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Prosumer behaviour in emerging electricity systems

Anna Mengolini

Supervisors

Prof. Ettore Bompard, Politecnico di Torino

Prof. Pietro Terna, Università di Torino

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FOREWORD

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Abstract

This dissertation investigates the interface between technology and society in the emerging electricity systems and in particular the role of the energy prosumer in the energy transition. It contributes to the understanding of the role of consumers in emerging electricity systems within the current EU energy policy context where consumer active participation is regarded as "*a prerequisite for managing the energy transition successfully and in a cost-effective way*". Emerging energy systems are characterized by a high level of complexity, especially for what concerns the behaviour of social actors. Social actors interact through physical and social networks by sharing information and learning from one another through social interactions. These interactions determine self-organization and emergent behaviours in energy consumption patterns and practices. I argue that the best suited tool to study emergent behaviours in energy consumption patterns and practices, and to investigate how consumers' preferences and choices lead to macro behaviours is agent based modelling. To build a sound characterization of the energy prosumer, I review the current social psychology and behavioural theories on sustainable consumption and collect evidence from EU energy prosumers surveys, studies and demand side management pilot projects. I employ these findings to inform the development of an agent based model of the electricity prosumer, Subjective Individual Model of Prosumer – SIMP, and its extended version, SIMP-N, that includes the modelling of the social network.

I apply SIMP and SIMP-N models to study the emergence in consumer systems and how values and beliefs at consumer level (as defined by social psychology and behavioural theories and informed by empirical evidence) and social dynamics lead to macro behaviours. More specifically, I explore the diffusion of smart grid technologies enabled services among a population of interacting prosumers and evaluate the impact of such diffusion on individual and societal performance indicators under different policy scenarios and contextual factors.

The analysis of the simulation results provides interesting insights on how different psychological characteristics, social dynamics and technological elements can strongly influence consumers' choices and overall system performance.

I conclude proposing a framework for an integrated approach to modelling emerging energy systems and markets that extend the SIMP model to also include markets, distribution system operator and the electricity network.

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1 Introduction

1.1 Motivation

The motivation for this dissertation is to better understand the interface between technology and society in the emerging electricity systems that is still surrounded by a poor understanding of its complexity and of the multiplicity of actors and perspectives at play.

The present system of energy supply and demand will need a significant change in order to address the three major challenges of European energy policy: sustainability, security of supply and competitiveness while guaranteeing energy equity. The increasing integration of renewable energy resources and the transitioning of the energy system to a more sustainable one pose challenges to the society at large. Specifically the active role of the consumer is fundamental in this transition. I argue that to address energy transition and the role that consumer will play in this transition a complexity science approach is needed in order to explore the multiplicity of actors and perspectives at play.

In order to explore this paradigm shift I will start by introducing the EU energy policy context and specifically how the consumer is presented in the EU energy policy documents (Chapter 1). Then I will proceed to introduce how complexity science may help in shedding light on the transitioning energy system and more specifically in exploring the role of the consumers in this transition and how the exploration of emerging behaviours may provide insights for policy making (Chapter 2). Then I will proceed to present theories and models of consumer behaviour and evidence from EU studies, surveys and smart grids pilot projects on consumer attitudes, preferences and concerns on emerging electricity systems from the individual and collective point of view (Chapter 3). Based on the findings of Chapter 3, I will present an agent based model of the electricity prosumer when exposed to several energy contracts (Chapter 4). I will analysis how social networks may influence consumer decision making processes and final energy choices (Chapter 5). In Chapter 6 I will introduce a framework for an integrated approach to emerging electricity systems. In Chapter 7 I will summarize the main conclusions of my research.

I see my thesis as a contribution to the ongoing discussion on the central role of the energy consumer/prosumer in the EU transition to a more sustainable energy system.

1.2 Political context

1.2.1 EU energy policy context

Energy policy is undoubtedly one of the most important and urgent EU political issues today. Being inherently linked to climate change and involving an array of actors at different levels (national and multinational) motivated by different interests and agendas, it can be considered one of the most complex issues at EU level, thus deserving high priority in the EU political agenda (Langsdorf, 2011). Indeed, energy policies at EU level and an integrated internal energy market are essential for the enhancement of energy security in the EU leading to better prices due to enhanced competition and increased integration of renewable energy resources.

Despite these advantages, the progress towards a common energy policy was limited in the first decades of European integration. Studies on the politicisation of the EU energy policy argue that *"energy policy has been usually interpreted as a bilateral consumer-supplier relationship, with scarce consideration for either coalition-building strategies within EU ore more responsible energy use at domestic level" (Ciambra, 2013).* The progress made with the first legislative package - *Directives 96/92/EC concerning common rules for the internal market in electricity* and *Directive 98/30/EC on common rules for the internal market in natural gas* - was mainly based on internal market and environmental regulations of the EU Treaties. Neither the "Treaty of Amsterdam" (1999) nor the "Treaty of Nice" (2003) brought major advances for a common energy policy.

Major advances for common energy policy came only in 2007 when EU heads of state and government endorsed the first EU "energy action plan" that resulted in the Commission's "**An energy policy for Europe**" strategy (European Commission, 2007) that laid down the three major challenges for European energy policy: sustainability, security of supply and competitiveness. The action plan was followed by changes in the EU legislation. With the Lisbon Treaty (1999) a new part on energy was added to the Treaty on the Functioning of the European Union (TFEU) with article 176a in Title XX (Title XXI with article 194 in the consolidated TFEU). The article reads: "*In the context of the establishment and functioning of the internal market, (…) Union policy on energy shall (..):*

- ensure the functioning of the energy market;
- ensure security of energy supply in the Union; and
- promote energy efficiency and energy saving and the development of new and renewable forms of energy; and
- promote the interconnection of energy networks".

The insertion of the title in the Lisbon Treaty specifically on energy relates a European Union's push toward a harmonized common energy policy and represents a huge step forward towards a common energy policy, explicitly promoting energy efficiency and energy savings as key elements.

An array of new legislations followed with the **Third Energy Package** (2009) (European Parliament and the Council, 2009b; European Parliament and the Council, 2009c; European Parliament and the Council, 2009d; European Parliament and the Council, 2009e; European Parliament and the Council, 2009f) that represents a further step towards the improvement of the functioning of the internal energy market. The package includes rules on the separation of energy supply and generation from the operation of transmission networks, the independence of national energy regulators, and increased transparency in retail markets to benefit consumers. It further established the Agency for the Cooperation of Energy Regulators (ACER). The third package together with other EU legislation also guarantees that **energy consumers** enjoy high standards of consumer protection. It establishes that all EU citizens have the right to have their homes connected to energy networks and to freely choose any supplier of gas or electricity offering services in their area. Moreover, the package urges that consumers have the right to access accurate information on their consumption data and associated electricity prices. This information on the electricity costs should be provided frequently enough in order to create incentives for energy savings and behavioural change. Such information provision could also create innovative services to effectively enable active participation of consumers in the electricity supply market. The deployment of smart metering infrastructure should facilitate this process. The Directive 2009/72/EC (European Parliament and the Council, 2009b) and the ensuing Recommendation on preparations for the roll-out of smart metering systems (Commission Recommendation, 2012) advocates that 80% EU electricity consumer should be equipped with smart metering systems by 2020, provided that the economic assessment of nation-wide smart metering roll out is positive. Smart metering systems are therefore recognized as having an important role in the achievement of energy savings.

Box 1.1: Energy legislative packages

The *first legislative package* (Directives 96/92/EC concerning common rules for the internal market in electricity and 98/30/EC on common rules for the internal market in natural gas) was replaced in 2003 by a *second legislative package* that enabled new gas and electricity suppliers to enter Member States' markets, and consumers (industrial consumers from 1 July 2004 and domestic consumers from 1 July 2007) to choose their own gas and electricity suppliers. In April 2009 a *third legislative package* seeking to further liberalise the internal electricity and gas market was adopted, amending the second package, and introducing a target for smart metering roll-out in EU (European Parliament and the Council, 2009b) .

A major step towards the definition of a common Energy Union Strategy comes in 2015 with the **Energy Union Package - Framework Strategy for a Resilient Energy Union with a Forward-looking Climate Change Policy** (European Commission, 2015a) that is considered as one of the priority in the Juncker Commission.

> **Box 1.2: Energy Union Strategy**
>
> On 25th February 2015 the European Commission adopted the "*Energy Union Package- A Frameworks Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy*" (European Commission, 2015a). The strategy sets out, in five interrelated policy dimensions, the goals of an energy union: energy security, solidarity and trust; a fully integrated European energy market; energy efficiency contributing to moderation of demand; decarbonising the economy, and research, innovation and competitiveness. The strategy provides detailed steps the Commission will take to achieve these goals, including new legislation to redesign and overhaul the electricity market, ensuring more transparency in gas contracts, substantially developing regional cooperation as an important step towards an integrated market, with a stronger regulated framework, new legislation to ensure the supply for electricity and gas, increased EU funding for energy efficiency.

The European Union views on consumer's role in energy market is further detailed in the European Commission Communication on **Delivering a New Deal for energy consumers** ('New Deal'), released as part of the Summer Package (15 July 2015) and designed to inform future actions in this field, including proposed legislation. The 'New Deal' highlights the need for greater transparency and better information around energy prices, emphasises the importance of easy switching between energy suppliers and recognize that demand response should be facilitated and community production initiatives encouraged. Furthermore the New Deal seeks to encourage the development of smart homes and networks that will require enabling new energy technologies. Finally the 'New Deal' calls for new measures to address vulnerable consumer and energy poverty in the EU (European Parliament Briefing, 2016).

The most recent step towards the Energy Union project is the presentation on 30 November 2016 of the **Clean Energy for All Europeans**, a package of measures with legislative proposals that cover energy efficiency, renewable energy, the design of the electricity market, security of electricity supply and governance rules for the Energy Union. The package also includes actions to accelerate clean energy innovation and to renovate Europe's buildings. It provides measures to encourage public and private investments, to promote EU industrial competitiveness and to mitigate the social impact of the transition to clean energy. The Clean Energy Package's main points are summarized in Figure 1.

Figure 1. European Union Energy Policy main points[1] - Clean Energy Package

The Clean Energy package provides important orientations in the field of consumer protection and engagement. The package specifically addresses the need to further develop a comprehensive policy and legal framework for *EU prosumers*, stating that in most parts of the EU, retail markets suffer from persistently low levels of competition and consumer engagement. Despite technical innovation such as smart grids, smart homes, self-generation and storage, *consumers are not sufficiently informed nor incentivized* to actively participate in electricity markets and are prevented from controlling and managing their energy consumption while saving on their bills and improving their comfort. With the revised Renewable Energy Directive (**Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources** (European Commission, 2016b)) consumers will benefit from stronger right to *produce* their own electricity (prosumer), and feed any excess back to the grid being remunerated for this; organise themselves into *renewable energy communities* to generate, consume, store and sell renewable energy (energy community); stop buying heat/cold from a district heating/cooling system if they can achieve significantly better energy performances themselves; obtain quality of information thanks to the consolidation of the functioning of the Guarantees of Origin system. All consumers across the EU will be entitled to generate electricity for either their own consumption, store it, share it, consume it or to sell it back to the market, thus making it easier for households and businesses to become *more involved* in the energy system, to *better control* their energy consumption and *respond to price signals.*

The proposal further articulates the concept of "*communities of consumers*" that will be entitled to produce, store or sell their electricity. Additionally, the proposal hope for an acceleration of the deployment of smart meters and for ensuring access to dynamic electricity price contracts which are

[1] http://one-europe.net/eurographics/european-union-energy-policy

essential to bridge the gap between consumers and the market. Consumers will get access to reliable and clear information on the best deals in the market, using certified online price comparison tools which will assist them in making informed choices.

Box 1.3: Clean Energy for all Europeans

Om 30th November 2016 the European Commission presented a package of measures to keep the European Union competitive and to ensure a clean energy transition. The "Clean Energy for All Europeans" (European Commission, 2016c) legislative proposals cover energy efficiency, renewable energy, the design of the electricity market, security of electricity supply and governance rules for the Energy Union. In addition the Commission proposes a new way forward for eco-design as well as a strategy for connected and automated mobility.

In terms of upcoming regulatory initiatives, besides the review of existing directives (electricity, energy efficiency, energy performance of buildings and renewable directives), the package presents a Proposal for a regulation on the Governance of the Energy Union (European Commission, 2016a) that sets out the necessary legislative foundation for the governance of the Energy Union. This legislative proposal will also be complemented by non-legislative facilitating measures and actions, including - but not limited to - efforts to ensure the full participation of Member States, consumers, producers and stakeholders at large in the governance process.

Considering the scope of the present thesis, it is worth mentioning that besides the European Commission Clean Energy Package, the European Parliament has called for a common operational EU definition of *prosumer* and for new energy legislation to provide measures for encouraging investment into self-generation capacity. Although the Energy Efficiency Directive (European Parliament and the Council, 2012) , the Renewable Energy Directive (European Parliament and the Council, 2009a) and the Guidelines on State Aid (European Commission, 2012) all include provisions addressing small scale electricity producers, the EU has no specific legislation on prosumers, self-generation or self-consumption. The European Commission is currently undertaking studies on mapping prosumers and associated existing regulations in EU member states.

1.2.2 The role of consumers in EU energy policy

The role of the consumer in EU energy policy has been increasingly better clarified and articulated in the various energy policy documents as highlighted in the previous section. They recognize the consumer's right to transparency and clear information, protection from unfair market practices and their increasing role as active player in the energy market. I will now briefly discuss how consumer's role, involvement and engagement in the energy transition is discussed and advocated in some of the EU energy policy documents.

