One more condition needs to be verified at last: the *Feasibility of Implementation*. In fact **if** another technology is being implemented it is only possible to begin with a new implementation **if** the current one is already halfway.

For the implementation to take place the Government will give subsidies to the Households, who will receive them and automatically install the technology by paying the *installation costs* and by adjusting their level of *satisfaction* according to the *difficulty of implementation* of that technology.

7.5.4 System Update

In this last Action situation the properties describing the Energy System and the Households are updated. The Calendar is adjourned, new Households are built and, if a new year is just started then 3 new technological systems will be made available.

In the following tables the details of the Operational Structure are described. Table 7.6 presents the Action Situations with their Plan specification and the Entity Actions' list. Table 7.7 presents the Entity Actions in details.

Table 7.6 – The Operational Structure: the Action Situation

ACTION SITUATION	Agents	Plan Type	Entity Actions
Routine	Households	Sequential	Consume energy
			Pay for energy consumed
			Express their satisfaction about the system
	Government	Atomic	Control the state of the system → Total Energy Consumption
Discussion	Decision-makers	Sequential	Control the Calendar
			Control the state of the system → Total Energy Consumption
	Decision-makers	Sequential	Evaluate different technology
			Vote for the preferred technological system
	Government	Atomic	Conclude the discussion
Implementation	Decision-makers	Sequential	Control the Feasibility of Implementation
			Give subsidies to households
			Update the Feasibility of Implementation
	Households	Sequential	Receive subsidies
			Pay the installation cost
System Update	Households	Sequential	Update Energy Requirements
			Update Energy Savings
			Update Energy Bill
			Update System Satisfaction
	Energy System	Sequential	Update Feasibility of Implementation
			Update Total Energy Consumption
			Update Total Energy Savings
			Update Total System Satisfaction
			Build new Households, once a year
			Update Total Households
	Decision-makers	Sequential	Update the calendar
			Update the Consumption threshold
			Once a year generate 3 new technological systems

Table 7.7 – The Operational Structure: the Entity Actions.

Action situations	Performer	Entity action	Role	Inst. Stat.	Decision-making	Precondition	Post-condition	Post-condition not do
Routine	Households	Consume energy	Consumers		Calculate their energy requirement		Update the energy requirement value	
		Pay for energy consumed		C1	Calculate the cost of the energy consumed		Update the energy bill value	
		Express their satisfaction			Calculate their level of Satisfaction			
	Government	Control the state of the Energy System			Control IF Total Energy Consumption is above threshold		Ask Decision-makers to Evaluate different technologies	
Discussion	Key-decision-makers	Control the Calendar	Decision-makers		If it is the 2nd month of a new year (1 year =12 time steps).		Then proceed controlling the total system consumption	
		Control the state of the system		DM1	Total Energy consumption above the threshold	If it is the 2nd month of a new year.	IF it is above threshold proceed with the discussion and the Evaluation of Technological Systems	If it is below threshold, do nothing.
	Key-decision-makers	Evaluate different technological systems	Decision-makers	DM2	Calculate the Utility for the 3 technologies available. Select the one with the highest value.	IF Government ask for it OR if the yearly control of the system's state resulted above the threshold.	Have 1 preferred technology	
		Vote for a technological system		DM3		Have 1 preferred technology	All the votes are gathered as well as the Utility values for all the alternatives.	
	Government	Conclude discussion	Decision-makers	DM4	The available funds are enough to cover the expenses for subsidies for that technology (Cost for policy implementation).	IF there are at least 3 votes for the same technology AND the cumulative Utility value associated to the winning technology, in that moment, is above a certain threshold.	1 technology is selected to be implemented. Update the number of Discussions with Positive Outcome.	
Implementation	Government	Control the Feasibility of Implementation	Decision-makers		Feasibility of Implementation set as positive.	If the result of the Discussion was positive ad 1 technology was selected to be implemented.	Proceed with the implementation. Update the number of Technology Implementations.	
		Give subsidies to households				If there are enough money in the Energy System fund	Update the money available in the funds.	
		Update the Feasibility of Implementation					Set the Feasibility of Implementation to NO.	
	Households	Receive Subsidies	Consumers			If a technology is being implemented, and the Government is giving subsidies	Update the Energy Bill of households	
		Pay the installation cost		C2		If a technology is being implemented, and the Government is giving subsidies	Update the Energy Bill of households	

System Update	Households	Update Energy Requirements	Consumers			If there is a NEW Technological Implementation underway AND it is in the second half of the implementation	Update the Energy Requirements of households accordingly	
		Update Energy Saving				If there is a NEW Technological Implementation underway AND it is in the second half of the implementation	Update the Energy Requirements of households accordingly	
		Update Energy Bill				IF the implementation is halfway completed	Update the Energy Bill of households accordingly	
		Update System Satisfaction			The Difficulty of Implementation of the technology (if any implementation is occurring) lower the satisfaction. Increase in Energy Savings raise it.		Update the satisfaction value accordingly	
	Energy System	Update Feasibility of Implementation			Control the calendar according to the time required implementing the technology. If the implementation is halfway the Feasibility is positive.	If there is an implementation underway or	Update the Feasibility of Implementation accordingly	
		Update Total Energy Consumption					Update the Total Energy Consumption accordingly	
		Update Total Energy Savings			Add the percentage of Energy Savings of the technology implemented	IF the implementation is halfway	Update the Total Energy Savings Accordingly	
		Update Total System Satisfaction			Calculate the average of all the Households' levels of Satisfaction		Update the Total System Satisfaction Accordingly	
		Build New Households			Control the calendar	Once a year		
		Update Total Households					Update the Total amount of Households	
	Key-decision-makers	Update the calendar			Every 12 steps = 1 year		Update the calendar variable accordingly	
		Update the Energy Consumption threshold			DEFINE A VALID CRITERIA FOR THE EXPECTED DECREASE OF THIS THRESHOLD		Update the Energy Consumption threshold accordingly	
		Generate 3 new technological systems			Assigned different values to the three properties describing the 3 technologies. Values to be taken from a given table.	Once a year (1st month)	Generate 3 new technologies that have different values for their 3 properties	

7.6 The Evaluative Structure

In the Evaluative Structure are included the concepts and variable to be used to assess model validity and model usability. In our case, what is most important to analyse is whether the implementation of the model will help exploring the system and providing answer to the research question(s). In figure 7.3 it is presented the interaction dynamics that is at the centre of our observation: the interplay between key-decision-makers' preferences and the urban energy system. In order to capture these dynamics we defined our "Problem Domain Variables" (Ghorbani, 2013). These variables represent those elements and concepts that will be observed to gather the patterns and outcomes useful for our investigation.

We have identified 4 of these problem domain variables: ***Total Energy Savings***, ***N° of Discussions with Positive Outcomes***, ***N° of Implementations***, and ***Satisfaction of Households***.

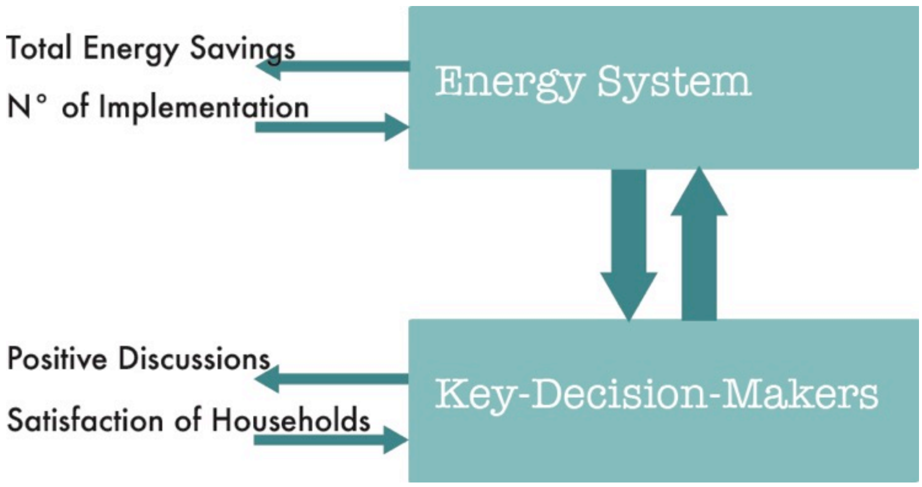


Figure 7.3 _ Interaction dynamics to be observed and the 4 problem domain variables.

In the rest of the section the four problem domain variables will be individually presented and described in their components, role towards other variables and the calculation defining their values,

7.6.1 Total Energy Savings

This variable registers the incremental percentage of energy savings that occurs in the Energy System as result of the implementation of different technological systems. In fact every time a technology is implemented, a certain percentage of energy saving per household is introduced in the system. Considering that the number of Households, and therefore of Energy Consumption and Energy Requirement, keeps increasing through the whole simulation, the total energy savings is expected not to grow steadily. This variable depends primarily from the amount and the type of Implementation that are developed in the system during the simulation.

Table 7.8 – Evaluative Structure: Total Energy Savings

TOTAL ENERGY SAVINGS		
Entity Action OR *Variable*	Direct OR Indirect Relation	Calculation
Control the Feasibility of Implementation	Direct	$$\frac{[Total\ Consumption(initial) - Total\ Consumption]}{100} = \\ = Energy\ Savings\ \%$$
N° of Implementations	Direct	
Total Consumption	Direct	
Energy Requirements of Households	Indirect	
N° of Households	Indirect	
Update Energy Requirements	Indirect	
Update Energy Savings	Indirect	
Energy Consumption Threshold	Indirect	

7.6.2 N° of Discussions with Positive Outcome

This variable registers the amount of Discussions among Decision-makers that concludes with a positive outcome, meaning with an agreement upon a technological system implementation. It is important for our research as it keeps track of the Discussion's dynamic, which, in turn, depends on the preferences of the key-decision-makers. When the outcome of a Discussion is positive it means that at least 3 decision-makers voted for the same technology. Nevertheless this feature of the model becomes even more important when specific preferences values are given for each of the 6 key-decision-makers, instead of the randomized variation. In order to add some realism to our model, for a technology to be actually implemented another requirement is that the sum of all the Utility values, calculated by each decision-maker in that moment, is above a defined threshold representing the Margin of Acceptance.

Table 7.9 – Evaluative Structure: N° of Discussions with positive outcome.

N° of DISCUSSIONS WITH POSITIVE OUTCOME		
Entity Action OR *Variable*	Direct or Indirect Relation	Calculation
Conclude Discussion	Direct	SUM of *Discussions with Positive Outcome*
Vote for a Technological System	Direct	
Decision makers preferences	Direct	
Margin of Acceptance (sum of Utilities for the preferred technology threshold)	Indirect	

7.6.3 N° of Implementations

This variable registers the total amount of technological implementations that actually take place during the whole simulation. In fact, once the outcome of the Discussion is Positive, for the implementation to actually take place some other conditions are required. These conditions are: the Feasibility of Implementation and the Economic Funds. The first assure that a technological implementation is begun if the previous technology is halfway completed or if there is no other implementation underway. Even though as previously mentioned money are not an important feature of this model, the second condition, which is the Economic Funds, assure that the government has a sufficient amount of money to invest, through subsidies, in the technological implementation.

Table 7.10 – Evaluative Structure: N° of Implementations.

N° of IMPLEMENTATIONS		
Entity Action OR *Variable*	**Direct or Indirect Relation**	**Calculation**
Control the Feasibility of Implementation	Direct	Updates the *N° of Implementations*
Give Subsidies to Households	Indirect	
N° of Discussion with Positive Outcome	Direct	
Conclude Discussion	Direct	
Economic Funds	Indirect	

7.6.4 Satisfaction of Households

This variable registers the average value of Satisfaction toward the Energy System as the Households perceive it. The variables that effect the Satisfaction of Households are: the Difficulty of Implementation of every technology that is being implemented, the increase and decrease of their Energy Bill and the Total Energy Consumption. This variable doesn't have any effect on any other variable or action. In fact, it has just been modelled to give back a value to the model's user to observe how the Consumers might perceive the Discussions and Implementations going on in the Energy System. It would be interesting, for future research, to model this variable as more interactive. For instance a high or low level of Satisfaction of Households could be another parameter that Decision-makers need to take into account when discussing about the chance of implementing any technology.

Table 7.11 – Evaluative Structure: Satisfaction of Households.

SATISFACTION OF HOUSEHOLDS		
Entity Action OR *Variable*	**Direct or Indirect Relation**	**Calculation**
Difficulty of Implementation of Technology (A, B or C)	Direct	Average of the SUM of Satisfaction of individual Households
N° of Implementations	Direct	
Total Consumption	Indirect	
Energy Requirements of Households	Indirect	
Energy Savings of Households	Direct	
Total Energy Savings	Direct	

7.7 Concluding remark and Expected results

The proposed methodological combination of CM and ABM has been here conceptualized through the MAIA framework.

The conceptual model we developed aim at observing the interaction dynamics between the key-decision-makers and the urban energy metabolism, as stated in the fourth sub-question guiding this stage of the research. In order to do so we conceptualized a simplified energy system where the core is represented by the discussion dynamics of key-decision-makers in response to the increasing level of urban energy consumption. This is the most important feature of the conceptual model and therefore many other aspects composing the energy system, such as types of energy sources, energy flows, and energy requirement are not included as considered not relevant in the observation of the discussion dynamic.