The role of engagement and involvement of consumers in sustainable consumption was clearly acknowledged by the EC Task Force for Smart Grids (2010): "*the engagement and education of the consumer is a key task in the process as there will be fundamental changes to the energy retail market. To deliver the wider goals of energy efficiency and security of supply there will need to be a significant change in the nature of customers' energy consumption (…). A lack of consumer confidence or choice in the new systems will result in a failure to capture all of the potential benefits of Smart Meters and Smart Grids*" (European Commission, 2010). The terms engagement, education and confidence emerge as key factors for smart grids success. The European Commission communication on **Smart grids: from innovation to deployment** (European Commission, 2011) further recognizes the importance of consumer awareness and underlines how "*developing Smart Grids in a competitive retail market should encourage consumers to change behaviour, become more active and adapt to new 'smart' energy consumption patterns*" (European Commission, 2011). However, the Communication also recognizes the complexity and uncertainty linked to this new technology: "*Neither is there clarity on how to integrate the complex Smart Grids systems, how to choose cost-effective technologies, which technical standards should apply to Smart Grids in the future, and whether consumers will embrace the new technology*".

The European Commission's 2015 **Framework Strategy for a Resilient Energy Union with a Forward-looking Climate Change Policy** (European Commission, 2015a) recognizes that consumers, enabled by smart grid technologies, will be able "*to reap the opportunities available on the energy market by taking control of their energy consumption (and possible self-production)*" and make informed choices on where and how buy their energy. The vision is of an Energy Union where citizens are placed at its core and are capable of taking ownership of the opportunities allowed by the energy transition and can "*benefit from new technologies to reduce their bills, participate actively in the market and where vulnerable consumers are protected*". The EC public consultation process on a new energy market design (European Commission, 2015c) further adds that one of the goals of the new energy market design is to offer consumers – households, business and industry – the possibility to actively participate (and benefit) in the European's Union Energy Transition. This goal requires "*a fundamental change in the role of the consumer on the electricity market*". The ensuing European Commission's Communication **Delivering a New Deal for Energy Consumers** (European Commission, 2015b) further clarifies the role of the consumer in the energy transition and identifies three key points for delivering a new deal for consumer:

- Empowering the consumer to act;
- Making smart homes and networks a reality;
- Special attention to data management and protection.

In particular "**empowering consumers to act**" identifies the main challenges consumers have to face in the energy market and suggests concrete actions to encourage consumers, who are the driving force of competition, to engage more with energy markets. It recognises that the combination of decentralized generation with storage options and demand side flexibility "*can further enable consumers to become their own suppliers and managers for (a part of) their energy needs, becoming producers and consumers and reduce their energy bills.* Decentralized renewable energy generation *"can usefully complement centralised generation sources"* and help reduce *"grid losses and congestion, saving network costs in the long-term that would otherwise have to be paid by the consumers".* In particular it is recognised that *"if consumers generate their own electricity form onsite renewable energy systems, they consume less electricity from the grid"* and that *"this will affect how network tariffs are calculated".* The Communication further underlines the importance of a cost-reflective and fair design of network tariffs that should be simple and transparent for the consumers, while at the same time supporting energy efficiency and the renewable objectives. As one of the follow up step, the Commission assures to provide the consumers with *"possibilities to become active energy players and gain from action, for example adjusting and reducing their consumption as prices evolve, helping balance out renewable energy variability by embracing demand response or producing or storing energy."* Consumer empowerment is specifically detailed as follows:

- saving money and energy through *better information*;
- giving consumers a *wide choice of action* (e.g.: switching suppliers, realising flexibility through demand response, reducing energy bills through self-generation and consumption; increasing participation through intermediation and collective schemes);
- maintaining *full protection* for consumers.

The 2016 European Commission Communication **Clean Energy for all Europeans** (European Commission, 2016c) further defines these points in a regulatory proposal that aims at *"accelerating, transforming and consolidating the EU economy's clean energy transition thereby creating jobs and growth in new economic sectors and business models".* The new electricity directive proposal argues that the energy transition creates new opportunities and challenges for market participants, allowing, through technological development, for new forms of consumer participation and cross-border cooperation. Consumers are recognized as essential to achieving the flexibility necessary to integrate variable, distributed renewable generation in the electricity system and their active participation as "*a prerequisite for managing the energy transition successfully and in a cost-effective way*". By empowering consumers to participate in the energy market more, and participate in new ways, citizens should benefit from the internal market in electricity (European Commission, 2016d).

1.2.3 The role of energy communities in EU energy policy

European consumer policy has been mainly based on the assumption that the consumer is a rationally acting individual and has its roots in the information paradigm that suggests that the consumer is able, willing and competent to deal with the information provided and to take informed rational decisions. The consumer is regarded as an individual where the collective dimension of consumer behaviour is still largely set aside (Micklitz *et al.*, 2011). However, there is evidence that suggests that for the deployment of smart electricity systems it may not be sufficient to address the complexity of the needed behavioural change with an individualistic approach (Jackson, 2005). The social dimension of consumer behaviour and engagement equally needs to be carefully taken into account (Allcott, 2011; Huijts *et al.*, 2012). The most recent energy policy documents increasingly recognize the collective dimension of energy use. According to the "New Deal", European consumers engage more and more in self-generation and cooperative schemes in order to better manage their energy consumption (European Commission, 2015b). Regional and local energy initiatives are seen as facilitators of consumer participation in the energy market and in the effective governance for the Energy Union. Such initiatives should be supported as they can provide a valuable link between decision-makers, citizens and innovators, opening new opportunities for local communities to play an active role in the energy transition. The directive proposal (European Commission, 2016d) argues that "*local energy communities can be an efficient way of managing energy at community level by consuming the electricity they generate either directly for power or for (district) heating and cooling, with or without a connection to distribution systems*". The proposal goes further arguing that community energy represents an inclusive option for all consumers "*to have a direct stake in producing, consuming and or sharing energy between each other within a geographically confined community network that may operate in an isolated mode or be connected to the public distribution network*". The aim of community energy initiatives is mainly to provide affordable energy for their member rather than being profit oriented like traditional energy company. Energy community initiatives directly engage with consumers and therefore can be best suited "*in facilitating the up-take of new technologies and consumption patterns, including smart distribution grids and demand response, in an integrated manner*". It is interesting to notice that the directive proposal acknowledge community energy role in fighting energy poverty through reduced consumption and lower supply tariffs. It is recognized that *"where they have been successfully operated such initiatives have delivered economic, social and environmental value to the community that goes beyond the mere benefits derived from the provision of energy service"*. However, the proposal argues that appropriate legal framework need to be put in place to enable energy community developments.

The concept of energy community further enhance the role of the consumer in the transition of the energy system; as some authors argues, the emerging energy systems are "*not about consumers or users,* *but about the active role of citizens, not only as consumers but also in shaping policies in the area of energy, i.e.: energy citizenship*" (Vesnic-Alujevic *et al.*, 2016) . As Devine-Wright suggests, an alternative view of the public is that of "energy citizens" where "*the potential for actions is framed by notions of equitable rights and responsibilities across society for dealing with the consequences of energy consumption*" (Devine-Wright, 2007) (page 71). Energy citizenship contrasts the social and psychological detachment of the public from energy systems that is embedded within centralized system. In contrast with the past view of energy consumer, for whom energy is simply a good to be expended in pursuit of personal goals, the energy citizen engages with energy as a meaningful part of their practices and is better understood in a community context. This view of an *EU energy citizen* with equitable right and responsibilities in shaping and defining the energy transition should be at the core of a reliable and transparent EU energy governance.

1.3 Framework of the research

1.3.1 Definitions

I will use in the next chapters several concepts related to energy systems. Some of them are still debated and do not yet have an agreed definition. Therefore I will define them here according to relevant literature in order to avoid confusion and misunderstanding in the following chapters.

'**smart grids**': an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies (as defined by the SmartGrids European Technology Platform)[2];

'smart metering system' means an electronic system that can measure energy consumption, providing more information than a conventional meter, and can transmit and receive data for information, monitoring and control purposes, using a form of electronic communication (European Commission, 2016d);

'**demand side management' (DSM):** refers to actions undertaken on the demand side of energy metres in order to match demand with the available supply (Warren, 2014);

In Figure 2 a categorization of DSM as proposed by (Warren, 2014) is presented.

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[2] http://www.smartgrids.eu/ETPSmartGrids

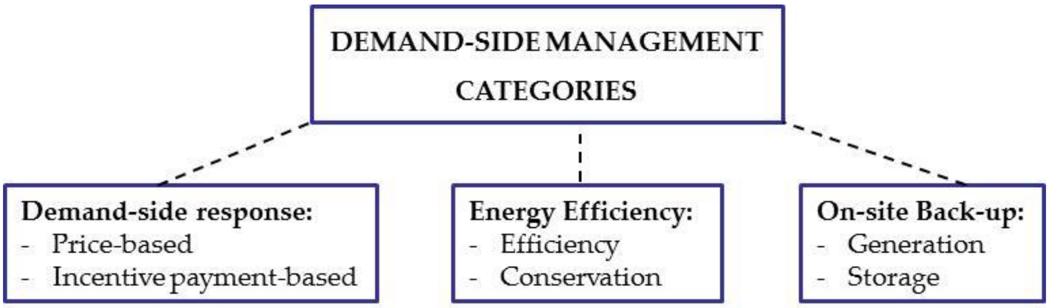


Figure 2. Demand side management categories (adapted from (Warren, 2014))

'**energy efficiency**': energy efficiency is the ratio of the useful output of a process to the energy input into a process as also defined in the Clean Energy Package (European Commission, 2016d) . Some authors refer to energy efficiency and energy conservation synonymously. However, improving energy efficiency may reduce the amount of energy needed to perform the same function, but this doesn't guarantee that energy use will reduce; it may stay at the same level, or even increase, thus producing a phenomenon known as rebound effect (Patterson, 1996; Warren, 2014; European Commission, 2016d);

'**energy conservation**': aims at reducing the overall energy demand through the year (Warren, 2014);

'**demand response':** demand response is mainly about shifting energy consumption during peak times to a different point in time to help balance supply and demand (Warren, 2014; Eurelectric, 2015a). The Clean Energy Package now provides a more extended definition of the term:" ***'demand response'*** *means the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including time-variable electricity prices or incentive payments, or in response to acceptance of the final customer's bid, alone or through aggregation, to sell demand reduction or increase at a price in organised markets as defined in Commission Implementing Regulation" (Proposal for a directive on common rules for the internal market in electricity p.52)* (European Commission, 2016d). Eurelectric (Eurelectric, 2015a) differentiates between implicit demand response (also called price-based) when consumer choose to be exposed to time varying electricity pricing that reflect the value and cost of electricity in different time periods and explicit demand response (also called incentive-based) where the results of demand response actions are sold upfront on electricity markets;

'**active customer'** means a customer or a group of jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy efficiency schemes provided that these activities do not constitute their primary commercial or professional activity;

'**local energy community**' means: an association, a cooperative, a partnership, a non-profit organisation or other legal entity which is effectively controlled by local shareholders or members, generally value rather than profit-driven, involved in distributed generation and in performing activities of a distribution system operator, supplier or aggregator at local level, including across borders;

'**prosumer**': prosumer is a relatively new term in the energy field that often denotes a consumer who both produces and consumes electricity. The Clean Energy Package acknowledges a "*lack of common rules for prosumers that may hamper self-generation"*. Eurelectric (Eurelectric, 2015b) defines prosumers as *"customers who produce electricity primarily for their own needs, but can also sell the excess electricity. Prosumers are connected to the distribution network with small and medium installed capacity"*. Examples of prosumers include: - **residential prosumers** who are citizens who produce electricity on their property, mainly by installing solar PV panels on their rooftops or through micro combined heat and power (micro-CHP); - **community/cooperative energy** such as citizen-led renewable energy cooperative, housing associations, foundations, charities, which are not commercial actors, but produce energy meant for self-consumption, mainly by solar PV panels and wind turbines; - **commercial prosumers** such as SMEs, department stores, office buildings, industry and other business entities whose main business activity is not electricity production, but which self-consume the electricity they produce, mainly with rooftop PV panels and CHP, leading to significant cost savings; - **public prosumers** such as schools, hospitals and other public institutions that self-generate electricity. It is however argued that production represents only one aspect of the serval where user driven value generation is central (NCE Smart Energy Markets, 2012; Greenpeace, 2016). A recent briefing of the European Parliament Research Service (EPRS European Parliamentary Research Service, 2016) provides a wider definition of prosumers pointing out that self-generation is not always considered a defining feature of prosumers. A broader understanding of the term 'prosumers' includes all consumers that not only passively consumer energy, but are also actively participating in the market, thus generating value for themselves or for the other players in the market. Prosumers can indeed produce energy savings through energy efficiency measures and demand-side response. Such reduced demand has a value on the market for which prosumers can be compensated.

For the scope of my work and acknowledging that a common operational EU definition of "prosumers" does not yet exists, I consider the broader definition of "electricity prosumers" as suggested in (NCE Smart Energy Markets, 2012; EPRS European Parliamentary Research Service, 2016; Greenpeace, 2016): *all consumers that not only passively consumer energy, but are also actively participating in the market, thus generating value for themselves or for the other players in the market*. The term consumer and prosumer will be used interchangeably in the present dissertation.

1.4 Methodology

The research methodology is presented in Figure 3. I first perform an extensive literature review on the available social psychology theories on sustainable consumption behaviour. Then I look for evidence into European surveys, studies and smart grids pilot projects to find out what are the current findings and developments for what concerns energy consumers attitudes, preferences and concerns towards sustainable energy consumption and emerging smart electricity technologies.