The expected results of our model (since the model implementation is outside the scope of this thesis) are connected to the 4 problem domain variables previously described.

1) The **dynamic trends of energy savings**, resulting from the yearly increase of the amount of households in the system (to recall the expected increase in urbanization), together with the possible implementation of technological systems, which in turns depends from the outcomes of the discussion among key-decision-makers, will show how effective are the discussions among decision-makers in reducing the total energy consumption.
2) The **discussions' outputs**, where the most impacting elements are the variation of preferences among decision-makers and the acceptance threshold, will show how easily an agreement fitting all the individuals' decisional criteria can be found.
3) The **total amount of implementation** achieved, which depends on the discussions' outcomes together with the feasibility of the implementation and the trends in energy consumption, will show firstly the level of success of such top-down discussion dynamics, and to a lower degree also the amount of technological implementations required to consistently decrease the urban energy consumption.
4) The **dynamic patterns of households' satisfaction**, which depend on the level of disruptiveness linked to a certain implementation, and to the amount of energy savings that are brought by it, will show the consumers' response to such top-down discussion and implementation dynamics. With some addition to the current conceptual model, this could also show how influential this factor is for key-decision-makers.

As our final remark we want to stress the relevance of the insights that could be brought through the implementation of such agent-based model investigating the influence the key-decision-makers exert on the urban energy metabolism. Such insights could then be of use of policy-makers and key-decision-makers themselves whenever investigating policy plans that require the participation of multiple-actors. They also could be of use for companies and organizations from other nodes of decision-making in assessing the implementation potential of technological systems that require the approval and participation of multiple-actors among which key-decision-makers. Finally they could be of use for the local community to understand the motivations behind the political and economical directions chosen for the urban energy system.

PART THREE

Chapter 8
REFLECTIONS

In this chapter we will critically interpret and discuss specific parts of the research process.

8.1 Reflections on the Case Study

Considering our scope, the Urban Energy Metabolism, one of our first research tasks has been proposing a specific definition for it (Chapter 3), so to be able to base the rest of our investigation on it. The definition was the result of the review of studies on energy metabolism, urban metabolism, and energy systems in general but also on the Amsterdam's energy system. In fact we decided to select a specific case study to base our investigation on.

Having proposed a suitable definition we moved forward in our research by investigating the case study in order to, first, define the main components, characteristics and boarders of an energy metabolism and, second, to define which are its nodes of decision-making. This part of the research unravelled into two parts:

1) A specific investigation of Amsterdam's energy system and especially the current political and administrative direction concerning its development. Results from this first part contributed to the second part but mostly contributed to a further refinement of the research scope: the energy consumption in the built environment.
2) The second part, instead, was a definition and description, on a more general level, of the components and characteristics of an urban energy system; followed by a description of the key-decision-makers suitable to our scope; and finally by the identification of the nodes of decision-making (which include the key-decision-makers) typical of an urban energy system. The main results of the second part of this investigation have been presented in two maps (figure 3.3 and 3.4) respectively representing the energy system and its nodes of decision-making.

As already mentioned, we firstly started our investigation looking into the selected case study, but we immediately moved away and generalized our description of urban energy metabolism and nodes of decision-making. In our opinion, in fact, this investigation can be generalized to every other urban environment in the OECD countries.

The point of discussion here is due to the apparent vanishing of the case study in the other parts of our research. It needs to be remarked that the use of a Case Study was mainly to have a reference context (1) to base our definition and description of urban energy metabolism, and especially (2) to identify specific key-decision-makers to engage for the core of our research.

It must be noted that this last task required more time and effort than expected. The unfamiliarity of the researchers with the local language, culture and energy system represented an obstacle only partially foreseen. In fact we anticipated to be able to gather more structured information concerning the Dutch energy system and its key-actors either from the literature, from experts or from previous researches and projects than we have actually been able to.

8.2 Reflections on the Choice Model

The development of the Choice Model and the related questionnaire represent the task that required the most time and effort together with the choice data collection. This was partly due to the researchers' limited expertise of the method and the related statistical concepts (e.g., RUT, MNL), but also to the importance of the choice experiment and model for the overall research. As a result we developed a suitable choice experiment for our research, which final design however had to be significantly reduced for many practical reasons (e.g. size of the experiment, amount of respondents required, time availability). The final design of the experiment was limited and of reduced size compared to the design originally developed. The reasons behind the design reduction, explained thoroughly in chapter 4, are solids, nevertheless it is possible that, having the chance to run again the choice experiment with the complete design, the results of the choice model would be different.

Another issue, about the CM, emerged this time from the analysis of the results, in particular it concerns s the 4th attribute, *Competence area addressed*, which was found to be irrelevant in the choice outcome, non representative of the observed sample and very likely to be obtained by chance. We interpreted this negative result arguing that the definition given to the respondents for the attribute was not sufficiently clear and open to misinterpretations. Similarly its levels were, for the respondents, neither comparable nor quantifiable. Having the chance to go back and design our choice experiment again we would most certainly substitute this attribute with a well-defined one. This attribute, in this case, would also contribute in gathering further information on the preferences of key-decision-makers, more suitable and relevant and than the *Competence area addressed*.
Another interpretation of this result is possible, in fact we can say that, in our specific experiment, the *Competence area addressed* by a specific technological-system seems to not have any role in the decision-making process. Key-decision-makers appear to be indifferent to the specific energy area that is being tackled as long as some energy savings are provided, the implementation is not too difficult and it does have a moderate cost. Nevertheless this is mostly a personal interpretation and speculation and can not be concluded with certainty, which, in turn, make it an interesting topic to be investigated by future research.

8.3 Reflections on the conceptual ABM

The first and fundamental discussion point about the model is the lacking of implementation, which does not allow us to fully validate the conceptual model either. Although there are some features of the conceptual model that should already be taken into account in the discussion.

As already mentioned, considering the amount of key-decision-makers we were able to engage with our choice experiment, the final results concerning their preference are generalized to the whole sample. In the conceptual model we included all the 6 nodes of decision-making in one composite agent: key-decision-makers. Currently their preferences, calculated according to the technologies available in that specific moment when a discussion is in place, are the same, as we have only one value for all of them form the CM results. In order to circumvent the problem and avoid uniformity of preferences among the agents we suggest using a normal distribution to vary the preferences' values. An assessment of the appropriateness of this values distribution is required before the implementation of the model. Obviously, if the CM could be run again with the participation of enough respondents from each of the 6 nodes of decision-making in order to be able to have individual preferences values for each node, this would overcome the problem in the first place.

In our conceptual model we included 2 thresholds representing the criteria to be met for certain events to take place. These are: (1) the total energy consumption threshold, and (2) the level of acceptance. The first represent the level of energy consumption that has to be reached in the energy system for the government to call for a discussion among the decision-makers. The second represent the minimum value of Utility inked to a technological-system that has been voted by the majority of the decision-makers. When the consensus among the decision-makers is found upon one technology, the Utilities perceived by all the agents participating in the discussion are summed up and the result is the Utility linked to that technology. At this point, in order to be implemented the Utility of that technology needs to exceed the acceptance threshold.
The numeric definition of these two thresholds was outside of the scope of our research, not only because we did not implement the model, but mostly because a solid and suitable quantification of these two values would require specific investigation concerning the limits of urban energy consumption, for the first, and the perception of technology and innovations, for the second, which were both outside of our research scope.

A similar issue is brought by the economical factor, which is present in our conceptual model but only as an external factor that is recorder through a variable but not actually modelled. Also in this case modelling the actual money exchange and economic dynamics would have added a complexity level to our conceptual model for which we did not have enough information and resources available, as it was not included in our research scope. While conceptualizing the model, though, we realized that it was necessary to include at least two economical dynamics: (1) the distribution of subsidies to households whenever a technological implementation was launched, and (2) the cost of policy implementation, which is basically the sum of the given subsidies, to mark the least amount of money the government is required to possess in order to launch a technological implementation. Several layers of complexity can be added to these two basic dynamics, however we argue these to be the indispensable ones, which would need some adjustment for a possible model implementation.

Chapter 9
CONCLUSIONS and DISCUSSIONS

9.1 Overview

Urban environments strongly depend on energy flows to fuel every activity, in particular considering the built environment, resulting as the largest energy consumer at a global level (75% of the total energy consumption according to Arrobbio and Padovan (2016)). The magnitude of their energy consumption equals to their driving potential for a sustainable development and environmental change.
Analysing the urban energy systems with a metabolic perspective it has been highlighted the presence of multiple nodes of decision-making where networks of actors actively make decisions that influence the overall energy metabolism. The aim of our research was exactly to gather insights on how decision-makers can influence, through their choices and preferences, the urban energy metabolism, and it guided us in the formulation of our research question:

> **How do key-decision-makers' preferences interplay with the Urban Energy Metabolism considering the energy consumption in the Built Environment?**

In order to fulfil the aim of our research and answer to the research question, we firstly proposed the definition of two cardinal elements: the urban energy metabolism and the key-decision-makers that compose the nodes of decision-making, who we especially wanted to focus on. Afterwards we propose a research framework composed by: (1) the investigation of a case study as a starting and reference element for observing an urban energy system and its nodes of decision-making; (2) the development of a Choice Model to study the preferences of key-decision-makers involved in the system with regards to the promotion of policies concerning the implementation of technological-system to reduce the energy consumption in the Built Environment; (3) the conceptual development of an agent-based model, through MAIA framework, where the results from the CM can be used to gather further insights on the influence dynamics between the nodes of decision-making and the urban energy metabolism.
In this final chapter we will retrace the results of our research unravelling specific answer to the four sub-questions and the main research question that guided our research process. In doing so we will also highlight possible limitations of our research and recommendation for future studies. Afterwards we will present the specific contributions brought by this thesis followed by suggestions for further research.

9.2 Main conclusions: answering to the research questions

In order to answer to the main research questions we formulated 4 sub-questions, on which we developed our research framework and that guided our study. We addressed each of them in our research, questions 1 and 2 in Chapter 3, question 3 in chapter 5 and question 4 in chapter 7. We will here recall these answers to round up the answer to the main question.

1) **What are the components, characteristics and boundaries of an urban energy metabolism?**

According to our results, the **components** an urban energy metabolism are the nerve centres of energy demand, of which we identified 7. These can also be defined as the 'nodes of energy requirement' and are: *Households, Public areas, Streets, Public Buildings, Offices and Retails, Industries and Enterprises, Infrastructures*.
The **characteristics** of and urban energy metabolism are defined by its types: of *energy sources*, which can be non-renewable or renewable; of *energy production* that can be locally generated or imported; of *energy flows*, either centralized or decentralized; and of *energy requirements*, which are Heating and Cooling, Electricity, and Fuel. The characteristics of the energy system define its **boundaries**, which might be *vague* considering that a great amount of energy required by the urban area comes from outside its perimeter and a likewise large amount of waste-energy and energy by-products comes out as well.

2) **Who are the key-decision-makers involved in the urban energy metabolism?**

In the urban energy metabolism there are 6 main **nodes of decision-making**. These nodes are: *Government, Energy Producers, Energy Suppliers, Network Operators, Knowledge Development and Others*. Each node is composed by a great variety of individual-decision makers. The extent of their **knowledge** and **decisional power** is considered greater than that of the general collective because of the influence it has on the energy metabolism. Furthermore they can **define the alternatives** the general community can choose among, especially in social, political and economical systems that are, still, mainly traditional, and where, therefore, the decision-making processes are mostly top-down. These decision-makers are, among others, *aldermen, urban planners and policy makers, managers and CEO, but also architects and designers, consultants and professors, building contractors and influencers*.
We went a step further and identified specific companies and organizations that compose the nodes of decision-making within our case study, Amsterdam's energy system, and individual **key-decision-makers** included in them.

3) **What are the preferences of the different key-decision-makers involved in the urban energy system?**

In this research we designed and developed a choice experiment, based on CM method, to estimate the preferences of key-decision-makers. The choice context defined was policy plans, at municipal level, for the implementation of specific technologies suitable to reduce the energy consumption in the built environment, more precisely at the households level. The choice-sets, describing the choice task, were composed by 3 unlabelled technological systems as alternatives (e.g., Residential PV System, District Heating, and Energy Retrofit – thermal insulation). Each alternative was described by 4 attributes: (1) Difficulty of Implementation, (2) Energy savings, (3) Cost of policy implementation, and (4) Competence area addressed.
The design settings of our choice experiment have been: Orthogonal Fractional Factorial Design with unlabelled alternatives and considering only the main effects.
In order to collect the preference data of key-decision-makers we developed a questionnaire and translated into an online survey format. The data collection process lasted for more than a month and a half during which we have been able to engage 49 key-decision-makers.

Considering the defined settings of our choice experiment the results from our choice model are:

- The *Difficulty of Implementation* is **the key factor** considered by key-decision-makers, when asked to express their preference and support on a policy plan promoting the implementation of different technological systems to reduce the burden carried by the built environment upon the energy system.
- The *Energy Savings* and the *Cost of Policy Implementation* are respectively **the other two relevant factors** in their choice outcome.
- Connecting the attributes to the actual preferences we can also conclude that key-decision-makers prefer **implementations that are as little disruptive as possible**, rather than implementations that entail high levels of energy savings or rather than implementations that require low investment costs for the municipality. When choosing among different technological systems, key-decision-makers prefer the ones with the lowest levels of disturbance even if those might entail higher cost for the municipality or lower levels of energy savings.
- Finally, we observed the *Competence Area Addressed* attribute to be an **irrelevant factor** on the choice outcome of the key-decision-makers. Nevertheless, this observation should be confirmed by future studies.