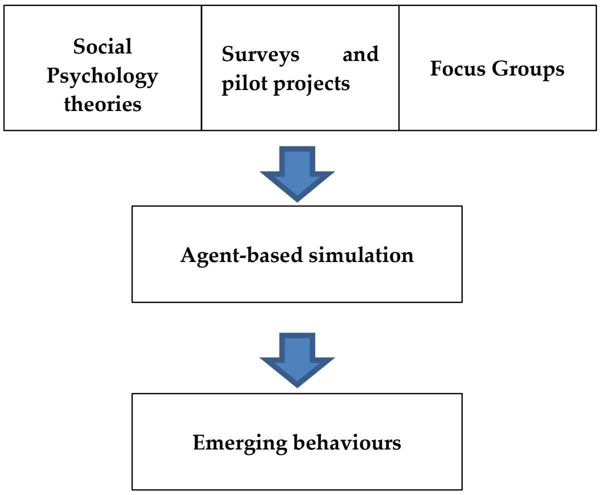


Figure 3. Methodological approach

I complement these findings with additional insights into consumers' drivers and barriers to smart electricity technologies running focus groups on smart home technologies. The knowledge collected in this first phase represents the base on which the model of the electricity prosumers is developed. The simulation tool used and best suited to represent and simulate the complexity of the consumer role in the emerging energy systems is agent based modelling. Agent based modelling is particularly suited to topics where understanding processes and their consequences is important. Agent based modelling is a popular tool in social sciences (Gilbert, 2008) where it has increasingly being used to build models where individual entities and their interactions are directly represented. ABM differs from variable-based approaches or system-based approaches offering the possibility of modelling individual heterogeneity representing explicit agent's decision rules while situating them in a space (geographical or other types). Through ABM of the electricity consumers, I will look for consumer's emerging behaviours that can provide insights into the mechanisms at play in energy consumer's choices and decisions.

1.5 Research objectives

The challenges concerning the consumer role in energy transition and highlighted in the 'New Deal', as discussed in section 2, suggest research questions whose answer is crucial in the in the ongoing policy making process. In particular:

- What kind of information is key to promote behavioural change and adapt consumption?
- Which are the elements that play a role in consumer switching rate (information, consumer values, preferences, social network, and barriers)?
- Which are consumers' drivers and barriers to participation in demand response programs?
- What are consumer's drivers and barrier to become prosumers?
- What are consumers' drivers to participation in energy community schemes?
- How can energy poverty and vulnerable consumer's issues be better addressed?

Figure 4 presents the main points of the "New Deal" concerning "empowering the energy consumer" and summarize the associated relevant research questions.

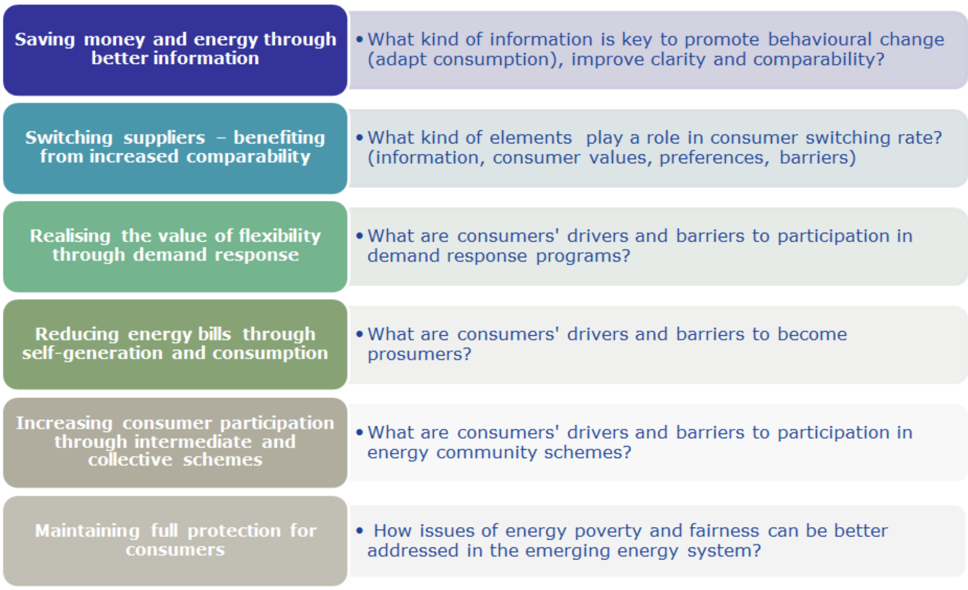


Figure 4. Empowering the consumers to act: research questions

The aim of the present thesis is to address some of these research questions through the analysis of the current trends and developments on emerging electricity systems (smart grids) in EU, specifically looking at demand side management projects and to gain further insight in consumer preferences and decision making processes through modelling technique.

The research objectives of my thesis can be unpacked into two main research questions:

1. What is the role that the European consumer is envisaged to play in the future electricity systems?

2. How can complexity science contribute to the understanding of the emergent socio-technical interface of the future electricity system?

The general research objectives can be further detailed as follows:

3. What are the values, goals and norms that drive the electricity consumer towards the adoption of smart grid technologies?
4. What are the consumer's drivers and barriers to behavioural change, participation in demand response and energy community schemes? Which barriers may hinder the consumer adoption of smart grid technologies?
5. What are the impacts of interacting electricity prosumers exposed to different polices on sustainability, market competitiveness and energy savings?

These questions will be further articulated and addressed in the following chapters.

1.6 Conclusions

In this chapter I have introduced the motivation of my thesis, setting the political context in which it is situated, namely the EU energy policy developments and specifically the role of energy consumers. I have provided a brief overview of the historical evolution of the EU energy policy and how the view on consumer's role has evolved in the different energy policy documents, recognizing its role and active participation as "*a prerequisite for managing the energy transition successfully and in a cost-effective way*". My research questions and proposed framework aims at addressing some of the challenges posed by this emerging role of energy consumer.

2 Energy and Complexity

2.1 Future energy systems and complexity science

The present system of energy supply and demand will need a significant change in order to address the three major challenges of European energy policy: sustainability, security of supply and competitiveness while guaranteeing energy equity. These three challenges entail complex interactions between public and private actors, governments and regulators, economic and social factors, national resources, environmental concerns and individual behaviours (World Energy Council, 2016). This emerging complexity calls for a broader methodological approach to energy studies to include also qualitative and more human cantered methods of data collection (e.g.: interviews, field research, focus groups, etc.) as well as novel simulation approaches (e.g.: agent based modelling) and should also cover issues of energy poverty, psychology and consumer behaviour, social practices theory, social construction of technological systems and so on (Sovacool, 2014; Rai *et al.*, 2016). This is important as the social and cultural context that surrounds the energy system and their mutual relationship cannot be neglected.

Emerging energy systems (also called smart energy systems or simply referred to as "smart grids") thanks to a pervasive incorporation of information and communication technologies will enable bidirectional communication and power exchange between suppliers and consumers, transforming the traditionally passive end-users into active players. These emerging energy systems can be conceived as complex adaptive systems; they can be represented in terms of dynamic complex multi-layer structure that integrates various different, interacting layers. The interconnections between the different layers exhibit an emerging complexity in which it is impossible to abstract the overall behaviour by the analysis of a single component (Masera *et al.*, 2013). Complexity science and its associated modelling methods allow the exploration of the interactions between these different elements of a system and of how the different elements of the system give rise to collective emergent behaviours.

Analysis of possible policy measures and instruments to approach the challenges that these emerging systems pose are still dominated by techno-economic models that do not reflect the full complexity of the energy systems, in particular for what concerns systems' interactions and actors' behaviours. *Emerging energy system*s should be treated as a "*system of systems*", in other words they should be seen as "*a collection of task-oriented or dedicated systems that pool their resources and capabilities together to obtain a new, more complex 'meta-system' which offers more functionality and performance than simply the sum of the constituent systems"* (IEEE-Reliability Society, 2014); they are composed of many self-governing components that respond to different economic and environmental drives beyond the simple operational ones. In this context, complex systems thinking and modelling is valuable in understanding the complexity of energy systems in order to address current and future policy challenges (Bompard *et al.*, 2012; Bale *et al.*, 2015).

The implementation of smart energy systems will change the way we live our lives and how we interact socially and culturally. Social actors in the energy landscape will need to adapt their behaviours, strategies and means of producing, delivering, storing, and consuming energy. Emerging electricity systems design and implementation will need to be coupled with broader social and cultural considerations in order for these to be successful.

A smart electricity system is not only a diverse set of dynamic, distributed energy suppliers, it is also an energy system which connects smart (i.e., responsive, energy efficient, and variable) users to sustainable (i.e., low carbon, renewable) energy sources. And the grid itself is smart whenever it is able to modify its output, and able to monitor, control and meter the energy demands of consumers in a regulated and fair way (Bompard *et al.*, 2012).

2.1.1 A research agenda for emerging electricity systems

The results of a JRC workshop on "Smart Energy Grids and Complexity Science" (2012) propose a series of points for a research agenda for a complexity science approach to emerging electricity systems that can be useful for the purpose of the present thesis. They propose:

- <u>a unified approach based on complex system views and methods</u>: this shall embrace the technological, social, business and environmental complexity of the emerging energy systems in a unified view that aims at promoting sustainability and resilience through model based problem solving;
- <u>acknowledgment of the complexity within and around the emerging electricity systems</u>: the energy system infrastructure and its evolution are closely intertwined with a wider set of contexts (i.e.: social, technical, economic, environmental..). The interaction of these contexts with the emerging energy system is difficult to be represented through traditional approaches. It is not only complexity within the energy system that emerges, but also complexity of the interactions with the surrounding contexts. Addressing complexity within and around the emerging energy system will provide the way to the full understanding of the overall sustainability of the system;
- <u>a multi-scale modelling approach</u>: the multi-scale phenomena that will emerge at societal, technological, environmental and business level and the system behaviour need to be properly addressed with multi-scale modelling using information or models from different levels. The aim is to develop an approach that include the growing links and correlations in and around the

emerging electricity systems, i.e.: how society and technology co-evolves, how new business and social models will enable new patterns for the generation, distribution and consumption of energy;

- new approaches to sustainability and resilience: emerging energy systems will entail new opportunities and scenarios that will encompass new risks that need to be taken into account. Complexity science may help in developing new approaches to resilience assessment;
- complexity versus simplicity: the challenge of a complexity science approach is to find ways of simplifying the representation and understanding of the systems. Approaching the heterogeneous characteristics of emerging energy systems with complexity science and theories lenses, simple rules and strategies could be designed and tested for a set of representative phenomena and scenarios;
- empowering stakeholders: at the core of the emerging energy system is the empowerment of stakeholders such as consumers, communities, governments and other institutions. Co-dependency of individuals will promote the creation of communities that will share benefits while receiving and paying fair tariffs for the electricity generated and consumed. There is the need to better understand the energy consumers and anticipate lifestyles in light of their adaptation to new social and economic settings. How easily will users adapt or adopt the new system? Which kind of support will they require from authorities and utilities? How long might it take for a fully functional "smart powered" society? In addition, one can foresee that emerging behaviours of prosumers/consumers will require and force the development of new mind-sets, which could parallel the emergence of social networks around the Internet. Some key questions could then be posed to society, e.g. How to change environmentally important behaviours?

2.1.2 Energy as a wicked problem

The emerging issues in the energy system transition are variably referred to as complex, wicked, untamed or unstructured (Valkenburg *et al.*, 2016). Wicked problems are in general poorly identified and defined and they are influenced by factors in multiple and often contradictory ways; they may be constantly changing and do not have objectively optimal solutions; any solution found will be deeply entrenched in the social context in which it has been developed (Brunswicker *et al.*, 2017). Proposed solutions for "energy wicked problems" may be addressing the symptoms instead of underlying causes. The knowledge base required for effective implementation may be weak, fragmented or contested. Wicked problem in policy research are characterized by unknown or very ambiguous goals and highly uncertain and poorly understood means-ends relationship (Head, 2008). It is argued (Head, 2008) that conventional explanations for "wicked problems" usually tend to focus on weaknesses and deficiencies in the public sector's implementation and delivery mechanisms (e.g.: lack of skills or competences, inadequate funding, poor communication and consultation, lack of commitment, lack of authority to achieve the right level of coordination, etc.). However, the concept of wicked problems "*potentially adds another layer of explanation and new research questions, focusing mainly on the* ***understandings that have shaped problem-identification*** *and thus the* ***frames for generating problem-solutions****" (Head, 2008).* Very often, due to the lack of this understanding, failures and unintended outcomes are likely to be endemic in many complex areas of policy and program delivery, for several reasons that may span from poor problem identification and scoping, the changing nature of the problem being addressed and, more specifically to energy policy, to the need to achieve a major shift in consumers' attitudes and behaviours without having put in place sufficient incentives or the right tools to ensure that such shifts are actualised. Considering the behavioural change that is advocated in the energy transition, traditional levers (laws, taxes, economic incentives and subsidies) may not suffice to realize the desired behavioural shift (Kolk, 2012). The "wicked" nature of the challenges posed by the emerging energy systems requires iterative ways of knowledge production as well as reflexivity in governance in order to address the complexity that emerges due to both normative (i.e.: uncertainties about how to decide and how to act) and factual uncertainty of the transitioning energy system. In science for governance, reflexivity is needed to device new strategies to cope with problems as well as to reflect if the same institutional structure of governance needs revision. Indeed the institutional structure of governance may need revision to facilitate the development of those novel strategies (Valkenburg *et al.*, 2016). This implies that the entity deciding about the validity of knowledge claims (what Kovacic (Kovacic *et al.*, 2015a) defines as "the story teller") reflects on the values and goals that have driven the "choice of narrative". In the case this narrative informs policy decisions, it is fundamental to verify the relation between the analyst's choice of values and the social shared values. These considerations will help me in shaping and framing my analysis on the role of the consumers in the energy transition that I will further develop in the following chapters.

2.2 Multi-layer and multi-player interaction in electricity system

Complexities arising inside and around emerging electricity systems prompt a multi-layered approach in which different disciplines and areas of expertise are pooled together.

Emerging electricity systems needs to be studied and understood as complex socio-technical systems with multiple physical, cyber, social, policy, and decision making layers; these layers also interact with changing external conditions (economic cycles, technological innovation, and prevailing and changing weather and climatic conditions). Many actors interact within this broader “system of systems”, such as prosumers, distributors, retailers, regulators and policy makers. They act via distributed decision making processes which impact the physically constrained network via diverse electronic means (from control and command systems to smart meters).

The complexity of the future electricity systems (smart grids) is acknowledged as a challenge by CENELEC that has visualized this complexity in the Smart Grid Architecture Model (SGAM) (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012). In the SGAM approach presented in Figure 5, the Smart Grid Plane covers the complete electrical energy conversion chain that includes generation, transmission, distribution, distributed electrical resources (DER) and customers. The zones represent the hierarchical levels of power system management and the five layers represent business objective and processes, functions, information exchange and models, communication protocols and components. Each layer covers the smart grid plane, which is spanned by electrical domains and information management zones.

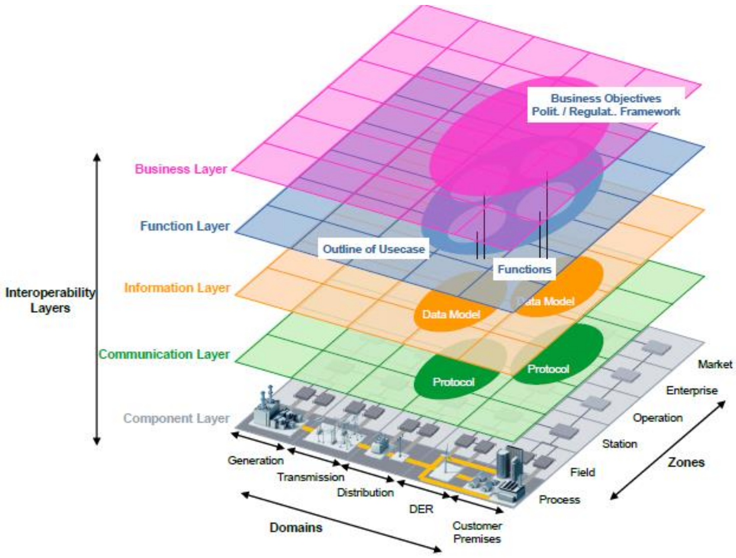


Figure 5: SGAM framework (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012)

The complexity of the smart electricity system rests on the multiplicity of interacting players that operate with, and within, a defined environment as independent decision makers with behaviours that are driven by individual as well as socially driven goals and attitudes. The broader socio-technical network forms a community with high levels of interaction and integration.

While much research has looked at the purpose and functionality of smart electricity systems, smart electricity systems themselves are merely one system in a "system of systems". As such, complexity is not just an attribute of the smart electricity systems alone, but also the systems interacting with it. For example, the increasing complexity of weather and climate, the increased complexity of social behaviour and the interaction of individuals guided by narrow economic rationality, the complexities of crisis management and emergency response and the overall organisational structure needed to manage all those complexities, must all be studied and modelled to adequately meet the emerging challenges that modern society will face (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012).

In this context, in order to understand the complexity of future electricity systems, there is the need to move focus and attention from a component-oriented to an interaction-oriented view of the electric power system. The goal of this systemic understanding is to identify tools and techniques for optimal decision-making that will enable society to achieve its energy, environmental, economic and social goals. The framework that should be developed will enable the identification of emerging problems and will provide new solutions and approaches (Bompard *et al.*, 2012).

Complexity sciences can help in modelling and analysing the dynamics and interactions of a broad range of actors and components constituting the technical, social and environmental aspects of smart energy systems thus assisting in investigating present and future challenges in and around future smart energy systems.

A smart energy system includes both local smart distribution grids - characterized by numerous independent participants like prosumers, retailers, distributed-generators, energy storage, EVs as well as technologies still to be invented - and transnational super grids - e.g. connecting large-scale time-varying renewable sources to national power grids and markets).

The main characteristics of these systems are (Bompard *et al.*, 2012):

- pervasive deployment of information and communication technologies (ICT);
- integration of renewable generation in support of energy, environmental and other policies;
- bidirectional communication and power exchange between suppliers and consumers/prosumers;
- multiplicity of interacting players operating with, and within, a defined architecture/market;
- enhanced network flexibility and reliability in a future smart energy system;
- newly required approaches for the monitoring, control and protection of power systems in both space and time.

Furthermore technical power systems will operate under varying environmental conditions, exchanging transactions in the power markets. A key concept in complexity science is "emergence". Though some emergent properties can already be anticipated, it is expected that important emergent properties of the future electricity systems remain unforeseen.

The hypothesis is that complexity sciences can help in identifying tools and techniques for optimal decision making encompassing policy and regulatory design, planning and investment, as well as real time operations. Smart energy systems research incorporating complexity sciences can provide models and guidelines for future developments, and for recognizing emerging behaviours and challenges.

As suggested by Bompard (Bompard *et al.*, 2014), a multilayer platform model includes the power, cyber, social and environment layers, along with threats and factors that may affect the system as presented in Figure 6.

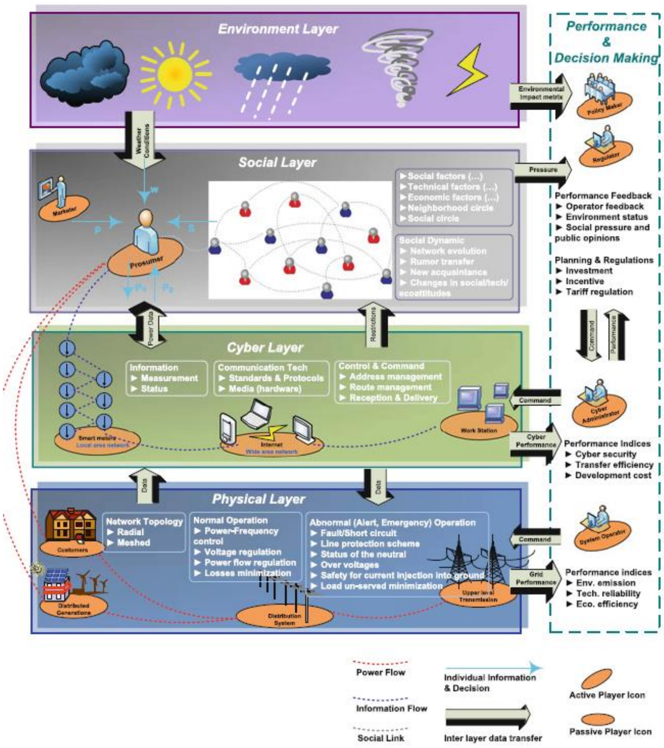


Figure 6. Multilayer platform of complex power system (Bompard *et al.*, 2014)

The **physical layer** includes all the hardware components and contains the electricity flows where physical variables and indices are computed, monitored, or optimized by the system operators. Here, the focus is mainly on MV/LV distribution networks, while including data and constraints from the upper transmission level. The **cyber layer** is the container of information flows, where all the operations and market-related data sets are managed: prosumer generation and consumption values, market prices, physical conditions, operational commands, and so on. Also various technical innovations are required in this layer, such as smart meters, optical and power-line communications, home area communications, wide area measurement system, and so on. The **social layer** aggregates the actors of electricity system, i.e. users, prosumers and marketers. This layer has been identified as the main source of complexities that lead to the unpredictable performance of the overall system. The value sense of each prosumer is initially decided by factors related to their psychology, education, profession and so on, and then evolving through the interactions within their social network. Also the social network itself is evolving through random relationships and the establishment of new or interruption of existing social links. The **environment layer** stands for the natural phenomena, and influences all the other layers. Most obviously, weather conditions, geographical conditions, and primary and secondary resource conditions, directly affect consumption and generation. Society typically imposes sustainability goals that require the respect of several environmental targets (emission, energy efficiency, and so on), with a key role for regulators.

Apart from environmental targets set by society, the overall performance of the system should include all the other dimensions: physical performance in terms of power security, power quality, reaction under emergency; technical performance in terms of technology penetration, technical reliability and efficiency; social performance in terms of satisfaction of the objectives set by regulations, individuals, and social groups; and market performance in terms of market power allocation, competitiveness, etc. (Bompard *et al.*, 2014). Of great importance are the interconnections between the different layers, as these connections are at the basis of the arising complexity. For example the weather conditions impact on the social layer (people behaviour) and on the physical layer (e.g. distributed generation); the physical layer exchanges data with the cyber layer, which performs measurements and provides commands, but influences also the environment layer (e.g. with pollutant emissions); the cyber layer is the mean for prosumers (social layer) to interact with the grid (physical layer). The decision-making processes interact with the other four layers. For example people (social layer) can exercise pressure on politicians for changes in the performance objectives; on the other hand, decision makers can obtain information from the cyber layer and provide commands to it, or can act directly on the physical layer (e.g. the system operators).

As mentioned in section 1.1, the complexity is not only related to the multiplicity of layers, but it is also related to the multi-scale dimension of the energy system itself and to the plurality of the available non-equivalent representations (Kovacic *et al.*, 2015b) that relate to different issues at different level of the system: demand side management, efficiency, reduction of distribution losses, integration of renewable resources and availability of natural resources. The term "electricity grid" has different interpretations depending at which level of the system the analysis is addressed. A representation of the different levels of analysis used to study the performance of electricity grid is proposed in Figure 7 as suggested by Kovacic. Each level of analysis is characterized by a different "system identity" and "potential system use". It is the coexistence of non-equivalent representations of the performance of smart grids that generate ambiguity in the interpretation of what an electric grid is and should be clearly understood and specified.

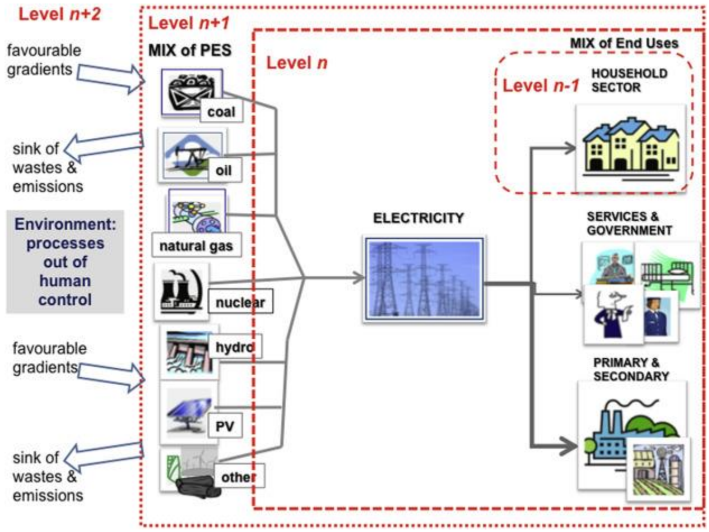


Figure 7. Different level of analysis used to study the performance of electricity grids (Kovacic *et al.*, 2015b)

The scope of this thesis is the analysis and simulation of the interface between the technical system (represented by the smart grid technologies) and the social layer, in the specific the household consumer. I therefore focus on level n-1.

2.3 Energy consumer and complexity

The key agents in emerging energy systems include household consumers, business energy users, energy conversion and supply companies, economic and environmental regulators, and governments (local and central). These agents respond and adapt to other agents and to external conditions, but lack the perfect rationality and foresight that is ascribed to them by many economic models. In particular, household consumers, as discussed in the previous section, interact through physical and social networks by sharing information and learning from one another through social interactions (Bale *et al.*, 2015). This determines self-organisation and emergent behaviours in energy consumption patterns and practices that may change over time due to contextual factors such as new policies, technologies and institutions. Energy consumer's empowerment is at the core of the European energy policy, however to promote the behavioural change that is needed and advocated traditional levers (such as laws, taxes, subsidies) may not be sufficient (Kolk, 2012) (Head, 2008). Insights on consumer's behaviours specific to energy need to be taken carefully into consideration. More specific to energy, individuals can have various roles in the emerging energy systems; they can be simple consumers, they can produce their own electricity (prosumers) and paraticipate in production and trading, or they can participate in collective energy production sharing energy and common goals at community level (energy communities). Only knowing more about what drives individual and collective consumer's energy behaviour will provide an understanding of the measures that could stir the consumer in the desired direction (Kolk, 2012). Consumer engagement is considered as a psychological process comprising cognitive and emotional aspects (Brodie *et al.*, 2013), where consumer engagement includes calculative as well as affective commitment and trust. However, energy is a peculiar product where the interaction between cognition and affect as traditionally recognized in consumer decision making, works differently (Kolk, 2012). Energy seems more a *think* than a *feel* product and is characterized by intangibility (invisibility of energy). Adding more variety of contracts and features (e.g.: green energy, additional services, product bundling) can add tangibility (more tangible cues). Affect can play a larger role than cognition with environmental issues and renewable energy. Energy consumers' switching behaviours have received attention and it is often see as a criterion for progress in liberalization and consumer engagement with the market (European Commission, 2016e) (Ofgem, 2016). However, it is argued that a high degree of switching does not necessarily mean real effective competition and the theoretical possibility exists that the absence of switching hints at perfect competition (Kolk, 2012). Therefore, the interrelation between contextual variables in specific geographical regions and the individual as well as collective and motivational aspects of energy consumption deserve further attention and should be further explored to verify how consumer's active participation can be better shaped. The research should go beyond the current criteria and measures used to indicate progress in market liberalization and consumer involvement in energy transition.

2.4 Modelling complexity in energy systems

The computer modelling approach advocated for complex adaptive systems is known as *Agent-Based Modelling (ABM)*. In this approach "*systems are modeled as collections of autonomous interacting entities ("agents") with encapsulated functionality that operates within a computational world*" (Borrill *et al.*, 2010). ABM has been widely applied in the analysis of socio-economic problems where it can solve some underlining limitations of traditional modelling tools (Boero *et al.*, 2015) linked to their lack of flexibility. The flexibility provided by ABM "*allows replication of the phenomenon of interest with a higher degree of realism than in other traditional models*" (Boero *et al.*, 2015). This specific feature of ABM has an impact on causality. The capability of replicating realistically the phenomenon, allows the researcher to investigate which mechanisms are at the origin of the phenomenon itself which is often not possible with equation-based models. In this sense ABMs have the capability to produce "generative explanations" to social phenomena, that is to say they can describe an observed social phenomenon "*in terms of the external (environmental and social) and internal (behavioural) mechanisms that generate it, rather than by inferring causes from observed co-variation" (Conte et al., 2014).* The generative nature of ABM seeks to provide an explanation to social phenomena by growing them. It is argued that the generative nature of ABMs has been underexploited due to the pressure to seek and deliver "simple recipes" (Conte *et al.*, 2014).