The societal and environmental implications of the CM's results are broad. Important decisional influence seems to be directed toward minor implementations, not disruptive nor drastic, which do not prioritize and aggressively address the reduction of energy consumption within urban environments. The urgency of making cities, and their built environments, sustainable, highly energy efficient and with (nearly) zero emissions is outdone by the effort and labour required by such systematic transition. The key-decision-makers, in traditional and top-down social, political and economical institutions governing

urban environments, seem to not be willing nor ready yet to take upon themselves the realisation of major and challenging transformations of the energy system. Consequently, the potential driving role, held by cities, toward a sustainable development and environmental change, seems to be far apart or, more precisely, proceeding at a slow pace.
The validity and importance of these implications would strongly benefit from the implementation of a dynamic model simulating the choice dynamics and their interplay with the overall energy metabolism, such as the Agent-Based Model that has been here conceptualized.

From these findings and implications we can draw some recommendations for: (1) policy-makers and (2) the ensemble of organizations developing and producing innovative technological-systems.
The (1) policy recommendation is to strengthen the importance given to the final outcome, in this case the actual energy savings, brought by a technological-system, when making decisions on this regard. The weight and impacts of urban energy systems, and the urgency to develop a circular urban metabolism are constantly growing bigger and bigger. Therefore they require the appropriate (or even the most) attentiveness and importance in policy-making discussions.
The recommendation for (2) the ensemble of organizations developing and producing innovative technological-systems is, instead, to take into account the attributes that have a major role for the key-decision-makers deciding upon their possible implementation. For instance, considering our results, we could suggest the research and development to work toward the enhancement of the ease of implementation of technological-systems, rather than mostly focusing on the improvement of the efficiency and cost reduction.

4) **How can the interactions dynamics between key-decision-makers' preferences and the energy system be observed?**

In order to observe and study the actual interaction dynamics between key-decision-makers and the energy metabolism we suggested a methodological combination of Choice Model and Agent-Based Model. In particular we suggested performing such combination through MAIA framework. MAIA framework represents a suitable bridge connecting the two methods considering its tested application in modelling social context and its accessibility to researchers unfamiliar with the programming environment.
We went a step further and conceptualize this methodological combination. We developed a model narrative, where it is represented a simplified energy system, aiming at observing the discussion dynamics among the six key-decision-makers in response to the increasing level of urban energy consumption. The results of the CM define, here, the decision-making criteria on which key-decision-makers will base their choice concerning the possible implementation of a technological-system to bring about energy savings' measures. This is the most important feature of the conceptual model and therefore many other aspects composing the energy system, such as types of energy sources, energy flows, and energy requirements are not included as considered not relevant in the observation of the discussion dynamic.

The expected results of our model (since the model implementation is outside the scope of this thesis) are: (1) the observation of dynamic trends of energy savings, resulting from the discussions' outcomes among the key-decision-makers; (2) the recording of the discussions' outputs, where we can observe how the variation of preferences among key-decision-makers influences the energy system; (3) the recording of the amount of successful technological implementations, which depend both on the discussions' outcomes, on the actual feasibility (economical and practical) of such implementations, and on the dynamic trends of energy consumption; (4) the observation of the patterns of households' satisfaction, in response both to the level of disruptiveness linked to the implementation of technological systems, and to the amount of energy savings, also in economical terms, that are brought by them.

9.3 Limitations and Recommendations

The core of the discussion about the research process has been developed in the dedicated chapter. Nevertheless here we want to highlight what we perceived to be the three main limitations, with the related recommendations, of our research.

Model Development

The implementation of the model was beyond the research scope and timeframe. We acknowledge that this represents a significant limit to the insights that we have been able to gather on the influence dynamics key-decision-makers exert on the urban energy metabolism. We do strongly believe that the application of our results in the shape of model implementation could significantly contribute in filling the current knowledge gap in the UM and EM literature.

Choice Experiment Design

Considering the authors' limited knowledge about the Choice Modelling method but also the limited timeframe and the typology of decision-makers under study, the final design of the choice experiment was simple and only partially tested (with a trial session). As explained in chapters 4 and 8, we had to significantly reduce the levels of the attributes in order to have a manageable experiment's size. Furthermore the typology of decision-makers we focused on also held the size of the experiment and of the questionnaire for two reasons: the limited amount of key-decision-makers we could have been able to engage, and the limited time availability they would have had to participate to our experiment.
Our recommendation for further research, in this regard, is attempting to overcome those difficulties, for instance through a larger research timeframe or a facilitated connection to a good amount of key-decision-makers, and instead prioritize the experiment's complexity in order to gather more information about the preferences and the whole decision-making process of key-decision-makers.

Variety of Key-decision-makers

The typology of decision-makers chosen for the investigation has represented a hindrance in different research stages. This has particularly been the case considering the limited familiarity of the researchers with the specific cultural and social environment investigated (i.e. the Dutch energy system and its key-decision-makers). Therefore our recommendation, in this regard, is to either select a geographical and social context, as case study reference, familiar to the researchers or to be ensured about the availability of a facilitation in connecting to key-decision-makers.

Another limitation is due to the typology of key-decision-makers under study. According to our research and our definition these actors are included into 6 main nodes of decision-making. We included, in our CM, respondents from all of them. Nevertheless, for each node we succeeded in engaging only a small number of decision-makers. Consequently the final results of our CM are generalized for key-decision-makers among the six nodes. Our recommendation, in this regard, would be to deepen the research and operate the CM separately for each node of decision-making, in order to observe whether the results would vary across them. This would be of particular importance and interest considering the final use of the new results in the Agent-Based Model.

Another limitation, as mentioned in chapter 3, is represented by the exclusion of Building Owners from the 6 nodes of decision-making. Especially when considering the energy consumption in the Built Environment and the possible implementation of energy saving technologies, Building Owners represent an important group of decision-makers with a substantial decisional strength and influence. We could not include this node because it is extremely difficult to categorize and to pinpoint Building Owners as they may be very different types of stakeholders, ranging from local government and banks, to cooperatives and house associations, to single individuals. Nevertheless we acknowledge their role and influence in shaping the urban energy metabolism, especially considering the Built Environment.

One final limitation needs to be addressed, the key-decision-makers, independently from the node of decision-making they belong to, and the role they have in the organization or company they work for, have been uniformly treated, in this research, as **influential people**. Nonetheless it is important to acknowledge that their individual types and levels of influence can be very different. For instance, the influence of a city alderman, in charge of the energy program, is larger and different from the influence of a senior researcher and university professor, over the decision on a policy-plan concerning the implementation of energy savings measures. In this regard, our recommendation for future research is to take the different typologies and level of influence into account, especially when developing the simulation Agent-Based Model.

9.4 Research Contribution

Here are briefly explained the main scientific contributions that have been given through this research.

In order to define the main contributions brought by this thesis we need to go back to the research gaps that this thesis intended to fill in. Studying key-decision-makers represents a novelty within UM and EM literature, which mainly focused on the quantification of the resource flows. Several authors have stressed the importance of the great variety of actors, governance mechanisms of urban flows and power relationships that exert a strong influence able to shape the total urban metabolism. Nevertheless these influence dynamics are not being addressed in the existing literature.

Therefore, this research contributed firstly to the understanding of preferences of actors whose influence and decisional power affects the society and the choice alternatives that are given to it, through the development of a CM.
Linked to it, our second contribution composed by the application of the Choice Model method in the UM field, which represent a total novelty. Several methods and tools are used such as MFA, LCA, SFA, MEFA and IO, but, according to our knowledge, Choice Model has never been used in this research area.

Thirdly this research contributed to the understanding of how the influence that key-decision-makers' preferences exert on the overall Urban Energy Metabolism can be observed, through the proposed combination of CM and ABM, especially with the conceptual agent-based model we developed using MAIA framework.
Linked to this, our fourth and final contribution. Several authors, in different fields, have successfully applied the combination of CM and ABM, but again never in the Urban and Energy Metabolism fields. Furthermore, and more importantly, what we have tried to illustrate, in our conceptual model, and in the discussion on the expected results, is that such methodological combination could significantly contribute to the understanding of the organization of cities as resulting from their planning and governance. Consequently this understanding could be of use to the guide future political and technological decisions.

In addition, the CM, the conceptual agent-based model and the overall research approach defined for this thesis can potentially be applied in other urban contexts, simply by adapting the choice modelling experiment and the conceptual agent-based model to the different energy system, where necessary.

9.5 Suggestions for future research

The first suggestion for future research concerns the methodological combination of CM and ABM through MAIA framework. We carried out this combination sequentially. Firstly we completely developed the CM and analysed its results, and only afterwards we began the conceptualization of the agent-based model through the 5 structures of MAIA framework. As a result we were only able to partially use the results of the investigation developed for the CM, and we were lacking of useful information for the conceptual model. The main results of the CM, key-decision-makers' preferences were accommodated in the conceptual ABM, together with the main results of the case-study investigation (i.e., the 6 nodes of decision-making). Nonetheless several other results were not useful for the conceptual model, which in return was lacking of other types of information that we did not gather, as we did not foresee to be of any use, and for which we had to make assumptions. Therefore we suggest avoiding such sequential combination of the methodologies in favour of an iterative one. More specifically we suggest beginning the conceptualization of the ABM together with the development of the CM.

The second and third suggestions are a direct consequence of the first one: the improvement of the design of the CM and of the conceptual ABM.
The improvement of the Choice Model's design, though, needs to be partially done independently from the methodological combination. In fact we mostly refer (1) to the engagement of a larger amount od key-decision-makers, possibly also to define different preference and utility values for each of the 6 Nodes of decision-making; (2) to the inclusion of all the attributes' levels as originally designed; (3) to the improvement of the design by re-defining the fourth attribute, which was found to be not significant partially because poorly defined.

The final and obvious suggestion is the implementation of the actual ABM based on the proposed conceptual model with the necessary adjustments.

APPENDIXES

APPENDIX A – Urban Metabolism

The Urban Metabolism (UM) concept has been in place for over 50 years but only in the past decade it has been brought back to life, with living discussions and interest among scholars in the fields of urban planning, architecture, industrial and urban ecology (Broto et al., 2012; Savini et al., 2015).

Several definitions of UM have been developed since Wolman first used the concept, in 1965, to model and estimate the flows of resources throughout a hypothetical American city (Wolman, 1965). Among all the existing definitions, two of the most recent are the ones leading the theoretical framework of this research. The first definition has been formulated by the MIT research team, lead by prof. Fernandez, according to whom urban metabolism is "*the study of material and energy flows arising from urban socioeconomic activities and regional and global biogeochemical processes*." (Fernandez, 2016). The second definition is provided by Arrobbio and Padovan (2016), describing urban metabolism as "*a multi-disciplinary and integrated platform that examines material and energy flows in cities as complex systems as they are shaped by various social, economic and environmental forces*".
We have chosen these definitions because they take into account all the key elements of UM in its broadest meaning, meanwhile describing it in a way that perfectly matches this research's scope. Both definitions, indeed, share the idea that complex networks of matter and energy flows, within cities, are **shaped by** and the **result of** anthropogenic and natural processes. This approach is in line with the one followed in this research with the aim of investigating the anthropogenic accountability in the current UM, by focusing on the choice preferences of influential actors and the influence dynamics their choices might exert on the overall metabolism.
As pointed out by Arrobbio and Padovan (2016), UM is indeed a multi-disciplinary field of study. Several disciplines have interpreted and built upon the metabolic metaphor in order to understand and study the environmental, economic, and social impacts of cities, each one with its own unique and different perspective.

Since the first studies about the metabolism of cities (Girardet, 1990, 1992; Wolman, 1965) it was clear that they have a linear and unsustainable metabolism, where new resources enter the urban system, undergo to several transformations and then leave the system as waste. Girardet (1990) has been acknowledged for the introduction of the concept of circular metabolism (Baccini and Brunner, 2012; Savini et al., 2015; Zhang, 2013), as the metabolism proper of the Natural ecosystem, in which resource use is implemented to have zero, or nearly zero, waste.
The circular Urban Metabolism approach shares the perspective of the Circular Economy models and of System Thinking, where, challenging the traditional linear economic model, outputs and waste from one system are seen as inputs and resources for other systems. The natural ecosystem metabolism is here considered as a sample model to follow, because of its efficiency in the resource use and minimization of wastes. In this research

the Urban Metabolism perspective considered is the Circular Urban Metabolism, therefore the two terms are used interchangeably.

UM perspective accounts for all kinds of resource flows that go throughout the urban system. These are commonly grouped into themes such as: Water, Energy, Waste, Food, Data, Materials, Mobility and Integration. In this research only the Energy theme is taken under study and defined as Energy Metabolism.