Common concepts in ABM are: *emergence, adaptation, interaction and sensing. Emergence* is where individual behaviours and interactions between entities lead to effects on the system aggregated level; what is interesting is to see the *adaptation* rules (e.g.: what decisions do agents make?) that might lead to emergence, where emergence shouldn't be imposed. There may be decisions that maximize explicit estimates of an agent's future condition (direct objective seeking) or agents may be given rules that mimic observed behaviour (indirect objective seeking). The interest is to explore local rather than global *interactions*. There may be direct or indirect interactions through the environment. Finally, *sensing* is the understanding of what information the agents have, if the information is partial and under what conditions the agents hold this information (Venhoeven *et al.*, 2016). Policies and stakeholders preferences can easily be introduced into ABM as exogenous rules.

Thanks to its flexibility, ABM has been used to study a wide range of behaviours in different research fields.

Agent based modelling is a popular tool in **social sciences** (Gilbert, 2008) where it has been increasingly used to build models where individual entities and their interactions are directly represented. It has recently been suggested as a possible better alternative tool in **climate economics** to Integrated Assessment Models (IAMs). According to Stern [15] ABM added value is that it seeks to provide more-realistic representations of socio-economics by simulating the economy through the interactions of a large number of different agents, on the basis of specific rules. Therefore, ABMs appear as a promising development to approach climate change challenges.

Agent based modelling is increasingly being considered as a suitable tool to address the complexity of **socio-technical systems** that are characterized by a strong interaction between the human and the technical system. ABM allows a better reflection on the complexity of socio-technical systems than standard techno economic modelling approaches (Epstein *et al.*, 1996; Gilbert, 2008; van Dam *et al.*, 2013; Boero *et al.*, 2015). A socio-technical approach seeks to understand and study the interactions of two deeply interconnected subsystems: a social network of actors and a physical network of technical artefacts (van Dam *et al.*, 2013). These two intertwined systems, as discussed earlier, constitute a complex adaptive system where the actions of a multitude of actors determine the development, operation and management of the technical network that in turn affects the behaviours of the actors. The electricity infrastructure represents a good example of a sociotechnical system where the physical electricity infrastructure provides electricity power through technological artefacts (wind, solar, thermal power plants, transmission lines, smart metering infrastructure). In terms of social system the electricity infrastructure involves a variety of actors, from power generators, distribution system operators, retailers, market operators and consumers to policy makers and regulatory authorities. Within a changing institutional framework the system is self-organizing and in a process of coevolution with the surrounding institutions and regulations. It is in this context of self-organization and co-evolution that ABM is considered as a better option to variable-based approaches or system-based approaches offering the possibility of modelling individual heterogeneity representing explicit agent's decision rules in a given space. ABM conceptualizes the components of the system and their interactions instead of producing a macro-level mathematical model (Alfaro *et al.*, 2017). *Agents* and *equations* are concepts of different order, where *equations* refer to the system description elements, while *agents* emphasizes the model elements (van Dam *et al.*, 2009). Agent based modelling offers a flexible structure through which is possible to develop detailed representations of complex agent systems, including the behavior of heterogeneous agents, their social interactions and the context in which they operate. In these models, actors can be represented as heterogeneous agents with different heuristics, the ability to learn, and to interact with each other and their environment. ABM has been successfully applied to modelling sociotechnical systems as for example supply chains, consumer lighting, CO_2 policies, electricity generation and mobile phone production, consumption and recycling network (van Dam *et al.*, 2013).

ABM has been recently used as a support **tool for planning electrification** efforts with the main objective to engage policy makers in less industrialized countries. The tool is considered as an alternative to time and data intensive approaches allowing the stakeholders to investigate the results of their decisions in a quick and flexible way in early stages of the process. In this context, ABM should not be used as a predictive tool but as a scenario generation package (Alfaro *et al.*, 2017) that can be useful in the development and evaluation of policy.

Various ABM have been developed for **diffusion of sustainable (household) technology**, such as water-savings innovation (Schwarz *et al.*, 2009), heating systems (Sopha *et al.*, 2013), smart metering (Zhang *et al.*, 2011), heating feedback devices (Jensen *et al.*, 2015) and electric vehicle diffusion (McCoy *et al.*, 2014). These studies, focusing mainly on technology adoptions by end-users, show how heterogeneity of actors, learning and interactions between actors and within social networks influence technology adoptions primarily by end-users. Recent studies have also applied ABM to study energy conservation behaviours (Zhang *et al.*, 2011; Chen *et al.*, 2012; Azar *et al.*, 2016). Some studies have also focused on sustainable consumption, such as green consumption (Bravo *et al.*, 2012) and the diffusion of green products (Janssen *et al.*, 2002).

ABM has recently begun to be applied also to **long-term evolution of energy infrastructure systems** (van Dam *et al.*, 2013; Rylatt, 2015; Busch *et al.*, 2017). These infrastructure-based studies move form an end-user focus, to the inclusion of supply chain actors and try to understand how the impact of policy and social dynamics on these actors' decisions influence the evolution of infrastructure systems.

Furthermore, ABM has been applied to study **electricity systems and markets**. Several large scale ABM have studied competitive wholesale electricity markets. In general, these models have focused on market and auction design, bidding strategies of large traders, anticipating regulations, changes in the number and type of suppliers and purchases, policy changes intended to reduce the chance of blackouts or decrease the environmental impact of generation.

2.4.1 Modelling energy consumer behaviour with ABM

Conventional tools used to understand energy systems, such as system dynamic models do not cope well with the complexity of consumer energy behaviours. Agent based modelling can be more suitable to represent the complexities of consumer behaviours and their decision making processes in ways that can improve understanding of the demand side of energy systems (Ajmone-Marsan *et al,2012)* (Rai *et al.*, 2016). In particular, as discussed earlier, there has been an increase in the last few years in the application of ABM to the study of consumer behaviour across a range of energy and environmental problems and sustainable energy technologies adoption (Chappin *et al.*, 2012; Kowalska-Pyzalska *et al.*, 2014; McCoy *et al.*, 2014; Jensen *et al.*, 2015; Ringler *et al.*, 2016; Alfaro *et al.*, 2017; Busch *et al.*, 2017). According to Rai (Rai *et al.*, 2016) these models combine three main goals: - to represent behaviour driven models of decision making that depart from the neo-classical rational view; - to incorporate heterogeneous agents and environments through rich datasets in order to provide more realistic setting that could be of help in developing decision-support tools; - **to study emergence in consumer systems, in particular how values and beliefs at consumer level (as defined by social psychology and behavioural theories) lead to macro behaviours such as adoption over time and space.** While ABM design and evaluation questions can be posed *ex-post* to evaluate the effects of policies and programmes after implementation, most of the current ABM research on energy related consumer behaviour focuses on policy design problems in *ex-ante* settings. In this context, agent-based simulations can provide insights into key aspects of the problem under analysis as for example the influence of social networks in shaping consumer's decisions on energy consumption choices or identifying critical aspects that deserve further analysis and focus in future empirical studies. These obtained insights can be used to assess the potential impacts of policies before any action is taken.

Rai (Rai *et al.*, 2016) provides an interesting and simple exemplification of the common elements of ABM that can be easily transposed to the energy field. He suggests a three step approach that is presented in Figure 8. The **first step** is to specify the factors that determine consumer's behaviours (micro-drivers); these factors are determined by the theory that informs the model. There is a significant variety of theoretical choices that may underpin consumer's behaviour, spanning from prospect theory, theory of planned behaviour, utility maximization, threshold behavioural rules and diffusion of innovations (see Chapter 3). The **second step** is to formalize the factors that determine consumer's behaviour through specific behavioural rules that may be used to determine how an agent will behave under certain circumstances. An ABM model will have to specify how (probability of a specific behaviour) and when an agent will behave. The **third step** is to represent the outcomes of agent's behaviours through aggregated values over time and space. The outcomes may be represented by adoption curves or switching behaviour. Depending on the model assumptions - that is to say on the chosen theory of behaviour - and on how these are operationalized, the shape of the outcome curves may vary dramatically. Indeed, it is the study of how agent's behaviours may produce emergent or unexpected macro-level outcomes that make ABM a well suited tool for complex systems analysis.

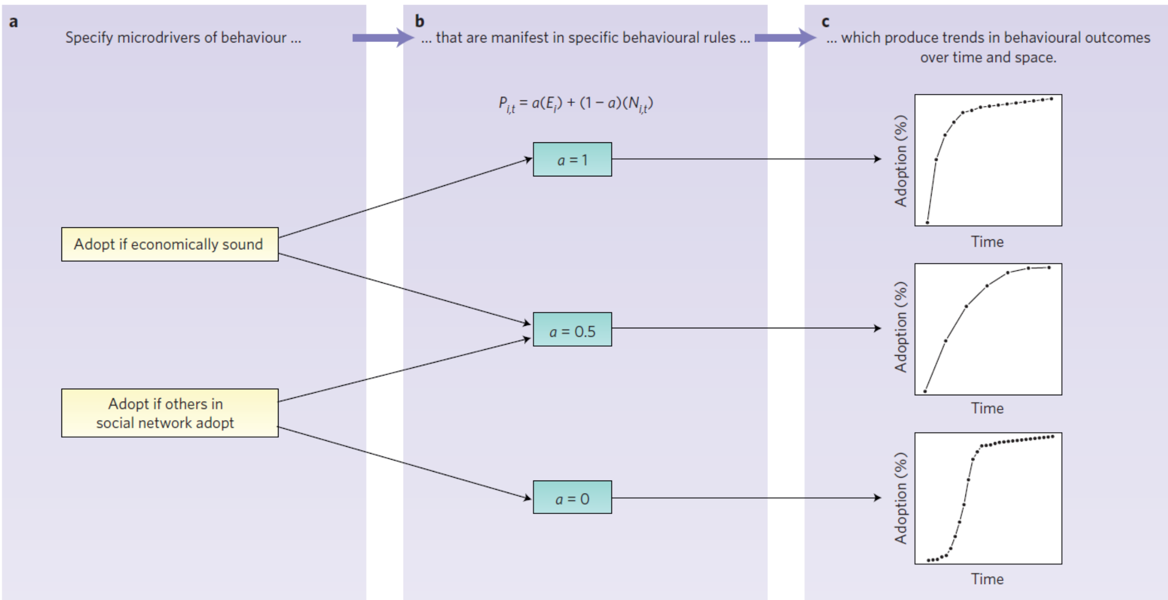


Figure 8. Common elements in ABM (Rai *et al.*, 2016)

a: specification of the general factors that drive the decisions and behaviour, which may be derived from complementary or competing theories of human behaviour. For instance, a theory of rational choice might emphasize the importance of economic costs and benefits to adoption whereas a theory of social influence will emphasize the importance of having other social contacts who have adopted. **b**: specification of a specific decision rule, such as the probability of adoption of agent i at time t ($P_{i,t}$) specified in the equation. Variables E_i and $N_{i,t}$ represent the ith agent's economic benefit of adoption and the proportion of social contacts who have adopted before time t, respectively. A model parameter (a) controls the relative importance of economic versus social influence factors. **c**: Varying model parameter a yields different emergent outcomes — in this case different adoption curves, which describe the saturation of the technology in the system over time (from (Rai *et al.*, 2016))

Agent based models can be built both for theory testing and predictive modelling of the demand side of energy. ABM can improve both ex ante and ex post policy design and evaluation (Rai *et al.*, 2016). ABM can have different scopes of analysis:

- formalization of theory in which case the model is likely to *be pitched at* a very abstract level; (theory testing)

- description of a wide class of social phenomena (e.g.: behaviour of consumers, development of industrial district);
- provision of specific model of particular social situation (e.g.: model of electricity markets).

These different types of agent-based model require rather different approaches to validation (Boero *et al.*, 2005). Agent-based models can be considered 'valid' if they produce strong fits at model validation stage, which means a positive answer to the question "did we build the right thing"? "are the results convincing?". Traditional validation seeks to verify whether the model is an accurate representation of the real-world system comparing experimental results and real-world data. However, these traditional methods are not always applicable to agent-based modeling since very often there is no "real system" available for comparison. Validation in agent based modelling focuses on understanding if a model is useful or convincing in the explanation it offers to the problems it seeks to explore. In ABM the real outcome of the model is to be sought in the increased insight and knowledge and not in the experimental results (van Dam *et al.*, 2013). Outcome of agent-based models can be validated through different methods, including (van Dam *et al.*, 2013):

- Historic replay;
- Face validation through expert consultation;
- Literature validation; and
- Model replication

When models are developed for theory testing, as it will be the case for the model I will present in Chapter 4, validation might involve a qualitative judgment.

2.5 Conclusions

This chapter has argued and substantiated the complex nature of emerging electricity systems and what are the features and interfaces that make this system complex and challenging to study.

I have argued that ABM is best suited to represent socio-technical system and in particular the energy consumer behaviour thanks to its flexible structure that allow the representations of complex agent systems, including the behaviour of agents, their interactions with the technical system, their social interactions and the context in which they operate

I am interested in studying the emergence in consumer systems, in particular how values and beliefs at consumer level (as defined by social psychology and behavioural theories) lead to macro behaviours such as adoption over time and space.

My research context is an ex-ante setting where the questions I want to address are related to estimating the effects on emergence of various contextual factors, endogenous social dynamics and possible policy alternatives.

3 The electricity consumer: theories and evidence

3.1 Introduction

The paradigm change introduced by emerging energy systems and leveraged by smart metering, energy efficiency and low carbon initiatives will bring unprecedented participation of different players to the energy supply business. Traditional energy retailers are becoming more active in the markets and are seeking to incentivize consumers' engagement in demand response schemes to reduce their overall energy costs. Some of the traditional consumers are also becoming energy producers (prosumers), increasing their potential to provide services to energy retailers and system operators. However, despite the efforts made in several national and international projects related with this topic, a flexible platform capable of securely supporting such services exchange is still lacking. These projects conceived solutions for specific scenarios, usually associated with smart metering, which resulted in closed, inflexible and potentially insecure platforms.

To develop solutions to support an active exchange of services between smart grid stakeholders, such as end-users, equipment manufacturers and service providers (current and new market representatives, electricity network operators and ICT) it is necessary to take consumers into consideration already in the development stage of the new metering solution and throughout the whole deployment process. Consumers' attitudes, concerns, expectations and behavioural patterns need to be carefully factored in the design of the new technological solution and in the development of consumer engagement strategies.

This chapter first presents the most important and relevant, for the purpose of this thesis, theories and models of consumer behaviours (section 3.2); then it provides empirical evidence of consumer attitudes, preferences and concerns first performing a review of surveys and consumer research initiatives carried out at European level and then analysing European demand side management (DSM) pilot projects (section 3.3). The chapter further explores (in section 3.4) the social dimension of the electricity consumer analysing community-based approaches employed in European DSM pilot projects and performing dedicated group discussions focused on the role of smart home technology in individual and collective energy behaviours. Finally, the chapter (section 3.5) provides an overview of the main challenges to address consumer concerns and assure fairness in the energy transition.

3.2 Consumer characterization: theories and models

3.2.1 Models of consumer behaviours

Research and studies in psychological aspects of energy system and on how to motivate sustainable and pro-environmental behaviour have increased in recent years. They recognize that human behaviour and perception are the bottleneck for many changes. However this research has typically focused on efficient energy use and addresses households as passive consumers rather than co-player in the energy system. Little is known yet on how to change and shape active participation of residential users in smart energy systems thus supporting them in achieving their active role of co-player in the future electricity system (Geelen *et al.*, 2013). In this context, understanding consumers' beliefs, values and social interactions becomes of paramount importance to develop successful strategies to fully involve consumers in the future electricity system. It is not sufficient to provide knowledge for producing change; knowledge has to match values and beliefs. If the knowledge is not in line with what consumers believe, then the information provided will be disregarded (Steg *et al.*, 2014). In the following sections, I will present a review of selected theories and models of consumer behaviour, sustainable consumption and behavioural change that I deem important in the process of understanding the future electricity prosumers and that have been widely used to explain environmental behaviours. This presentation is not exhaustive. For an extended review on motivating sustainable consumption see Jackson, 2005 (Jackson, 2005).

3.2.1.1 Adjusted expectancy-value theory

The **Theory of Planned Behaviour** (Ajzen, 1991) is considered an example of an adjusted expectancy-value theory (Jackson, 2005). It uses the basic idea of rational choice theory, i.e.: choices are made based on the outcomes of the choices and the value attached to those outcomes, but also includes elements of affective and moral antecedents of behaviour only to the extent that these elements are modelled as beliefs or evaluation of specific actions. The behaviour is determined by the individual intention to perform it. In turn, the behavioural intention is driven by attitudes, subjective norms and perceived behavioural control (Figure 3.1). *Attitudes* towards a given behaviour depend on the *beliefs* about and *evaluation* of the outcomes of that behaviour and depend on the weighing of various costs and benefits, in terms of time, money, effort and social approval. *Subjective norm* refers to the perceived social pressure to perform or refrain from that specific behaviour. The subjective norm is constructed as an individual belief about what other people who are important to me think of that specific behaviour, rather than the individual personal belief about the behaviour (referred to as personal norm) (Jackson, 2005). *Perceived behavioural control* refers to people's perception of their ability to perform a given behaviour; it originates from self-efficacy theory that claims that expectations such as motivation, performance, feelings determine effects and behavioural reactions. The theory of planned behaviour is one of the most influential attitude-behaviour model in social psychology, thanks also to the fact that the model is expressed in a mathematical equation that can be easily used to carry out empirical studies.

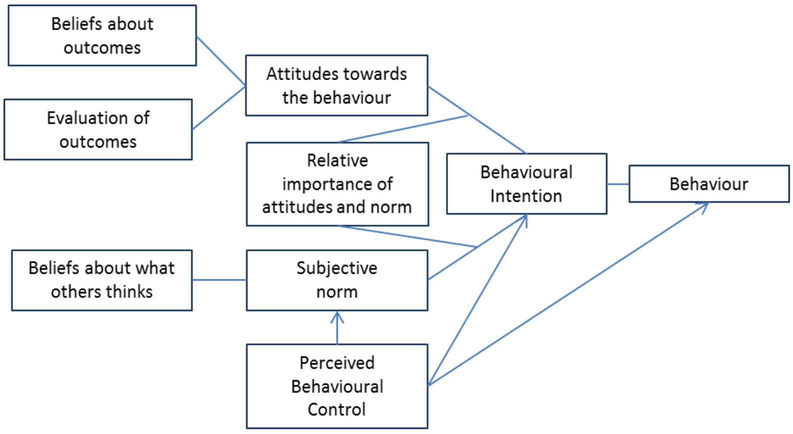


Figure 9. Theory of Planned Behaviour, (adapted from (Jackson, 2005))

The theory of planned behaviour has been widely applied to the understanding of behaviour in a vast range of different contexts and it has been most frequently used in literature to explore pro-environmental behaviour (recycling, travel mode, food choice, water conservation) and energy conservation (, green electricity consumption (Litvine *et al.*, 2011); intention to generate own power (Leenheer *et al.*, 2011); sustainable energy technology acceptance (Huijts *et al.*, 2012); household direct and indirect energy use and savings (Abrahamse *et al.*, 2009); smart meter diffusion (Zhang *et al.*, 2011)). However, the theory of planned behaviour remains an adjusted expectancy-value theory that incorporates normative influences on individual consumers through the concept of subjective norm. Moral behavioural antecedents can be included only if they are modelled as attitudinal beliefs about the outcome or evaluation of the outcome of specific actions.

Some attempts to adjust the theory of planned behaviour to incorporate moral beliefs have shown that the inclusion of moral beliefs improves the predictive power of the theory in areas where pro or anti-social dimensions of behaviour are relevant (Jackson, 2005).

3.2.1.2 Moral and Normative Conduct

The **Norm Activation Theory** proposed by Shalom Schwartz in 1977 is one of the most widely applied models of moral behaviour. It considers pro-environmental behaviour as a form of altruistic behaviour, since individuals have to give up personal benefits to satisfy collective interests (i.e: the environment) (Abrahamse *et al.*, 2009). The theory is founded on the idea that personal norms, that is to say feelings of strong moral obligation that people experience for themselves, are the only direct determinants of pro-social/altruistic behaviours (Jackson, 2005) (Abrahamse *et al.*, 2009). Behaviour in accordance with personal norms may lead to a sense of pride while behaviour not in accordance with personal norms may lead to a sense of culpability. According to the theory, personal norms are activated by two antecedents: awareness of the consequences of one's action on the environment and feeling of responsibility for these behavioural consequences (Figure 3.2). First, a person needs to be aware of the consequences that their behaviour may have on the others and on the environment (*awareness of consequences*). Then, a person needs to feel personally responsible for these behavioural consequences (*ascription of responsibility*). The relationship between personal norm and behaviour is stronger in the case where people are aware of the negative consequences and feel personally responsible for these negative consequences. In the case where one is unaware of negative consequences and denies responsibilities the link is weaker. The norm activation theory has been successfully applied to a range of pro-environmental behaviours such as recycling (Bratt, 1999) car use (Bamberg *et al.*, 2003), water conservation (Harland *et al.*, 1999)and energy conservation (Steg *et al.*, 2005; Abrahamse *et al.*, 2009).

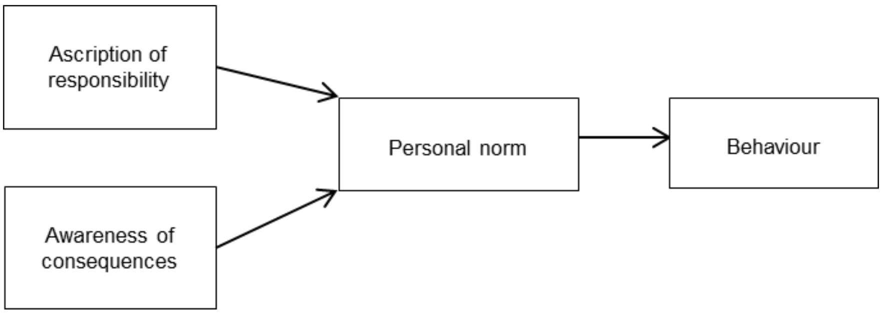


Figure 10. Norm Activation Model (Schwartz, 1977)

Research shows that norm activation model seems to be successful in explaining low-cost environmental behaviour, but appears less effective when the behavioural settings are characterized by strong constraints on behaviour, e.g. when the behaviour is too costly in terms of effort, money or time (Steg *et al.*, 2005). An adaptation of Schwartz's theory is proposed by Paul Stern and colleagues (Stern *et al.*, 1999) (Stern, 2000). They propose the **Value-Belief-Norm theory**. The theory postulates that environmental behaviour results from pro-environment personal norms, i.e. a feeling of moral obligation to take pro-environmental actions (Figure 3.3). These personal norms are activated by beliefs that adverse consequences threaten things that the individual values (*awareness of consequence for valued objects*, AC) and beliefs that the individual can act to reduce this threat (*ascription of responsibility to self*, AR). The value-belief-norm theory proposes that awareness of consequences and ascription of responsibility beliefs are dependent on general beliefs on human–environment relations (e.g.: the new environmental paradigm (NEP) whiting which human activity and a fragile biosphere are seen as inextricably connected) and on relatively stable value orientations. Typically, three general value orientations are distinguished: an *egoistic* value orientation, where people try to maximize individual outcomes, an *altruistic* value orientation, reflecting concern for the welfare of other human beings, and a *biospheric* value orientation, reflecting concern with non-human species or the biosphere. *Self-enhancement* (egoistic) and *self-transcendent* (altruistic and biospheric) values seem to be particularly relevant to understand beliefs, preferences, attitudes, norms and behaviours in the environmental domain (Venhoeven *et al.*, 2013). The stronger the biospheric and altruistic values, the more likely the person will accept the new environmental paradigm; the stronger the egoistic value, the less likely the person will accept this paradigm. The causal chain proposed in value-belief-norm theory moves from relatively stable and general values to beliefs about human–environment relations (NEP). These beliefs about human-environment relations lead to awareness of the environmental consequences of one's actions and this in turn leads to awareness of one's responsibilities to reduce those consequences. Based on this, the person develops a personal norm to engage in pro-environmental actions (Steg *et al.*, 2005) (Jackson, 2005).

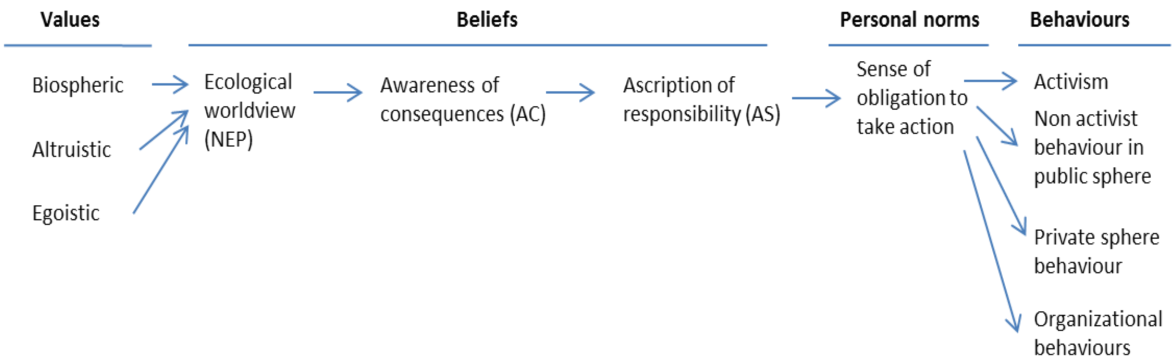


Figure 11. Value-Belief-Norm Model (adapted from (Stern, 2000))

Stern explicitly acknowledges that behaviours may result from multiple motives. Different value orientations may coexist in the same individual and may be differently prioritized according to the specific social context. Stern argues that individual behaviour derive from the set values that receive attention in a specific context.

The argument that individual behaviour stems from saliency of specific contextual values finds support in the **Theory of Normative Conduct** developed by Cialdini (Cialdini *et al.*, 2006) that addresses the influence of social context on personal conduct. According to this theory two kinds of norms exist: *a descriptive norm* that refers to what perception we have of what is normal in a given situation; an *injunctive social norm* that explicitly reflects the moral rules and guidelines of the social group. Injunctive norm tends to motivate and constraint our action through the promise of social rewards or sanction (Jackson, 2005). The effect of social norm in guiding individual behaviour has been demonstrated in recent research on energy conservation. Allcott (Allcott, 2011) demonstrated that the use of comparative electricity bills that employs injunctive social norm - conveying the message that energy conservation is pro social - affect consumer behaviour. The study demonstrated that non price-intervention can substantially and cost-effectively change consumer behaviour.