The research area covered by UM approach is indeed broad and complex. The metabolic perspective, in fact, addresses multiple and interconnected dimensions such as: the dynamism of all the resource flows (or themes) that exist in the urban area and are linked to anthropogenic activities (Baccini & Brunner, 2012). It also takes into account the connections and interactions among social, environmental, technological and political systems. Furthermore, it includes multiple nodes of decision-making at multiple levels (political, urban planning, resource management, mobility, building, service), where different networks of actors actively makes decisions that influence the overall urban metabolism. The definition given by Arrobbio and Padovan (2016) exactly addresses this complexity, describing UM as "*a multi-disciplinary and integrated platform that examines material and energy flows in cities as complex systems as they are shaped by various social, economic and environmental forces*".
In Urban Metabolism studies, in order to analyse the urban phenomena and to define possible solutions, all the features underlying the metabolism are taken into account. These features are commonly grouped into themes such as: Water, Energy, Waste, Food, Data, Materials, Mobility and Integration. For each theme several actors and parties are engaged: small and big companies, municipalities, research centres, architecture studios, political parties, consultancies, NGOs, house-owners and, of course, the citizens. Each actor has an active role in shaping urban flows as well as production and consumption patterns.

Literature Review on UM

Urban Metabolism, which is the conceptual framework of our research, benefits of a great amount of literature developed in the past 70 years (considering the first accredited use of the concept by Wolman in 1965). In particular we reviewed some of this literature in which clearly emerges the interdisciplinary character of the UM perspective. Two papers in particular have been of great importance: Broto et al. (2012) and Newell and Cousins (2014). They both compare and analyse the historical applications of UM, individuating the disciplines that contributed, with their own specific approach, to it.

Broto et al. (2012) explores how the UM concept is approached by five different disciplines: Industrial Ecology, Political Ecology, Political Economy, Ecological Economics and Urban Ecology. They then define, through a comparative analysis, six themes. These six themes are shown in figure 2.1. Four of them are particularly relevant for our research scope: the first two and the last two.

In the first theme the city is intended as an ecosystem, which has two main practical implications: first, the natural ecosystem is seen as an archetype; second, the city reveals its parasite nature (city as dependent form its surroundings) (Odum, 1989). Natural ecosystems are presented as cyclical and efficient in their use of resources, while cities are presented as problematic and inefficient with a linear metabolism (Girardet, 1990, 1992). Within this theme, urban ecologist challenged the nature as archetype vision, suggesting instead to look at urban ecosystem through Complex system theory, where "*The city is regarded as a dynamic, complex, and adaptive system linking social and ecological systems*" (Broto et al., 2012).

Table 1 Six urban metabolism themes

Theme	*Key question*	*Emphasis on*
The city as an ecosystem	What lessons from the functioning of ecosystems can be applied to design and plan better cities?	Nature-inspired models of development in urban planning and design
Material and energy flows in the city	What methods can account for material and energy flows through the city and can these provide suggestions for their optimization?	Comparative analyses of cities and models of urban planning in relation to their efficiency in allocating materials and energy
The material basis of the economy	What policy measures can break the link between urbanization, economic growth and resource consumption?	The material limits of the economy and macroeconomic models to achieve economic and resource stability
Economic drivers of rural–urban relationships	How do economic relations shape the distribution of flows between urban regions and their surroundings?	Forms of territorial organization in relation to different modes of economic circulation
The reproduction of urban inequality	How do existing urban flows distribute resources across the city and who controls these processes?	Patterns of unequal access to resources and the control of these patterns by urban elites
Resignifying socioecological relationships	What socioecological practices have the potential to reimagine and reconfigure existing socioecological flows?	Alternative visions and models of socioecological flows in cultural production, everyday practices, and policy innovations

Figure A.1 – Table from Broto et al. (2012) summarizing the six interdisciplinary UM themes

The second theme encloses all the literature that focuses mostly on accounting the magnitude of materials and energy flows within cities. The discipline contributing the most in this theme is Industrial Ecology (IE), where the ecosystem metaphor has been used also in relation to industrial systems (i.e. Industrial Symbiosis, Industrial Metabolism) (Ayres, 1989; Frosch and Gallopoulos, 1989). The IE definition of UM is "*the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste*" (Kennedy et al., 2007). The MFA (Material Flow Accounting) methodology, in particular, is the suggested tools for the assessment of the material and energy's flows and stocks within the urban system. From the 90's, when, in general, attention and interest around UM approach was growing (Baccini and Brunner, 2012; Broto et al., 2012; Decker et al., 2000; Kennedy et al., 2011; Kennedy et al., 2007; Newell and Cousins, 2014; Zhang, 2013), the number of MFA's studies on cities also started to flourish. MFA in UM studies is proven to be successful as it allows identifying urban inefficiencies, patterns of resources' use, and the linear nature of cities' metabolisms. Moreover it offers quantification to support the design of new and appropriate policy measures and to help steer cities toward a sustainable development (Broto et al., 2012; Kennedy et al., 2007). Nevertheless it also has a strong limitation as it directs too little attention to the "*integration of the social and political drivers of material and energy flows*" (Broto et al., 2012). Therefore, what emerges from this theme is that the application of MFA on UM needs to be implemented to include the drivers of the material and energy flows so to be able to assess not only their magnitude but also the mutual shaping-relationship between a society and its resource flows (Broto et al., 2012; Newell and Cousins, 2014).

The fifth theme includes Political Ecology (PE) studies that, even though not explicitly related to UM, look at the dynamics of inequality reproduction in the urban environments. Within this theme one key concept for our research is highlighted: the governance of urban flows and power relationships exert a strong influence able to shape urban flows dynamics. What emerges from the reviewed studies is that "*The powers of ecological processes are socially mobilized to serve particular purposes, usually associated with strategies of achieving or maintaining positions related to social power*" (Broto et al., 2012). This PE approach and studies are of particular interest for our research because they draw attention to the influence politics, governance and power dynamics have on the existing distribution of resources.

In the sixth theme are collected several PE studies that moved another important critic to UM's understating of cities, stating that the metabolic perspective "*fails to theorize the process of urbanization as a social process of transforming and reconfiguring nature*" (Swyngedouw, 2006). Contrarily it emphasised that a specific urban metabolism represents societal, historical, political, and economical phenomena of the urban environment to which it belongs. Furthermore these studies stresses the great variety of actors and mechanisms that have the power to shape the urban flows, such as: "*a wide array of policies, designs, and management styles alongside forms of cultural production, routine interactions, and everyday practices*" (Broto et al., 2012).

The comparative analysis performed by Broto et al. (2012) clearly showed the interdisciplinary character of the UM perspective. Moreover it highlighted critics moved to the different approaches, as well as current knowledge gaps and limitations to the understanding of urban metabolism. These gaps especially exist because no study have yet succeeded at analysing the UM as a complex adaptive system constantly shaped by the interactions of social and technical systems, but also by the dynamics of power and governance existing behind the resource networks.

The study performed by Newell and Cousins (2014) aims at analysing the limits as well as the potential of UM approach, firstly discussing the use of the 'metabolic' metaphor with its different interpretations, and secondly performing a bibliographic analysis that led to the definition of "*Three 'ecologies' of urban metabolism*" (Newell and Cousins, 2014). These three ecologies confirm, in a more generalized manner, the six themes distinguished by Broto et al. (2014). They are: the Marxist ecology, the Industrial Ecology and the Urban Ecology, each of them representing a different school of thought, a different approach to the common urban metabolism metaphor. A table summarizing the three ecologies and their main characteristics is presented in Figure 2. The one that is more relevant for our research is the first: the Marxist ecology.

The Marxist ecology is divided into two internal clusters, the Urban Political Ecology and the UM approach based on the Metabolic rift. The first cluster uses the metabolic metaphor to describe urban spaces as a "*socionatural hybrid*" (Newell and Cousins, 2014), where the dynamic character of the relationship between nature and society gives shapes to the circulation, mostly uneven, of resources; some emphasis is also given to the power structures that contribute to the shaping of the urban metabolism. The Metabolic rift cluster also uses the metabolic metaphor to describe the interconnected relationship

between nature and society, but it is perceived as an antagonistic relationship, building on Marxist's concept of '*rift*' between the humans and the environment caused by the diffusion of capitalism.
Several are the studies of urban systems preformed using MFA, starting from the earliest influential study on the metabolism of Hong Kong (Newcombe et al., 1978).

Table 1. Characteristics of the three ecologies of urban metabolism.

	Marxist ecologies	Industrial ecology	Urban ecology
Metaphorical conception	Metabolism as nature–society relations	Metabolism as biological organism	Metabolism as ecosystem
Network clusters	1) Urban political ecology 2) Metabolic 'rift'	1) 'Traditional' urban metabolism 2) 'Vienna School' of socio-economic metabolism	—
Theoretical influences/key figures	Marx; Harvey; Bellamy-Foster; Smith; Swyngedouw; Gandy; Kaika; Keil; Heynen	Lavoisier; EP Odum; HT Odum; Wolman; Ayers; Kennedy; Fisher-Kowalski; Weisz; Schandl	Complex systems theory; EP Odum; Pickett; Grimm; Alberti
Emphases	• How dynamic nature–society relationships shape outcomes, including (re)production of inequality and rift • Social power	• Quantifying 'flows' and 'stocks' • Optimizing and reducing material 'throughout'	• Internal complexity of urban ecosystem processes • Sub-system interactions • Ecosystem function to inform sustainability
Language	• Movement as networked circulations • Urban as created ecosystems • Nature–society dialectic • Production of nature	• Movement as input–output • Flows as throughput • Beyond the city as 'hinterland'	• Movement as feedback loops • Flows as structure–function linkages • Internal transformations • Nature–society hybridity
Methods/models	• Historical materialism • Qualitative approaches	• Mass-balance approaches • Material flow analysis (MFA) • Emergy analysis • Life cycle assessment (LCA)	• Ecologically informed complex systems models
Critiques/perceived limitations	• Isolated scholarly network • 'Methodological cityism' • Social at expense of ecological • Marxist dominated	• 'Black boxing' of urban processes • Aspatial rendering of 'hinterland' • Nature–society dualism • Flows instead of stocks • Apolitical	• Bounded sense of 'urban' • Apolitical • Complexity at expense of distal flows

Figure A.2 – Table from Newell & Cousins (2014) summarizing the main characteristics of the three ecologies and their limitations

At last, another source needs to be individually mentioned because of its importance for this research.
Baccini and Brunner (2012) in 1991 firstly associated the use of the metabolic metaphor to the Antroposphere. In their book '*Metabolism of the Antroposphere*', they theorized and performed metabolic analysis at very different levels, starting from the unit at the core of the urban environment, the household, to continue to the city and the regional levels, in line with their idea that "*It is the anthropogenic metabolism of a human society – made up of millions of inhabitants – that gives the full picture*" (Baccini and Brunner, 2012).
Furthermore they distinguish four fundamental categories of human activities that try to include the entirety of basic human actions (*to nourish, to clean, to reside & work, to transport & communicate*), which they use to relate the flows and stocks of materials throughout households, cities and region (Baccini and Brunner, 2012). Baccini and Brunner (2012) thoroughly analysed the metabolic approach to the study of urban ecosystem, nonetheless they mostly dwell into the technical and quantitative aspects, only briefing touching upon the social and qualitative aspects influencing urban metabolisms. Therefore, once again, we can see the lacking of research that explicitly has its focus on those aspects from a metabolic perspective.

As this part of the literature review has shown, the research area covered by UM approach is broad, complex and multidisciplinary, and it has steered the research toward a different understanding of cities (Broto et al., 2012; Newell & Cousins, 2014; Zhang, 2013). The metabolic perspective, in fact, addresses multiple and interconnected dimensions such as: the dynamism of all the resource flows that exist in the urban area and are linked to anthropogenic activities (Baccini & Brunner, 2012; Decker et al., 2000; Kennedy et al., 2007; Kennedy & Hoornweg, 2012). It also takes into account the connections and interactions among social, environmental, technological and political systems (Odum, 1969; Swyngedouw, 2006). Furthermore, it includes multiple nodes of decision-making at multiple levels (political, urban planning, resource management, mobility, building, service), where different networks of actors actively makes decision that influence the overall urban metabolism (Broto et al., 2012; Savini et al., 2015).
The literature review on UM studies has also shown that the influence of the nodes of decision-making on the urban metabolism is being investigated the least even though recognised as fundamental driver of materials and energy flows within urban ecosystem, as well as potential drivers for urban system's innovation (Baccini and Brunner, 2012; Savini et al., 2015).

APPENDIX B – Energy Metabolism

The concept of Energy Metabolism is used by several authors (Fath et al., 2010; Ginard-Bosch and Ramos-Martín, 2016; Kuznecova et al., 2014; Pincetl et al., 2012; Yang et al., 2015; Zhang et al., 2014) to convey the shift of their research focus on the urban energy system, by means of the UM perspective.
Therefore, according to this perspective: the energy system is considered as a complex adaptive system; several dimensions are taken into consideration (environmental, social, economical, technical) and accounted for their role in shaping the system's metabolism. Furthermore different areas of the energy system are considered (production, supply, use,) and its boundaries, even though related to the urban environment, are flexible, because of the intrinsic nature of the ecosystems' metabolism metaphor as well as because of the dependence of urban energy systems on its surroundings, both for its inputs and outputs. In other words, the fundamental characteristics of UM are applied to the urban energy system.
For this thesis the concepts of energy system and energy metabolism are intended as a unique one, since the main difference is given by the framework and perspective that is used to analyse them. An analysis and configuration of the energy system, or energy metabolism, under study is given in the second part of the thesis, as it is part of the investigation's results, in Chapter 3.