3.2.1.3 Goal Framing Theory

With new insight from motivational and social psychology theory, Steg (Lindenberg *et al.*, 2007) introduces the **Goal Framing Theory** which postulates that "*goals govern or "frame" what people attend to, what knowledge and attitudes become cognitively more accessible, how people evaluate various aspects of the situation, and what alternatives are being considered*" ((Lindenberg *et al.*, 2007)p. 119). This theory proposes that environmental behaviour is guided by three overarching goals: hedonic goals, gain goals and normative goals. Hedonic goals lead individual to focus on ways '*to feel better right now*' such as avoiding effort, seeking direct pleasure or seeking excitement. Gain goals lead individual to focus on '*improving resources*' such as money and status. Normative goals lead people to focus on '*acting appropriately*' and make them particularly sensitive to what they think ought to be done, such as contributing to a clean environment or showing appropriate behaviours. Goal framing theory suggests that one goal is strongest in a particular situation and mainly influences preferences and decisions, while the other goals are in the background and influence the strength of the focal goal. Values determine the likelihood that a particular goal is strongest in any situation, as they influence the extent to which goals are chronically accessible. This implies that normative goals to act appropriately are more likely to be strong in a particular situation when people strongly endorse altruistic or biospheric values, while gain goals are more likely to be central when people strongly endorse egoistic values. Steg et al. further suggest (Lindenberg *et al.*, 2007) that it may be useful to distinguish two types of *self-enhancement* values to understand environmental beliefs, attitudes, norms and actions as well, namely, *egoistic a*nd *hedonic values*. There is research that supports the importance to distinguish between these two types of self-enhancement values. Studies in the Netherlands, Japan, Indonesia and Mexico validated the distinction between hedonic, egoistic, altruistic, and biospheric values indicating that hedonic and egoistic values form distinct value clusters. Hedonic and egoistic values were found to be correlated and this is in line with the value typology proposed by Stern (Stern, 2000), as both reflect self-enhancement values. Recent research indicates that it is important to include hedonic values in studies on environmental beliefs, preferences, norms and actions (Steg *et al.*, 2014). In line with the Goal Frame Theory, Steg et al. (Steg *et al.*, 2014) further propose a theoretical framework, the **Integrated Framework for Encouraging Pro-Environmental Behaviour** that suggests two basic strategies to encourage pro environmental actions: the first strategy focus on reducing the conflict between hedonic and egoistic goals on one hand and normative goals on the other end; the second strategy focus on strengthening normative goals, therefore weakening the relative strength of hedonic and gain goals. Though the first strategy is important when pro-environmental behaviours are costly, it may lead to not sustained pro-environmental actions since people are likely to act pro environmentally only as long as it is pleasurable and profitable to do so (e.g.: drivers receiving a premium when they practiced a safe and environmentally friendly driving style; keeping speed limit was promoted by gain goals and not by normative goals. However, when the premium is not anymore available, drivers will revert to the old driving style). On the other hand, strengthening normative goals can encourage pro environmental actions even when these actions can be somewhat costly. Normative considerations are predictive of pro-environmental beliefs, norms and actions and that individuals are prone to engage in pro-environmental actions even though this may be costly and require effort. Steg et al. (Steg *et al.*, 2014) argues that the strength of normative goals depends on which values people endorse as well as on situational factors/cues (that it to say, situational cures that activate or deactivate different types of values)that activate and support the accessibility of these values.

3.2.2 Sociality and the self

Many of the social-psychology models discussed in the previous section assume an individual approach to consumer behaviour. However, evidence shows that humans are very often constrained by what other think, do and say. Some social theories suggest that our behaviours and attitudes are socially constructed. For example Giddens (Giddens, 1984) argues that consumption behaviours can be viewed as a set of "social practices" that are influenced on one hand by social norms and lifestyle choices and on the other by institutions and structure of society. Giddens suggests a distinction between "practical" and "discursive" consciousness. Practical consciousness is the everyday commonly accepted knowledge that people use to do things, while discursive consciousness is "*what actors are able to say or to give verbal expression to, about social conditions, including especially the conditions of their own action*" (Giddens, 1984). Evidence suggests that intentional or goal-oriented behaviours require elaboration in discursive consciousness. These kinds of theories signal the social embeddedness of environmentally significant behaviour. They also suggest that behavioural change must occur at the collective, social level. This insight is important in devising strategies to change habitual behaviours. Indeed, individual oriented strategies may not be sufficient. In this context, Shove (Shove, 2010) makes a strong case for going beyond what she defines as the dominant paradigm of 'ABC' – attitude, behaviour and choice – where behaviour is considered to be shaped by causal factors and external drivers and argues in favour of social theories of practice that emphasise endogenous and emergent dynamics where people are carriers of "practices".

Individual strategies answer the need of the consumers to increase their hedonic (e.g.: in term of comfort) or egoistic (e.g.: in term of saved money) well-being (*hedonic well-being*, e.g. feeling pleasure). However, as argued by some authors, pro-environmental (biospheric) and pro-social (altruistic) behaviour can also be a source of well-being (*eudaimonic well-being*, e.g. feeling meaningful) by providing a sense of meaning in life, of self-actualization in "doing good". It is important to convince people that their behaviour is right and meaningful, and stimulate people to choose this behaviour of their own free will (Venhoeven *et al.*, 2013). Environmental campaigns centered more on people's feelings, instead of exclusively appealing to their calculation are considered an important and unexploited route to encourage pro-environmental behaviour (Taufik *et al.*, 2016).

In this context, recent streams of research are investigating ways to activate consumer's response by leveraging more on collective dynamics (feeling meaningful), shifting from an individual approach to energy management to a "collegial" one where consumers are seen and approached in their social context. Growing attention is given to strategies to promote active participation of end-users at community level, and to the role that communities can play in the future electricity system (Dóci *et al.*, 2015) (van der Schoor *et al.*, 2015) (Anda *et al.*, 2014) (Alvial-Palavicino *et al.*, 2011).

3.2.2.1 The concept of homophily

The exchange of ideas and information occurs most frequently between two individuals that are similar or "homophilus". Homophily as defined by Rogers (Rogers, 1983) "*is the degree to which pairs of individuals who interact are similar in certain attributes, such as beliefs, education, social status, and the like. In a free-choice situation, when an individual can interact with any one of a number of other individuals, there is a strong tendency for him to select someone who is most like him-or herself*". The homophily principle that "similarity breeds similarity" influences networks ties leading to homogenous networks with regards to values, goals, behaviours and interpersonal characteristics (McPherson *et al.*, 2001). However, Steffes et al. (Steffes *et al.*, 2008) point out that tie strength between individuals and homophily, though related, are separate constructs. While homophily refers to similarities of characteristics of individuals in relationships, tie strength is a property of the relationship itself. Individual generally have a wide range of relationship ties, ranging from strong ties (e.g.: close friends, family members, etc.) to weak secondary ties (e.g.: acquaintances). It is argued that weak ties can be critical to the dissemination of information between tightly woven strong tie clusters. Research has shown that homophily and social ties have powerful implications in the way people behave, form their attitudes, interact with each other and make decision. However, it is argued that more research is needed in particular to explore the dynamics of network change over time through which networks and other social entities co-evolve (McPherson *et al.*, 2001) and to assess the influence of social ties and homophily on consumer sustainable behaviour adoption. In Chapter 4 and 5 I will explore how homophily and other form of social ties can influence energy consumer choices.

I will borrow from the theories that I have here presented in developing the framework for the electricity prosumer that I will present in Chapter 4 and Chapter 5.

3.3 Electricity consumer characterization: empirical evidence from EU surveys and DSM projects

3.3.1 Introduction

As I have already argued in the previous sections, the smart electricity grid, through the incorporation of information and communication technologies, will enable the bi-directional communication and power exchange between suppliers and consumers, transforming the traditionally passive end-users into active players. In this context, consumers' habits and daily routines and the social and cultural context in which they act become key elements for the successful deployment of smart electricity grids.

In the traditional electric power system, the customers have been "disengaged" from the upstream side of the electricity meter as the technology did not allow for any interaction between the consumer and the power supplier (Sioshansi, 2011). The transition to the new paradigm will require, along with the technical transformation of the grid, a cultural change in the way end-users interact with the power system. The role of consumers is among the biggest challenges of the smart grid dilemma, as consumers have their own and diverse needs and priorities that may not be aligned with what experts and engineers expect. There is therefore a need to understand the consumers in order to develop strategies to motivate and involve them in the future electricity system. This process is tightly related with the evolution of the electricity networks. Empowering consumers to manage their electricity consumption, while enabling them to actively contribute to the operation of the distribution network, requires taking full advantage of the capabilities of smart grid technologies (Mengolini *et al.*, 2013).

In many Member States, the energy saving potential is one of the stronger drivers towards the adoption of smart meters. The deployment of intelligent metering systems and other enabling technology, however, will not deliver the expected results unless consumers are involved at the early stage of any smart grid initiative. Smart metering systems are tools to enable consumers' active participation in the energy market and to promote system flexibility through demand response schemes and other innovative services. It is the consumer's use of the smart measurement infrastructure - and not the infrastructure in itself - that can lead to energy savings in the use of the electric devices and improve in this way system efficiency.

Consumer engagement strategies need therefore to be developed for consumers to successfully assume their new role as active participants in the electricity system. Reluctance to the installation of the smart metering technology or even its mere passive acceptance will not help to realize the predicted benefits; it is necessary to move from technology acceptance to technology support.

In the last few years, the number of studies aimed at exploring and understanding consumers' awareness, perceptions and concerns of smart grid technologies has been increasing (Noppers *et al.*, 2016) (Diaz-Rainey *et al.*, 2008; Krishnamurti *et al.*, 2012; Mah *et al.*, 2012) (Goulden *et al.*, 2014) (Hast *et al.*, 2015) (Pothitou *et al.*, 2016). These studies generally acknowledge the positive attitude of consumers towards smart grid technologies but they also recognize the need to address erroneous beliefs and misconceptions that still exist about these new technologies and to strive for trust, transparency and feedback to gain consumer involvement and acceptance. A few studies have focused specifically on the deployment of smart metering systems and on the factors that can promote or deter acceptance of the new technology (Krishnamurti *et al.*, 2012) (Alabdulkarim, 2013) (Chou *et al.*, 2014) (Park *et al.*, 2014) (Pothitou *et al.*, 2016).

Research has shown that consumer preferences may also be bounded by *social* and *cultural issues*. For example a recent study on consumers' attitudes towards green energy in China and their willingness to buy green electricity or renewable energy systems shows that energy savings and energy security were most often chosen as motivations for buying green energy and environmental reasons were less frequently chosen, though these were recognized as benefits of buying green energy (Hast *et al.*, 2015). Similar studies in the US (DeCicco *et al.*, 2015) reports instead that consumers do not favour energy affordability on environmental concerns, showing that consumers are concerned about the impact of energy on the environment as they are about its affordability. Studies on energy consumption feedback have shown that while feedback is both necessary and valuable it is not sufficient to bring about changes in behaviours. Such a limited approach fails to consider broader social and cultural influences on household energy use. For example, ethnographic research conducted in comparable houses shows energy consumption differences of up to 300% (Karlin *et al.*, 2015) (Hargreaves *et al.*, 2010; Gram-Hanssen, 2011); this underlies the importance of the people in the home and the social aspects of their energy use (Hargreaves *et al.*, 2010). Research on the impact of knowledge about environment and energy issues on potential pro-environmental behaviours (Pothitou *et al.*, 2016) has shown a significant correlation between environmental values and knowledge and energy savings. Furthermore, household energy savings appear to be linked to gender and employment status.

All these studies further demonstrate how *individual values* as well as *social and cultural aspects* influence energy consumption and highlights the *complexity of the energy issues*. Energy issues can be not only difficult to manage technically, but in some contexts difficult to manage socially and politically since they present diversity of perspectives that can fragment and complicate energy decision-making (Sovacool *et al.*, 2016). Research grounded on theories of social practice has pointed out that smart energy system practices (in the specific smart homes) are shaped by both "horizontal" (between household members and between different households) and "vertical" (between household and service providers) relationships with other actors involved in the smart energy production and consumption. These relationships and information flows may produce unpredictable and emergent practices that deserve further exploration (Naus *et al.*, 2014). It is in and through energy practices that the relationships between actors are consolidated or become more configured (Shove, 2010).

Having presented the most relevant social psychology theories in the previous section, in this section I will provide an overview of the attitudes, preferences and concerns of European consumers, as presented by European surveys, pilot projects and comparative studies. The analysis presented is an elaboration of the activities performed by JRC within the H2020 AnyPlace project (AnyPlace H2020 Project, 2015).

3.3.2 Consumer's attitudes, preference and concerns: evidence from EU surveys

Several surveys and initiatives have been carried out at European level to understand the attitudes, preferences and concerns that drive the energy consumption behaviour of European consumers. An overview of the findings (in terms of the exploration of "awareness, understanding and attitudes towards active demand", "attitude and behaviours towards energy efficiency and active demand" and "attitudes and preferences towards smart metering systems") of the surveys carried out within three different projects – *Advanced, E-balance and USmartConsume*r – is presented in Table 3.1. Not all Member States are covered, but the surveyed countries are representative of different geographical areas and can give some useful information on the general trends occurring at European level

.

	Advanced	E-balance	USmartConsumer
	Awareness, understanding and attitudes towards active demand	Attitudes and behaviours towards energy efficiency and active demand	Attitudes and preferences towards smart metering systems
	Quantitative sample	Quantitative sample	Quantitative sample
DE	1001		496
ES	1000		173
FI			138
FR	1002		
IT	1007		315
NL	1001	1647	
PL	1004	1632	154
PT		1661	
SE	1006		
UK	1000		270

Source: Advanced, E-balance, USmartConsumer

Table 1. Overview of initiatives exploring consumers' energy consumption attitudes and behaviours

In all surveys *quantitative research tools* - such as structured interviews or questionnaires - are used to explore different aspects of consumer's energy consumption behaviours. In some cases the use of quantitative tools has been complemented by the use of *qualitative tools* - such as focus groups or semi structured or open interviews – to get a deeper understanding of the motivations and drivers for behavioural change in energy consumption. As shown in Table 1, the scope of the quantitative surveys changes slightly from project to project. In this section I will briefly present the main findings from these European surveys (carried out within the context of these three EU projects) on consumer attitudes and concerns.