Literature Review on Energy Metabolism

In our literature research we came across several sources that were explicitly focusing on the energy metabolism in urban environments (Balogh et al., 2014; Fath et al., 2010; Kuznecova et al., 2014; Zhang et al., 2014). All of these studies share the same quantitative focus and aim, even more marked than what emerged from the previous review of literature on UM. Among the methodologies used and suggested in these studies there are: MFA, SFA, MEFA, LCA, Network Analysis, MuSIAEM, IO. Below, the reviewed paper are shortly presented with the aim to describe the literature background about Energy Metabolism and position our research in it.

Balogh et al. (2014), in their study, intend the urban energy metabolism as the respiration process of cities in which primary sources, mostly provided by more or less distant areas outside of the city's boundaries, are transformed and consumed by the economic activities within. With the methodological tool developed within IE, Material and Energy Flow Accounting (MEFA), they observe the evolution of the respiration-production ratio through important historical periods or energy landmarks (industrialization, fossil fuel era, post-indutrialization) (Balogh et al., 2014).

Fath et al. (2010) apply ecological network analysis to develop a model describing the urban energy metabolism, through a case-study of four Chinese cities. Five sectors emerge from the ecological network model: Energy exploitation, Energy transformation, Industrial sector, Households (or Living sector) and Recovery. Using network analysis Fath et al. (2010) individuate the main links existing in the urban energy metabolism among the 5 sectors and also with its surroundings. Afterwards they quantify these links' magnitude through network utility analysis, using data related to energy consumption. Network utility analysis is finally used to determine the pattern of interactions among the sectors. As a result they identified 5 intersectorial ecological relationships: "*competition, exploitation, control, mutualism, and neutrality*" (Fath et al., 2010). In conclusion they suggest their findings to be used to identigy potenital problematic links and propose improvements.

Kuznecova et al. (2014) develop a methodological approach to assessing the resilience of urban energy systems, and in particular develop a set of indicators and a final Resilience Index through an energy metabolism perspective. In explaining the importance for urban systems to be resilient, because of their vulnerabilities and dependencies upon other systems, Kuznecova et al. (2014) express an important concept shared by our research's premise "*the importance of improved planning which, however, would require new institutional frameworks and inclusion of different stakeholders to address the complex coordination issues across sectors*" (Kuznecova et al., 2014). Furthermore the preparatory steps in their methodology, to identify the research's goals and the system to be examined, have been similarly used in our research.

Zhang et al. (2014) use Input-Output (IO) analysis to study both the direct and indirect flows of energy consumption among sectors. Afterwards, using the results of their IO tables they developed an "*urban energy metabolic network model*" where, applying Ecological Network Analysis, they were able to calculate the magnitude of the indirect energy consumption flows. Combining the indirect flows with the direct ones they finally obtained the embodied energy consumption, and the relative carbon footprints, of the studied urban energy metabolism (Beijing as case study), divided by consumption sectors. In conclusion they found out that, in their case study, the indirect consumption represented the most impacting factor.

To conclude this part of the literature review we must point out: the already mentioned variety of tools used by researchers to investigate the urban energy metabolism, and the generally shared quantitative approach. Two more aspects emerged through the reviewed literature, which are important for the current research: the Complex System approach and the presence of multiple decision-making nodes in the network defining every urban energy metabolism.

APPENDIX C – Steps to develop an ABM

The 10 steps illustrated by Nikolic et al. (van Dam et al., 2013) have the aim to guide the modeller through the whole procedure, form the very initial process of observing the reality and individuating the problem, the system and the actors, to the final process of validating and using the model. These 10 steps are:

1) Problem formulation and actor identification;
2) System identification and decomposition;
3) Concept formalization;
4) Model formalization;
5) Software implementation;
6) Model verification;
7) Experimentation;
8) Data Analysis,
9) Model validation;
10) Model use.

In this thesis an ABM of the system under study will be only *conceptualized*, leaving the final steps, form the software implementation on, as a suggestion for further research. The first four steps that are part of the Conceptualization stage are here explained.

Problem Formulation and actor identification

A researcher, the modeller, usually selects the modelling procedure when there is a problem that needs to be addressed and/or a lack of knowledge about a system that need to be filled-in. Models, as a means to improve our understanding of a system and the dynamics that take place within it, must have as final aim the providing of insights and not of exact numbers nor answers. In order to do so and fulfil the scope of the model, the system under study has to be observed to clearly define the problem and the actual lack of knowledge, as well as emergent patterns existing or expected. At the same time the modeller needs, in this step, to have clear in mind the owner of the problem, which will constitutes the observer of the model, and the actors, or agents, that are involved in the system with their own characteristics and roles. In synthesis this is what this step is about: clearly defining the problem that is being addressed and the problem-owner, and then carefully observing the system to identify its components, agents and dynamics and clarify the initial expectations.

System identification and decomposition

In this step the structure of the model, as shown if figure 4.1, starts to be shaped. At this point the modeller has to define what are the components, boundaries and structure of the system that will be modelled. This is a very crucial and difficult stage of the modelling process. It builds up from the first stage and requires the modellers to make several assumptions and simplifications. Nevertheless the researcher has to try to obtain as much information on the system as possible. This can be done through literature research, interviews, surveys or roundtables with the problem owner(s) and other relevant stakeholders.

All the available information with the necessary simplifications and assumptions, on the agents, their states and actions, and on the environment will be compiled in an *Inventory*. This will then be used for the *Structuring* phase, where the structure of the model is finally created specifying the actions and interaction that take place, the iterative processes, the limits of the system and the functioning of the environment.

Concept formalization

The concept formalization step consist in a translation of all the components and information of the model in a formal language that is sufficiently clear and without ambiguity so that the computer can exactly process the information as the modeller intended it. The concepts of the model can be formalized using elements such as variables, objects, lists, strings, numbers, etc. Furthermore the relations and hierarchy among those concepts have to be formalized as well. This constitutes the ontology of the model, which will be at a later stage easily transformed into programming language.

Model formalization

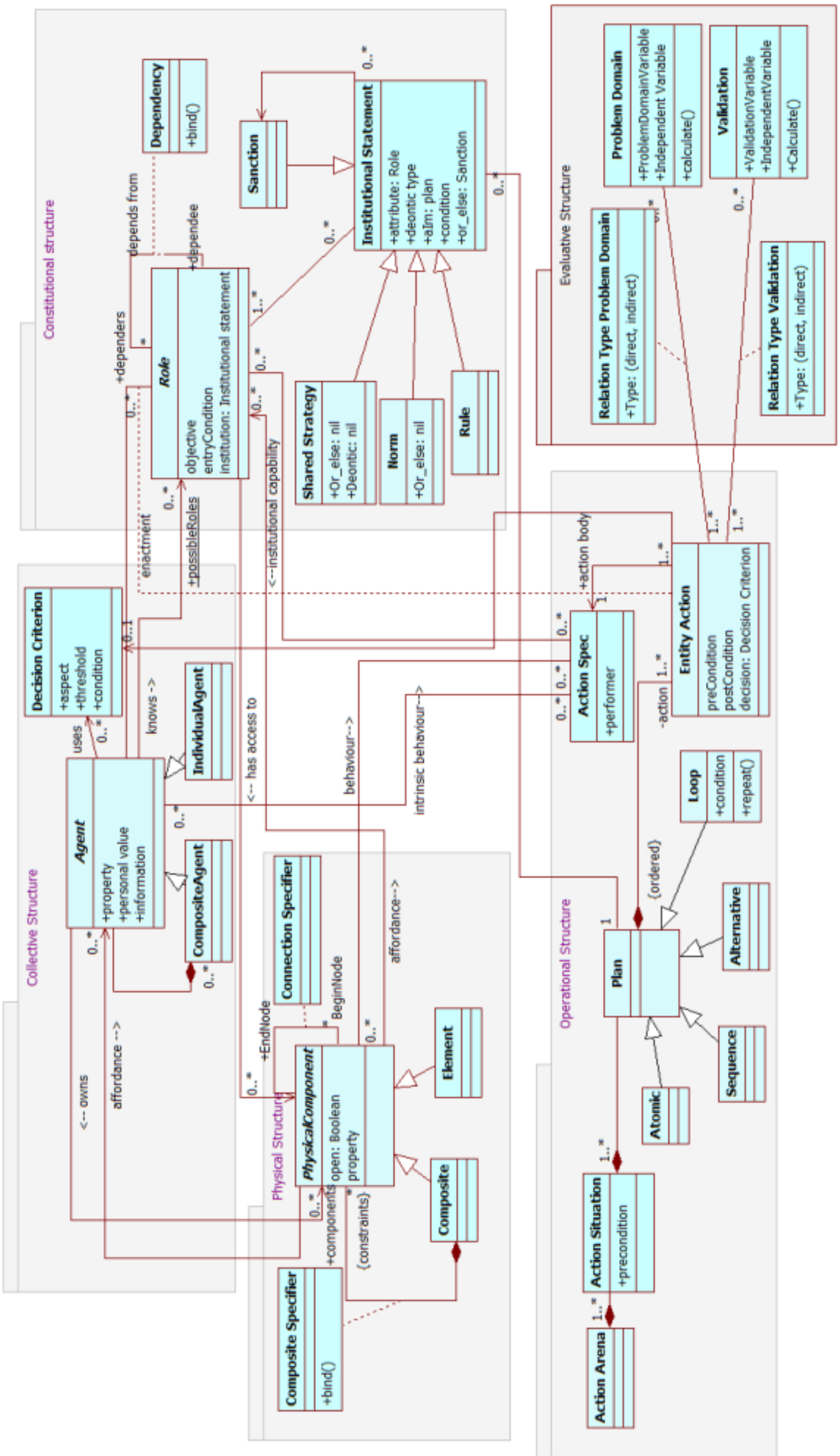
At this point, all the model's elements, concepts and information have been defined and characterised and it is therefore possible for the modeller to move forward and describe *what* and *when* is exactly going to happen in the simulation model. Two sub-steps are suggested here, the first is the creation of a narrative and the second is the translation of the narrative into pseudo-code.

The narrative represents the story behind the model. Writing the narrative requires the modeller to think and write what is going to happen in the model, for instance the interactions among agents, the changes in their states or in the environment as a consequence of some other interaction. In other words, the narrative contains the sequence of actions and events that take place in parallel during every time unit. While writing the narrative it is common to realize that some features of the model were not been considered yet, which gives an idea of the importance of this step.

Once the narrative is completed it can be translated into an algorithm, or pseudo-code, that will guide the modeller during the software implementation step.

APPENDIX D – Maia meta-model overview

Maia meta-model. Complete overview of the 5 structures (Ghorbani, 2013).



APPENDIX E - Questionnaire

Instruction to fill out the survey:

This research is part of a Master Thesis in Industrial Ecology (from Delft University of Technology and Leiden University) developed in collaboration with the City-zen project (http://www.cityzen-smartcity.eu/), AMS Institute (Amsterdam Institute for Advanced Metropolitan Solutions); www.ams-amsterdam.com/) and Amsterdam Smart City (www.amsterdamsmartcity.com)

Completing the survey takes about 10 minutes. The survey consists of 3 parts:
1) Background information
2) Preferences for 12 alternative policy-plans
3) 4 follow-up questions

Privacy
The research results are used for research purposes only and can not be traced back to individuals. Individual responses are never made public; Your information will be treated as confidential.

QUESTIONNAIRE

PART 1 – BACKGROUND INFORMATION

Some useful information concerning the context:

Information:	Data:	Source:
N° of households in Amsterdam	417096	(Gemeente Amsterdam, 2015)
Average of m2 per households	74m2/dwelling	(CBS, 2016)
Average household size	2.2 persons	(Blok et al., 2015)
Average energy requirement per household	58 GJ	(Blok et al., 2015)
Current CO2 emissions in Amsterdam	4437 kTon/year	(Municipality of Amsterdam, 2015b)
National Goal for energy savings, defined in the "Energieakkoord"	1.5 % reduction of energy consumption each year until 2020	(Municipality of Amsterdam, 2015a; Nijpels, 2014; SER, 2013)

In order to answer to the questionnaire, please imagine yourself as a policy-analyst or a decision-maker for the city of Amsterdam.
Because of your knowledge and expertise in the energy sector and/or for the housing sector, you have been asked to take part to a discussion concerning the improvement of energy efficiency in the residential stock, taking into account the Dutch National goal for energy saving by year 2020, defined in the "Energieakkoord". You will be given 12 tables in which 3 alternative policy-plans are described, through selected attributes. For each table you are asked to choose one policy-plan.
NAME*: ____

(*This information is required only to check out your name from the participants' list and avoid disturbing you in the future. The outcomes of the questionnaire are completely anonymous.)

GENDER: (Female) (Male)

EDUCATION LEVEL:

- o High School
- o MBO
- o HBO
- o Bachelor Degree
- o Master degree
- o Phd

TYPE OF COMPANY/ORGANIZATION** YOU ARE PART OF:

____

ROLE (in the company/organization you work for):

____

HOW LONG HAVE YOU BEEN HOLDING THIS ROLE (in the same company/organization)

____

YOU HAVE PREVIOUSLY BEEN PART OF (or *an active stakeholder in*) A PROJECT RELATED TO:
(Cross all the options that apply)

- o Energy system in Amsterdam
- o Residential Stock in Amsterdam
- o Energy efficiency
- o Urban metabolism
- o Energy metabolism
- o Sustainable energy system in Amsterdam
- o Circular Economy
- o Other:_____________
- o none of the above

PART 2 – PREFERENCES

The options described in the choice sets are based on already existing technological systems, which are being implemented in the municipality of Amsterdam. Each option refers to a different technological-system. The technological level here considered may be more advanced than the level currently available.

The attributes defined to describe the different policy options are the following:

Attribute name	Definition	Units
Difficulty of implementation for the municipality	Describes the different levels of complexity of the infrastructure that is required to be implemented, in order for the technological system to be operative and effective.	Low, Medium
Energy savings	As a result of the implementation of that specific technological system this represents the percentage of energy that can be saved **by 2020**, if the implementation is fully achieved.	%
Cost of policy implementation	Cost to be undertaken by the municipality supporting the implementation of a specific technological system. This cost is intended to describe the investments in subsidy for citizen or for the establishment of the appropriate infrastructure.	€
Competence area addressed	Describes which types of energy consumption the technology is going to tackle.	Electricity, Heating, …

Note that for each question the values for the options are constantly changing.

On the following pages you will see 12 choice sets. We ask you to select one of three options.

QUESTION 1

The three policy options to reduce residential energy consumption are here described according to the values assumed by the four attributes in this specific case. ***According to these values, which option would you choose****?*	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	High	Medium
Energy savings	3.2%	4.8 %	7.7%
Cost of policy implementation	39,000,000 €	37,500,000 €	62,800,000 €
Competence area addressed	Electricity	Heating and hot water	Electricity and Heating

Which option do you prefer?	A	B	C

QUESTION 2

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	High	Medium	Medium
Energy savings	5.2%	6.5%	7.7%
Cost of policy implementation	39,000,000 €	55,700,000 €	55,800,000 €
Competence area addressed	Electricity and hot water	Heating and hot water	Heat loss prevention
Which option do you prefer?	A	B	C

QUESTION 3

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	High	Medium	High
Energy savings	6.9%	6.5%	4.7%
Cost of policy implementation	39,000,000 €	37,500,000 €	62,800,000 €
Competence area addressed	Electricity and hot water	Heat loss prevention	Electricity and Heating
Which option do you prefer?	A	B	C

QUESTION 4

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	Medium	High
Energy savings	6.9%	3.3%	7.7%
Cost of policy implementation	39,000,000 €	37,500,000 €	62,800,000 €
Competence area addressed	Electricity	Heat loss prevention	Heat loss prevention
Which option do you prefer?	A	B	C

QUESTION 5

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	High	High
Energy savings	3.2%	6.5%	7.7%
Cost of policy implementation	39,000,000 €	55,700,000 €	55,800,000 €
Competence area addressed	Electricity and hot water	Heat loss prevention	Electricity and Heating
Which option do you prefer?	A	B	C

QUESTION 6

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	High	Medium	High
Energy savings	5.2%	3.3%	6.4%
Cost of policy implementation	39,000,000 €	37,500,000 €	55,800,000 €
Competence area addressed	Electricity	Heating and hot water	Electricity and Heating
Which option do you prefer?	A	B	C

QUESTION 7

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	High	High
Energy savings	5.2%	3.3%	6.4%
Cost of policy implementation	42,700,000 €	55,700,000 €	55,800,000 €
Competence area addressed	Electricity	Heating and hot water	Heat loss prevention
Which option do you prefer?	A	B	C

QUESTION 8

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	Medium	High
Energy savings	6.9%	4.8%	4.7%
Cost of policy implementation	42,700,000 €	55,700,000 €	62,800,000 €
Competence area addressed	Electricity and hot water	Heating and hot water	Heat loss prevention
Which option do you prefer?	A	B	C

QUESTION 9

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	High	High	Medium
Energy savings	3.2%	6.5%	6.4%
Cost of policy implementation	42,700,000 €	37,500,000 €	62,800,000 €
Competence area addressed	Electricity	Heating and hot water	Heat loss prevention
Which option do you prefer?	A	B	C

QUESTION 10

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	Medium	High	Medium
Energy savings	5.2%	4.8%	4.7%
Cost of policy implementation	42,700,000 €	37,500,000 €	55,800,000 €
Competence area addressed	Electricity and hot water	Heat loss prevention	Electricity and heating
Which option do you prefer?	A	B	C

QUESTION 11

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	High	High	Medium
Energy savings	6.9%	3.3%	4.7%
Cost of policy implementation	42,700,000 €	55,700,000 €	55,800,000 €
Competence area addressed	Electricity	Heat loss prevention	Heat loss prevention
Which option do you prefer?	A	B	C

QUESTION 12

According to these values, which option would you choose?	**OPTION A**	**OPTION B**	**OPTION C**
Difficulty of implementation for the municipality	High	Medium	Medium
Energy savings	3.2%	4.8%	6.4%
Cost of policy implementation	42,700,000 €	55,700,000 €	62,800,000 €
Competence area addressed	Electricity and hot water	Heat loss prevention	Electricity and heating
Which option do you prefer?	A	B	C

PART 3 – FOLLOW-UP QUESTIONS

To answer to the following questions assign a value from 1 to 7 according to your personal opinion and experience.

To what extent do you perceive the energy metabolism* in Amsterdam to be sustainable and efficient?
(taking into consideration the circulation of energy inflows and outflows within the geographical boundaries)*

(Not at all) **1** **2** **3** **4** **5** **6** **7** (Completely)

To what extent do you think the improvement of Amsterdam's energy system is high on the municipal agenda?

(Not at all) **1** **2** **3** **4** **5** **6** **7** (Completely)

To what extent do you think the improvement of the energy efficiency of the residential stock in Amsterdam is high on the municipal agenda?

(Not at all) **1** **2** **3** **4** **5** **6** **7** (Completely)

Finally, do you think some fundamental information** was missing in the description of the policy-plans? If yes, can you please briefly specify which type of information?
*(** information that you think is fundamental for a decision-maker to take into account in order to choose any policy plans)*

DO YOU WANT TO RECEIVE THE RESULT OF THE STUDY? If so, please fill-in with your email address:

____

APPENDIX F – Standard email

Day, Month, 2016

Participation in Master Thesis research (TU Delft)

To the attention of Name of the Addressee
Work/Role title
Name of the Organization/Company

Dear Mr / Mrs / Miss / Dr / Sir or Madam / To whom it may concern   Addressee Name

My name is Francesca Klack. I am an international student of the master in Industrial Ecology at TU Delft and Leiden University. I am currently working on my master thesis, which, in collaboration with **AMS Institute,** the **City-zen** project and **Amsterdam Smart City**, investigates the influence of decision-makers on the energy metabolism of Amsterdam, supervised by Dr. Amineh Ghorbani and Prof.dr. Ellen van Bueren.

I have contacted you / your company because you are actively involved in the Amsterdam energy system / in the City-zen project / a member of the AMS network. For my thesis research I am collecting data regarding **policy choices about energy efficiency in the built environment**. For that I developed a questionnaire to investigate the preferences of **key decision-makers**. Therefore I would highly appreciate if you could dedicate no more than **10 minutes** to answer to this questionnaire (this is the link: http://tbm.collector-survey.tudelft.nl/nq.cfm?q=11F7BE6B-C697-4973-88A9-CAAC07746FC8) before the 15th of December. If you instead prefer to arrange a **15 minutes meeting** (with the energy department manager) to answer to my questionnaire I would be glad to have the chance to meet you. The questionnaire and the eventual outcomes of the interviews are completely anonymous and private.

Your participation to this survey is of high value because the results of my research will contribute, with insights concerning the influence of decision-makers, **to the City-zen project** development and to the on-going multi-disciplinal researches concerning **Amsterdam future development** performed within **AMS Institute**.

Furthermore, I would be glad to share the overall results of my research (with you / your company).

Thanks for taking the time to read my email.
Wij danken u zeer voor uw medewerking. (Thank you very much for your cooperation)
Looking forward to hearing from you.

Kind regards,

Follow-up Email

[Follow-up] Participation for Master Thesis research (TU Delft)

21st November 2016
Name of the Addressee
Work/Role title
Name of the Organization/Company

Dear ,

A week ago I have sent you an email concerning my thesis research and your participation in the questionnaire I developed to investigate **key-decision-makers preferences**.
For more detailed information on the research you can refer to the text of my previous email (here below). The questionnaire (here is the link: http://tbm.collector-survey.tudelft.nl/nq.cfm?q=11F7BE6B-C697-4973-88A9-CAAC07746FC8) will take you **no more than 10 minutes** and it will be available until the 15th of December.

Your participation to the questionnaire is of high value for my research since your own experience as key-decision-maker represents a **unique contribution** to my study.

Thanks a lot for your time and your cooperation.
Looking forward to hearing from you.

Kind regards,

APPENDIX G – Detailed research on Future Plans for Amsterdam's Energy System

Amsterdam's Structural Vision

Table 5.2 _ Summary of the 7 spatial task of the Amsterdam's Structural Vision (Lauwers et al., 2011)

Densify	Intensify the use of the available space to host more people, activities, services and amenities. This will allow to improve the energy and transport management and to not overcome the municipal landscape. The construction of 70,000 dwellings is planned before 2040.
Transform	Mono-functional areas, such as business parks, will be transformed into areas with urban fusion of business and residential functions.
Public transport on the regional scale	Great improvement of the current transport services at the regional level by means of metro, trains and rapid bus. Increase of the number of "P+R" facilities to improve and better encourage the transfer between private and public transport especially when entering the city region.
High-quality layout of public space	Life quality in the city is a theme with increased importance; this also means the improvement of the quality of public space, especially in marginal regions as the one in the vicinity of the A10 ringroad. More space for pedestrian and cyclist; special attention is to be given to the area with more shops and humans and cars' traffic.
Invest on the recreational use of green space and water	Greenery and water in public space are important for the citizens' welfare as well as for the economy of the city since they have became a prerequisite for businesses to establish themselves in a specific area.
Converting to sustainable energy	A great energy efficiency has to be reached in the short period to be ready for the transition to a post fossil-fuel era. "*A big step can be made by rendering the existing housing stock more energy-efficient, and Amsterdam has also chosen to generate a large proportion of its energy needs itself, which includes the collection of solar energy on rooftops, the construction of a closed heat-transfer system in order to be able to transport residual heat, and the installation of wind turbines. Amsterdam will also be investing in sustainable energy generation throughout the region*." (Lauwers et al., 2011)
Olympic Games Amsterdam 2028	Plan the layout, for the necessary structures, in AMA to fulfil the Dutch ambition to host the Olympic Games in 2028.

Sustainable Amsterdam Agenda

Table 5.3 _ Summary of the 5 pathways of the Sustainable Amsterdam Agenda. (Municipality of Amsterdam, 2015a)

Pathway	Goals and Ambitions
Renewable energy	To generate 20% more sustainable energy per citizen compared to 2013. This is to be facilitated by enabling the construction of new wind turbines, by facilitating the growth of the solar energy system and with the expansion of the heating grid. To use 20% less energy per citizen compared to 2013. The second goal is to be facilitated by improving the sustainability of the building stock, encouraging energy-saving measures within households as well as climate-neutral new constructions.

Clean Air	The municipality aims at setting higher standards for the clean air, looking at the "*real health effects of the individual inhabitants*". Reduction of the soot emissions and after 2025 the motorised traffic will have to be as clean as possible. Intensification of the electric vehicles by increasing the number of public charging stations.
Circular Economy	To have a clear vision of the system in order to be able to start a real transition towards a circular economy. Stimulate research and innovation. To improve significantly the separate waste collection and recycling systems. This is with the ambition "*to separate 65% of domestic waste for reuse by 2020*".
Climate-resilient city	To begin now to adapt the city to greater volumes of water, but also to be prepared for dryer situations. Determine, within the coming Municipal Executive duration, what it is necessary to transform Amsterdam in a climate-resilient city.
Sustainability of the municipality's Operational Management	45% reduction by 2025 of the CO2 emission of the operational management, compared to 2012. To have a sustainable procurement and the related sustainability of the production chains. 75% increase by 2025 of the proportion of separate waste collection in the municipal offices, compared to the previous 40% proportion-

From the Sustainable Amsterdam Agenda (Municipality of Amsterdam, 2015a). Here are listed the approaches and specific actions included in the Renewable Energy pathway for each of the four components. (Municipality of Amsterdam, 2015a)

APPROACHES:

1) .Solar energy:

- Informative campaigns for roof owners to get to know the opportunities of solar energy;
- Several actions are directed towards the adjustment, or scrap, of local as well as national rules that obstruct the transition to renewables (i.e. laws about buildings' aesthetic, building rights concerning leasehold properties);
- Demonstration of the impediment represented by national regulations (for instance tax rules) to the local sustainable development, and consecutive call for action towards the specific laws;
- Encourage and support the establishment of partnerships and arrangements to make use of roof surfaces that are of property of associations, businesses or social real estates;
- Offer financial support initiatives.

2) Wind energy:

- Discussion between central and provincial governments for the location of wind turbines. Aim: to create space for a generation capacity of 250 MW by 2025 and 400 MW by 2040;
- Look for wind turbines sites in the proximity of the Amsterdam port area, the Noorder IJplas, and the NDSM Wharf;
- Offer to Amsterdam inhabitants and business to purchase locally produced renewable energy as well as to participate in its production;

3) Renewable heating:

- WestpoortWarmte (WpW), a partnership between Nuon and AEB Amsterdam (both major actors in the development of a district heating grid), has a long-term target of 230,000 connections to the DH grid by 2040. This goal has been adapted to the current Municipal Executive term, and approved by the municipality. The short-term goals are 81,000 connections by 2018 and 102,000 by 2020;
- In 2015, the municipality together with stakeholders developed the "Heating Action Plan" a framework to guide all the actors working on urban development and transformation to make proper choices and arrangements concerning the connection of new DH sources to the existing grid or to underground heat storages;
- Investigation of the possibilities given by "*geothermal energy and large-scale thermal solar energy*" (Municipality of Amsterdam, 2015a), and water cycle. Feasibility studies and trial projects are planned;

4) Existing housing stock (the measures proposed are based on the SER Energy Agreement):

PRIVATE HOUSEHOLDS or HOUSING ASSOCIATIONS:

- Agreement with the housing associations to commit to the SER Energy Agreement to bring the average of their properties to Label B by 2020;
- Collaboration between municipality and housing associations to produce renewable energy;
- The municipality aims at developing, together with private parties, 1,000 "Zero Energy Buildings" ("Nul op de meter-woningen", NOM) dwellings. This represents the official trial of the NOM concept, which if it proves to be successful it will be further promoted;
- Evaluation of the previously promoted schemes for energy conservation in households, and decision on new schemes for which "*the starting point is: effectiveness and connection to the framework of the Sustainability Agenda*"(Municipality of Amsterdam, 2015a);

BUSINESSES and the PRIVATE SECTOR:

- To determine, by 2018, the efficacy of the Environmental Mangement Act (Wet milieubeheer), by examining whether all the 950 large-scale energy consumers and the municipality itself have complied with their obligation or whether specific agreements were made for this purpose;
- Small business do not have to comply with any requirement, nevertheless they are encouraged to take energy saving measures, to this end the municipality offers to them, for free, informative sessions, energy scanning and consultation concerning practicalities;

SCHOOLS:

- Between 2015-2018 the category B of Schedule of Requirements for Clean Schools (Programma van Eisen (PvE) Frisse Scholen) will be implemented in 111 schools, primary and secondary;
- From January 2015 all new primary and secondary schools will be constructed meeting the program of the Schedule of Requirements for Clean Schools;

SPORTS FACILITIES:

- Implementation of the Sustainable Amsterdam Sports Clubs project (Duurzame Amster- damse Sportverenigingen) for, at least, 25% of the outdoor sports club;
- Economic investments and application for specific funds (e.g. Sportaccommodatiefonds or the Energy Fund) to be able to invest to improve the sustainability and the energy measures of the existing facilities;

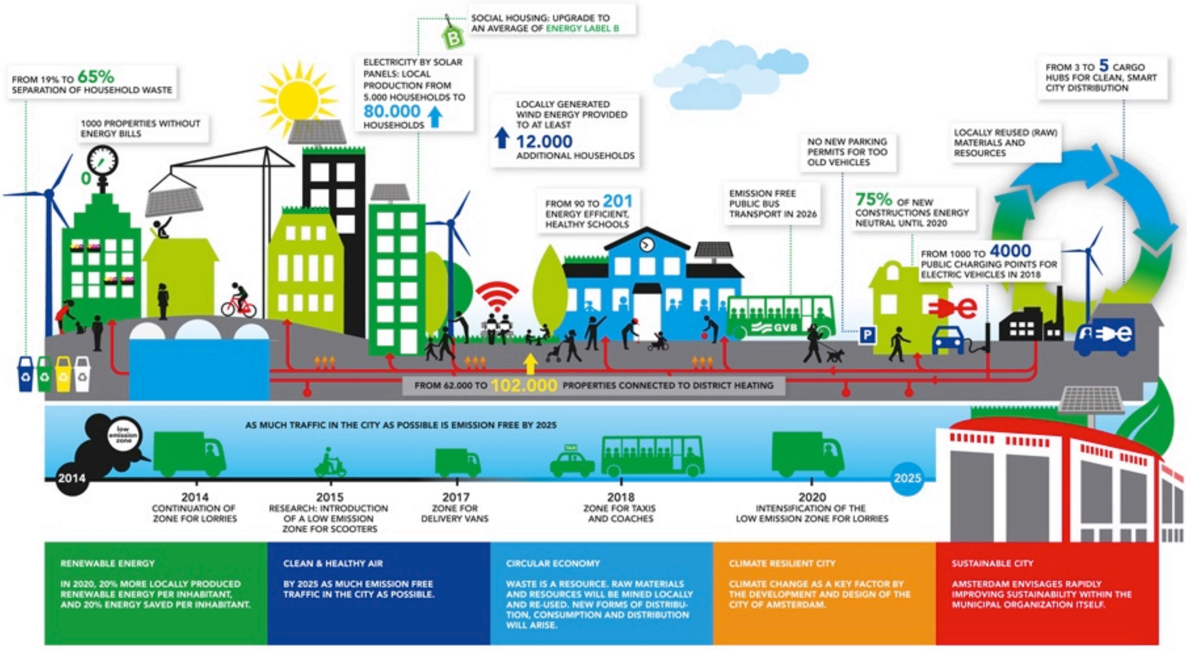


Figure G.2 _ Info graphic showing the 5 pathways of the Sustainable Agenda. (Municipality of Amsterdam, 2015a)

Energy Agreement

Table 5.6 _ Summary of the 10 components of the Energy Agreement. (SER, 2013)

Saving Energy	The aim is to reach an annual saving on energy consumption of 1.5%. The packages of measures that have been approved are expected to generate a 100 PJ saving by 2020. The measures are directed both towards the built environment and towards the energy efficiency increase of commercial sectors, agriculture and industry. The Built environment: the key here is the personal interest of individuals and business in regard to energy savings. Therefore the arrangements concern a combination of: providing information, raising awareness, reducing the burden, guarantee funds and economical supports. The Commercial sectors, agriculture and industry: the key for them is to increase their energy-efficiency to become more competitive, create employment and fulfil climate-related goals in a cost-effective way.
Scaling up renewables energy generation	The goal, given by the Dutch Government, is to generate 16% of the national energy through renewable sources. The parties involved foresee to reach the goal by 2023, while the 14% is going to be reached by 2020. The main arrangements are: Offshore wind power scaled up to 4450 MW by 2023; Onshore wind power scaled up to 6000 MW by 2020; To tackle the factors limiting the scaling up of other renewable sources by July 2014;

	The use of biomass by coal-fired power plant is promoted but limited to 25 PJ generation Substantial reduction of energy costs, for instance of the SDE+ (which stands for "Sustainable Energy Incentive") extra charge on households and business' energy bills, money that will be reinvested to foster energy generation from renewables; Construction of a more efficient offshore network (TenneT being the responsibility holder for this project).
Decentralized energy generation	The aim is to encourage people or cooperatives to generate decentralised renewable energy. More generating options will be offered as well as support for local and regional initiatives from local and central governments, when needed. The local generation, by cooperatives or owners' associations, and local use (within a "*postcode rose*") of renewable energy will be also economically promoted with a tax relief of 7.5 eurocents per kWh.
Energy transmission network	<u>Measures to make the transmission network more flexible:</u> Development and introduction of smart grids and demand-side management; Development of storage capacity, also taking into account previous energy transformations; Studying the impact of those innovations on the infrastructure through specific experiment; <u>Measures concerning European cooperation:</u> Closer collaboration with the Energy Forum, the countries in North Sea region, and with Germany in a bilateral way; Promotion of an effective EU regulatory framework; Promotion of an European approach towards the integration of electricity and gas market; Commitment to the transparency of the procedure for international projects
EU Emissions Trading System (ETS)	The parties involved in the Energy Agreement agreed upon four important requirements for an efficient ETS. They also have formed a lobby to strive in Brussels to implement a package of improvements from January 2020.
Energy generation from fossil fuels and coal-fired power stations	Minimising the capacity of the existing coal-fired power plants: 3 will be closed on January 2016 and the remaining two in July 2017; The use of CCS (Carbon Capture and Storage) technology is defined as unavoidable to be applied by both industry and coal-fired power plants. It is the national government's responsibility to define a strategy for CSS's role in the long-term energy transition.
Mobility and transport	The ambitious target to foster a more efficient and sustainable mobility has been set at 60% CO_2 reduction by 2050. To achieve this target the parties involved have established a more detailed agenda with small steps in 12 main areas, as well as an overall shared strategy about the foreseen fuel mix.
Employment opportunities	A great number of employment opportunities will be created by all these investments in the energy sector. Specifically the goal is to create 90,000 full-time jobs from 2014 to 2020.
Energy innovation and energy export	To fulfil the Dutch ambition to become an international frontrunner for its clean technology expertise, the intention is to "*quadruple the economic value of the clean energy technology chain by 2020 compared to 2010. […]The method used to achieve these aims consists of six elements, namely financing, domestic market development, international market development, establishment of legislation and regulations, connecting up with the SME sector, and human capital.*"(SER, 2013).
Funding programme	All the implementations planned in the Energy Agreement required the creation of an important funding programme that has been agreed upon by several parties such as

	financial companies and umbrella organizations (banking associations, insurer associations, etc.). The programme will focus both on large-scale as well as small-scale and decentralized investment projects.

Figure G.2 _ Some participants to the negotiations for the Energy Agreements. (Nijpels, 2014)

APPENDIX H – Specification of the Energy Requirements

Table 3.4 – Specification for the energy requirements of each component of the energy system.

	Heat & Cooling	Electricity	Fuel
Households	- Heating of the house in the winter; - (possible) Cooling requirement in the summer;	- Electric appliances (fridge, freezer, computers, TV, kitchen utensils, chargers, washing machine, dishwasher…); - Possibly for cooking (electric stoves); - Internal lighting system and additional lighting appliances;	- Cooking; - Heating (mainly in old generation dwellings);
Public Areas	/	- Streetlights; - Traffic lights; - Neon sign; - Electrical appliances;	/
Streets	/	- Streetlights; - Traffic lights; - Neon sign; - Safety measures/instruments;	/
Public Buildings	- Heating the buildings during the winter; - Cooling requirement during the summer;	- Electric appliances (computers, screens, chargers, audio-visual equipment…); - Internal lighting system and additional lighting appliances;	- Heating (mainly in old generation buildings);
Offices & Retails	- Heating the buildings during the winter; - Cooling requirement during the summer;	- Electric appliances (computers, screens, chargers, audio-visual equipment, cash register, robotic machines…); - Possibly for cooking (electric stoves); - Internal lighting system and additional lighting appliances; - Neon signs;	- Heating (mainly in old generation buildings);
Industries & Enterprises	- Heating the buildings during the winter; - Cooling requirement during the summer;	- Electric appliances (computers, screens, chargers, audio-visual equipment, cash register, robotic machines…); - Possibly for cooking (electric stoves); - Internal lighting system and additional lighting appliances; - Neon signs;	- Heating (mainly in old generation buildings);
Infrastructures	/	- Communication's infrastructures; - Transportation's infrastructures; - To operate energy carriers and distribution systems;	- Transportation's infrastructures; - To operate energy carriers and distribution systems;

APPENDIX I – Preliminary steps of the Choice Modelling

Preliminary alternatives

1) Diffusion of **Solar Energy** production → Solar panels on households' roofs (Decentralized Renewable Energy)
2) **Smart Meters** distribution & Implementation of **Smart Grid's** connections
3) Implementation of the **District Heating connection** (also related to implementation of **Combined Heat-Power**)
4) Implementation of the current buildings' conditions → **Refurbishment**, better **Insulations** measures, Promote the investments to get a Higher **Energy label** → **ENERGY RETROFITS**
5) Heat pumps → promotion of heat pumps' installations
6) Pret-à-loger → skin for existing buildings (very specific & niche technology)
7) Small Wind-turbines on roofs
8) Implementation of Air Insulation's systems
9) Implementation of Glazing system (Double glazing; collecting energy (e.g. PowerWindow))

Preliminary attributes

- Investment costs;
- Operational costs;
- Comfort (of consumers) → Ease of use;
- Efficiency level;
- Impact on the system → Independence → comprehensive solution;
- Affordance;
- Safety;
- Available knowledge;
- Households Size (energy requirements increase with increasing households sizes BUT! The share of direct energy use decreases slightly with rising households sizes (Moll et al., 2005)).
- Environment → Contribution to a better environment
- Economic savings
- Energy savings
- ROI
- Payback time
- Bureaucratic barriers
- Increased value of the properties (buildings)
- Legitimacy → Perceived public Image

- Public opinion
- Current availability of the technology (knowledge)
- Values / Lifestyle
- Future potential
- Safety
- Energy payback time
- Energy label gained by the house

Preliminary Choice set matrix with coding

	OPTION A (Residential PV System)	coding	OPTION B (District Heating)	coding	OPTION C (Energy retrofits . Thermal insulation	coding
Difficulty of Implementation for the municipality	Low	1	/	/	Low	1
	Medium	2	Medium	2	Medium	2
	/	/	High	3	High	3
Energy Savings	3.2%	1	3.3%	1	4.7%	1
	5.2%	2	4.8%	2	6.4%	2
	6.9%	3	6.5%	3	7.7.%	3
Cost for the policy	31,100,000€	1	/	/	29,300,000 €	1
	39,000,000 €	2	37,500,000	2	55,800,000 €	2
	42,700,000 €	3	55,700,000	3	62,800,000	3
Competence area addressed	Electricity	1	Heating	1	Heating	1
	Electricity and Hot water	2	Heating and Hot water	2	Electricity and Heating	2
			Heat loss	3	Heat loss	3

Code for the experimental design generation

```
? This will generate a sequential orthogonal factorial design
Design
;alts = Alt1, Alt2, Alt3
;rows = 12
;orth = seq
;model:
U(Alt1) =  b1 * A[1,2] + b2 * B[1,2,3] + b3 * C[1,2] + b4 * D[1,2] /
U(Alt2) =  b1 * A[1,2] + b2 * B[1,2,3] + b3 * C[1,2] + b4 * D[1,2] /
U(Alt3) =  b1 * A[1,2] + b2 * B[1,2,3] + b3 * C[1,2] + b4 * D[1,2] $
```

Choice-sets from Ngene

Scenario 1

	alt1	alt2	alt3
a	1	2	1
b	1	2	3
c	1	1	2
d	1	2	2
Choice question:			

Scenario 2

	alt1	alt2	alt3
a	2	1	1
b	2	3	3
c	1	2	1
d	2	2	1
Choice question:			

Scenario 3

	alt1	alt2	alt3
a	2	1	2
b	3	3	1
c	1	1	2
d	2	1	2
Choice question:			

Scenario 4

	alt1	alt2	alt3
a	1	1	2
b	3	1	3
c	1	1	2
d	1	1	1
Choice question:			

Scenario 5

	alt1	alt2	alt3
a	1	2	2
b	1	3	3
c	1	2	1
d	2	1	2
Choice question:			

Scenario 6

	alt1	alt2	alt3
a	2	1	2
b	2	1	2
c	1	1	1
d	1	2	2
Choice question:			

Scenario 7

	alt1	alt2	alt3
a	1	2	2
b	2	1	2
c	2	2	1
d	1	2	1
Choice question:			

Scenario 8

	alt1	alt2	alt3
a	1	1	2
b	3	2	1
c	2	2	2
d	2	2	1
Choice question:			

Scenario 9

	alt1	alt2	alt3
a	2	2	1
b	1	3	2
c	2	1	2
d	1	2	1
Choice question:			

Scenario 10

	alt1	alt2	alt3
a	1	2	1
b	2	2	1
c	2	1	1
d	2	1	2
Choice question:			

Scenario 11

	alt1	alt2	alt3
a	2	2	1
b	3	1	1
c	2	2	1
d	1	1	1
Choice question:			

Scenario 12

	alt1	alt2	alt3
a	2	1	1
b	1	2	2
c	2	2	2
d	2	1	2
Choice question:			

The 12 choice-sets' combinations.

Choice situation	alt1.a	alt1.b	alt1.c	alt1.d	alt2.a	alt2.b	alt2.c	alt2.d	alt3.a	alt3.b	alt3.c	alt3.d
1	1	1	1	1	2	2	1	2	1	3	2	2
2	2	2	1	2	1	3	2	2	1	3	1	1
3	2	3	1	2	1	3	1	1	2	1	2	2
4	1	3	1	1	1	1	1	1	2	3	2	1
5	1	1	1	2	2	3	2	1	2	3	1	2
6	2	2	1	1	1	1	1	2	2	2	1	2
7	1	2	2	1	2	1	2	2	2	2	1	1
8	1	3	2	2	1	2	2	2	2	1	2	1
9	2	1	2	1	2	3	1	2	1	2	2	1
10	1	2	2	2	2	2	1	1	1	1	1	2
11	2	3	2	1	2	1	2	1	1	1	1	1
12	2	1	2	2	1	2	2	1	1	2	2	2

APPENDIX J – Choice Model Results from Biogeme

BIOGEME Code

```
[Choice]
Choice

[Beta]
// Name Value LowerBound UpperBound status (0=variable, 1=fixed)
EASE_IMPL          0      -10000            10000  0
EN_SAVING          0      -10000            10000  0
COST_POLICY  0      -10000            10000  0
EN_AREA            0      -10000            10000  0

[Utilities]
// Id Name Avail linear-in-parameter expression
1 Opt1 AV1 EASE_IMPL * x11 + EN_SAVING * x12 + COST_POLICY * x13 + EN_AREA * x14
2 Opt2 AV2 EASE_IMPL * x21 + EN_SAVING * x22 + COST_POLICY * x23 + EN_AREA * x24
3 Opt3 AV3 EASE_IMPL * x31 + EN_SAVING * x32 + COST_POLICY * x33 + EN_AREA * x34

[Model]
// MNL stands for "multinomial logit model"
$MNL
```

1st Results

```
Model: Multinomial Logit
Number of estimated parameters: 4
Number of observations: 587
Number of individuals: 587
Null log-likelihood: -644.885
Cte log-likelihood: -630.382
Init log-likelihood: -644.885
Final log-likelihood: -420.126
Likelihood ratio test: 449.519
Rho-square: 0.349
Adjusted rho-square: 0.342
Final gradient norm: +9.114e+001
Diagnostic: Radius of the trust region is too small
Iterations: 71
Run time: 00:00
Variance-covariance: from analytical hessian
```

Sample file: Data-FK-withSPSS-3.dat

Utility parameters
****

Name	Value	Std err	t-test	p-val		Rob. std err	Rob. t-test	Rob. p-val	
COST_POLICY	-7.58e-008	7.47e-009	-10.15	0.00		7.79e-009	-9.73	0.00	
EASE_IMPL	-1.28	0.125	-10.19	0.00		0.130	-9.78	0.00	
EN_AREA	-0.0832	0.115	-0.72	0.47	*	0.106	-0.78	0.43	*
EN_SAVING	0.815	0.0541	15.05	0.00		0.0558	14.60	0.00	

Utility functions
****

```
1	Opt1	AV1	EASE_IMPL * x11 + EN_SAVING * x12 + COST_POLICY * x13 + EN_AREA * x14
2	Opt2	AV2	EASE_IMPL * x21 + EN_SAVING * x22 + COST_POLICY * x23 + EN_AREA * x24
3	Opt3	AV3	EASE_IMPL * x31 + EN_SAVING * x32 + COST_POLICY * x33 + EN_AREA * x34
```

Correlation of coefficients
****

Coeff1	Coeff2	Covariance	Correlation	t-test		Rob. covar.	Rob. correl.	Rob. t-test	
COST_POLICY	EN_AREA	5.86e-011	0.0680	0.72	*	9.32e-012	0.0112	0.78	*
EN_AREA	EN_SAVING	-0.000724	-0.116	-6.75		-0.000406	-0.0684	-7.27	
EASE_IMPL	EN_AREA	-0.000603	-0.0418	-6.86		-0.00109	-0.0785	-6.83	
COST_POLICY	EASE_IMPL	3.16e-010	0.338	10.19		3.61e-010	0.356	9.78	
EASE_IMPL	EN_SAVING	-0.00265	-0.392	-13.52		-0.00259	-0.357	-13.14	
COST_POLICY	EN_SAVING	-2.32e-010	-0.572	-15.05		-2.44e-010	-0.561	-14.60	

Smallest singular value of the hessian: 61.4849

2nd Results

Model: Multinomial Logit
Number of estimated parameters: 4
Number of observations: 587
Number of individuals: 587
Null log-likelihood: -644.885
Cte log-likelihood: -630.382
Init log-likelihood: -644.885
Final log-likelihood: -420.112

Likelihood ratio test: 449.547
Rho-square: 0.349
Adjusted rho-square: 0.342
Final gradient norm: +1.311e-003
Diagnostic: Convergence reached...
Iterations: 7
Run time: 00:00
Variance-covariance: from analytical hessian
Sample file: Data-FK-For Standardization Correct.dat

Utility parameters
****

Name	Value	Std err	t-test	p-val		Rob. std err	Rob. t-test	Rob. p-val	
COST_POLICY	-0.759	0.0748	-10.14	0.00		0.0781	-9.71	0.00	
EASE_IMPL	-1.29	0.125	-10.29	0.00		0.131	-9.86	0.00	
EN_AREA	-0.0706	0.116	-0.61	0.54	*	0.107	-0.66	0.51	*
EN_SAVING	0.814	0.0541	15.04	0.00		0.0558	14.59	0.00	

Utility functions
****

1 Opt1 AV1 EASE_IMPL * x11 + EN_SAVING * x12 + COST_POLICY * x13 + EN_AREA * x14
2 Opt2 AV2 EASE_IMPL * x21 + EN_SAVING * x22 + COST_POLICY * x23 + EN_AREA * x24
3 Opt3 AV3 EASE_IMPL * x31 + EN_SAVING * x32 + COST_POLICY * x33 + EN_AREA * x34

Correlation of coefficients
****

Coeff1	Coeff2	Covariance	Correlation	t-test	Rob. covar.	Rob. correl.	Rob. t-test
COST_POLICY	EASE_IMPL	0.00319	0.339	4.35	0.00367	0.359	4.22
COST_POLICY	EN_AREA	0.000588	0.0680	-5.16	9.85e-005	0.0118	-5.23
EN_AREA	EN_SAVING	-0.000708	-0.113	-6.65	-0.000378	-0.0634	-7.16
EASE_IMPL	EN_AREA	-0.000621	-0.0428	-7.00	-0.00112	-0.0798	-6.95
EASE_IMPL	EN_SAVING	-0.00269	-0.396	-13.57	-0.00267	-0.366	-13.15
COST_POLICY	EN_SAVING	-0.00232	-0.573	-13.71	-0.00245	-0.562	-13.24

Smallest singular value of the hessian: 57.4733

APPENDIX K – Missing information according to the Respondents

Missing Information
I felt it was quite abstract to evaluate. Also, for me the 'easy of implementation' doesn't really trigger me. 'High' or 'medium': I'd say they (at the municiplaity) just take the challenge!
It was not clear to me if the % savings was related to a specific category or to the energy use in total. I've answered the questions with the last one in mind. Also terms like energy metabolism might not be clear to everyone. Also the difference between heating and heat loss prevention should be more clear. I assume now that heating is related to installations and heat loss prevention to insulation. And what about electricity: is this reduction or production?
It is important to make sure decision makers are aware of the shares of energy consumption for space heating, hot water, cooking and electricity, so they can focus on the largest use types.
Insight into the difficulty factor is hard to judge. If the costs are given I assume that for that money the policy plan is executable and the relevant resources can be attracted. But if not more information is needed to judge that. Questions in PART 3 do not contain the option 'do not know' / 'no opinion'
I think the opportunity for new business, and the opportunity to involve citizens and industry in implementing the solution and in profiting from the implementation are missing - in addition to costs, there are spin-off effects and (unforeseen) positive effects as a result from mobilizing support for the actions and from the opportunities that are being created for third parties.
?
No
The relation with policy aims on energy efficiency and emissions
In your questionair there is absolutely no information about lock ins or the possibilities the city has. It's only a choice between scenario's, none of which you tell if it's attainable.
Sustainability from the energy, not only saving.
Heating is pretty broad, also hot water: 30 degr or 100 degr makes all the difference, because lower temperatures are easier to solve. But maybe I misunderstood.
number of houses applied to. More exposure means more people are affected by the policy plan which will result in more awareness. I'd rather help 100 dwellings to be 10% more efficient than 10 dwellings for 100%.
The description goes to efficiency, cost and complexity; the spatial component is missing. Some of the proposals require more space in a city that does not have that. In the policy plans the ownership of the solution is also missing; who is going to do it. The difficulty for the municipality is one thing, but most of the time they are not the ones executing the plans. This should be part of the consideration.

Partnership with companies, housing associations, and residents.
(1) The time horizon is missing. I am willing to take a small reduction, at low cost and medium difficulty, if I believe this can be the start of a bigger change. (2) The competence areas will mix in the energy transition. (3) Energy/climate is of limited importance in the decision making process in spatial planning. Or at least, allocation of all cost to energy is rather silly.
In order to assess the policy plans properly, for me it would be important to have a better understanding of the technical concepts behind the plans, e.g. to avoid choosing short term gains but creating a lock-in for the deep renovation required to meet e.g. the Paris agreement. Municipalities should understand that the easy-wins in the short term do not help to meet long term ambitions of deep renovation
Political salience - whether a plan is controversial or well regarded in the community.
Time horizon (solar panels can be changed quickly, whereas a waste water or drinking water infrastructure will be in place for a 100 years) Aimed at new buildings / renovations or at the existing stock. Circularity (connecting across traditional borders that separate economic sectors, for example waste water - energy - agriculture)
The budget available
Yes, a lot of info was missing, context, technology, stakeholders, specification of the geographical area/neighborhood, etc...

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