The **Advanced** project focused on the interaction between consumers and technology and on consumers' level of awareness, understanding and attitudes towards active demand. The quantitative research was based on an online survey carried out in eight European countries involving over 8,000 consumers (Advanced FP7 Project, 2015). Some interesting findings that can be useful in identifying consumer's attitudes and preferences are the following:

- ✓ Consumers are still not well aware of their electricity consumption;

- ✓ Saving money is the main driver for paying attention to energy consumption at home;
- ✓ Data privacy is still a concern for many consumers.

The E-balance project investigated consumers' needs, requirements, and concerns to assess the preliminary potential of the E-balance approach, unveil possible obstacles, and determine consumers' requirements to be mapped into their business model. The findings of the online survey launched in three Member States (Poland, The Netherlands and Portugal), are consistent with those highlighted by the Advanced project:

- ✓ For the vast majority of consumers the most important driver for the acceptance of the new technology is the reduction of electricity bills and the control over their electricity bill;
- ✓ The main consumers' concerns are the perceived cost-effectiveness of the solution, the amount of involvement needed to use the system effectively and privacy issues.

Finally, the **USmartConsume**r project took a slightly different angle. The aim of their market survey was to understand consumers' wishes and how they will behave if they are given the right tools and information. The findings regarding the level of consumers' awareness of their electricity consumption and consumers' main attitudes and concerns towards the new technology are in line with the literature and with the results presented by the Advanced and E-balance projects namely:

- ✓ Control over electricity bills and the reduction of electricity bills are still the main drivers of consumers' interest for the new technology;
- ✓ Data security and privacy are main concerns, in particular data abuse by third parties.

The USmartConsumer project also investigated consumers' preferences regarding feedback solutions and the way smart meter data are presented. The findings showed that websites, tablets, mobile applications and In-Home Displays (IHD) are the favourite feedback tools in all countries, but there are strong differences among them. Detailed paper invoices (letters) do not seem to appeal the consumer.

Concerning feedback visualization, most consumers prefer having smart meter data presented in several ways, for a better comprehension (e.g.: table and numbers, charts, etc.)

The three studies analysed shed some light on consumers' attitudes, preferences and concerns. Table 1 provides an overview of the main findings grouped into four main categories, i.e. attitudes that drive consumers' behaviour (feedback information), the channels and devices used to deliver smart meter data (feedback solutions), the way this information is presented to the consumers (feedback visualization) and the main consumers' concerns.

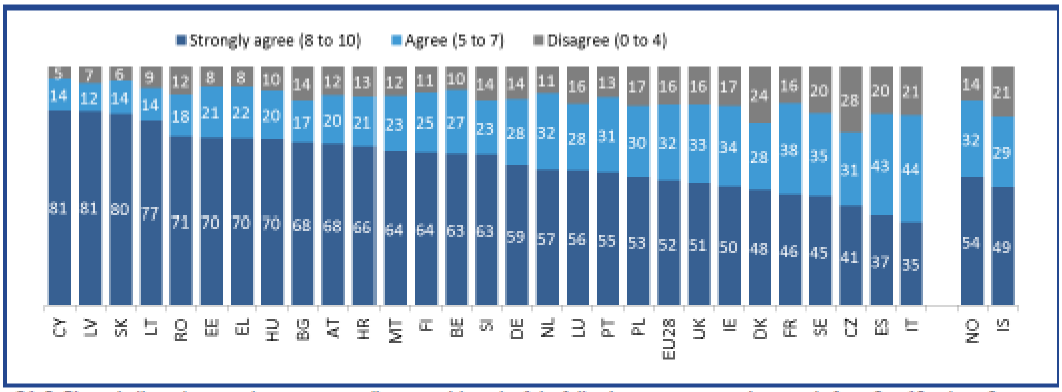
	Surveyed aspects	Findings
Feedback information (consumers' attitudes)	- monetary - environmental - social responsibility	Monetary saving is the most important driver for most of the countries
Feedback solutions	- web portal - smartphone/tablet - IHD - letter	High interest in web portal, IHD and smart app. Low interest in text messages and paper format
Feedback visualization	- tables and numbers - charts	Smart meter data need to be presented in several ways for better understanding
Consumers' concerns	- privacy and security - loss of control - change in comfort level	Privacy and data security are still major concerns

Table 2. Summary of findings from European surveys

The results of the surveys however should be taken with some caution, as the respondents' answer is influenced by a variety of circumstances, e.g. national circumstances, the survey sampling methods and the way the questions are formulated. In some cases the respondents interviewed have never seen a smart meter or a feedback interface: the risk of misunderstanding by the respondent is thus high, even if the survey provided an explanation.

In this context, it is important to mention the ongoing effort at EU level to investigate if a well-functioning electricity market is in place for consumers in the EU and to assess how the performance of retail electricity markets for consumers has developed in the recent year. A study on these questions has been recently released: "*Second consumer market study on the functioning of the retail electricity markets for consumers in the EU*" (European Commission, 2016e). Part of the study is specifically dedicated to survey consumer's awareness, attitudes and experiences with electricity services and uses.

More specifically, the study assesses the awareness of EU consumers of "*how much they pay for their electricity"* (Figure 12). It emerges that across EU28, 52% of respondents said that they know how much they paid for electricity. However a variation is visible among countries in Europe, where in country as Italy and Spain a considerable lower level than in Slovakia, Lithuania and Cyprus is observed.

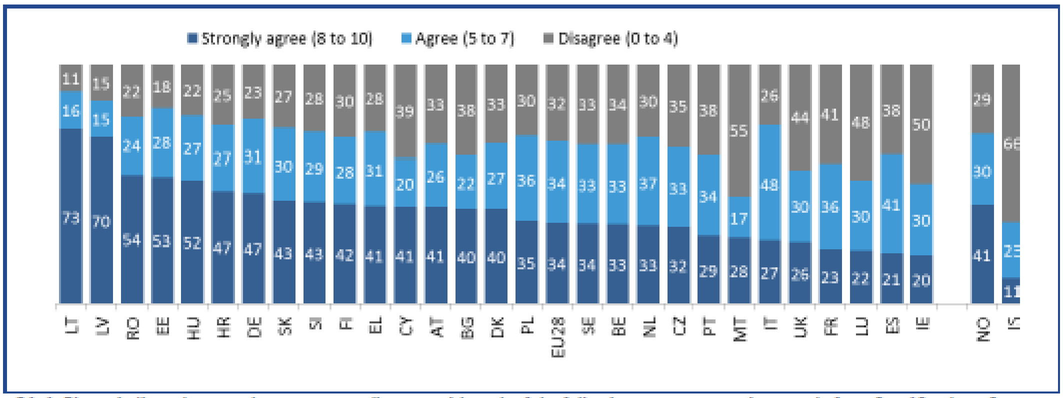


Q1_2. Please indicate how much you agree or disagree with each of the following statements, using a scale from 0 to 10, where 0 means that you "totally disagree" and 10 means that you "totally agree". "I know how much I pay for electricity (per month, year or any other frequency)"
%, by country, Base: all respondents

Source: *Second consumer market study on the functioning of the retail electricity markets for consumers in the EU (European Commission, 2016e)*

Figure 12. Agreement with the statement: "I know how much I pay for electricity (per month, year or any other frequency)", by country

In addition, the study also assesses consumer awareness of "*how much electricity they use*" (Figure 13). In this case a larger variation across countries is observed in the proportion of respondents who answered that they were aware of how much electricity they used**.** It appears that consumer's awareness of their electricity consumption in term of KWh is lower than monetary awareness.

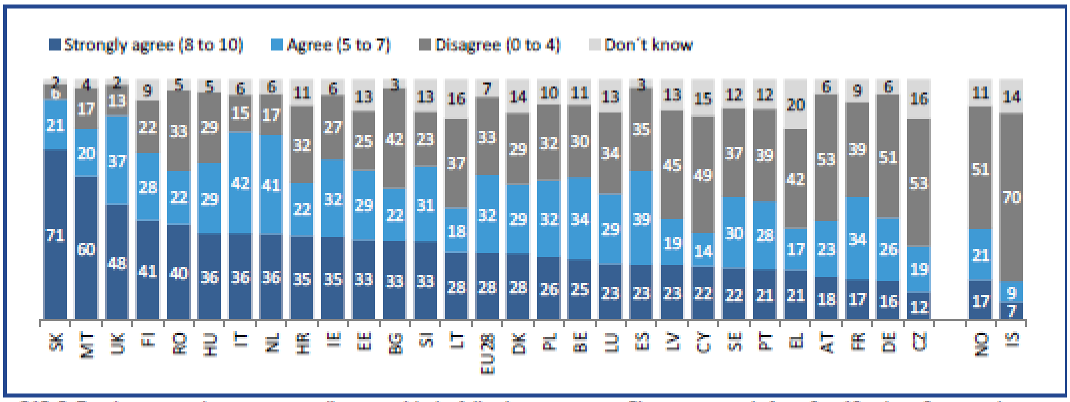


Q1_1. Please indicate how much you agree or disagree with each of the following statements, using a scale from 0 to 10, where 0 means that you "totally disagree" and 10 means that you "totally agree". "I know how much electricity I use (per month, year or any other frequency) in kWh"
%, by country, Base: all respondents

Source: *Second consumer market study on the functioning of the retail electricity markets for consumers in the EU (European Commission, 2016e)*

Figure 13. Agreement with the statement: "I know how much electricity I use (per month, year or any other frequency) in KWh", by country

The study also investigates consumer's awareness of smart metering infrastructure: "*I am aware of smart meter and* what they do" (Figure 14).



Q15_3. To what extent do you agree or disagree with the following statements. Please use a scale from 0 to 10, where 0 means that you "totally disagree" and 10 means that you "totally agree": I am aware of smart meters and what they do

Source: *Second consumer market study on the functioning of the retail electricity markets for consumers in the EU (European Commission, 2016e)*

Figure 14. Agreement with the statement: "I am aware of smart meters and what they do", by country

It emerges that awareness of smart meters is low in most Member States. Across the EU28, 33% of respondents disagreed with the statement "I am aware of smart meters and what they do" and further 7% replied with a "Don't know" response. The study goes further on smart metering analysis, presenting a case study on smart meters that illustrates that smart meter deployment should be accompanied with appropriate data visualization systems, to ensure that the consumer receives customized feedback on their energy use. This case study will be further explained in Chapter 4.

From the studies presented till know I can draw the conclusion that consumer's awareness on electricity use and smart electricity system enabling technologies is not uniform across Europe. A significant numbers of consumers do not know much about their electricity use and on the potentiality of smart metering infrastructure. This affects the decisions they make regarding their electricity contract or in making savings.

In the next section I will enrich the findings coming from surveys; in particular I will provide an overview of how consumer engagement strategies are increasingly being employed in EU DSM pilot projects with the results of some pilot projects carried out in Europe.

3.3.3 Consumer's attitudes, preference and concerns: evidence from EU DSM projects

Demand side management pilot projects provide an important means to see what works and what doesn't in real-life experiences. To build on this vast knowledge base I analysed some of the projects included in the JRC database, which to date represents the most comprehensive and updated database of smart grid projects in Europe. Since 2011 the JRC has monitored the state of the art of smart grid projects in Europe with a view to assess current developments and draw lessons learned. The first comprehensive inventory of smart grid projects was published in July 2011 (Giordano *et al.*, 2011) and its updates were released in 2013 (Giordano *et al.*, 2013) and in 2014 (Covrig *et al.*, 2014). The inventory has proved to be an important instrument to monitor the direction Europe is taking, to benchmark investments and to accelerate the innovation process.

In this section I explore some of the projects in the database to see how consumers' issues have been tackled, what lessons I can learn from these experiences and how these lessons can be integrated with the results of EU surveys presented in section 3.3.2. The analysis presented below is based on the smart grid projects presented in the JRC Reference report "Smart Grid projects in Europe: lessons learned and current developments", 2011 (Giordano *et al.*, 2011). It is an elaboration of the work published in the peer reviewed article " *Consumer engagement: An insight from smart grid projects in Europe*" (Gangale *et al.*, 2013), conference paper "*Enabling consumer engagement in the future electricity networks*" (Vasiljevska *et al.*, 2013) and in the JRC Scientific and Policy Report "*The social dimension of Smart Grids*" (Mengolini *et al.*, 2013)

3.3.3.1 Consumer engagement in EU demand side management projects

Out of the 281 projects present in the JRC 2011 catalogue those with a main or secondary focus on consumer engagement were singled out and approached with a more specific questionnaire. The aim was to collect additional information on key aspects of customer engagement, to identify the main activities being undertaken and to identify possible future challenges in consumer engagement. I acknowledge the relatively small number of projects with a focus on consumer engagement. However, though limited, the analysis presents an overview of the trends at European level on consumer engagement in smart grid projects. Moreover, this small number is in itself a finding that indicates that more work is needed in order to include and better understand the focal role that consumer engagement plays for the success of the smart grid paradigm.

3.3.3.1.1 Methodology: survey design and data collection

The projects included in the catalogue annexed in the JRC Report (Giordano *et al.*, 2011) were thoroughly screened to identify and analyse those with a focus on consumer engagement. I considered both projects where consumer engagement represented the only objective and projects where it represented only a stage of a larger initiative. At the end of the screening process, 65 projects out of 281 were identified as having a focus on consumer engagement. A questionnaire was distributed to the respective project coordinators to gather more detailed information about the projects' objectives, targeted sectors, motivational factors, successful strategies and obstacles to consumer engagement. The analysis of the projects revealed that projects involving consumers are characterized by the pursuit of two main objectives: gaining deeper knowledge of consumer behaviour (*observing and understanding the consumer*) and motivating and empowering consumers to become active energy customers (*engaging the consumer*). These two objectives are strongly interrelated and many projects pursue both of them simultaneously. Clearly, the observation of consumer behaviour is of paramount importance for the design of any project aiming at engaging the consumer, but it is also key to its success, as it enables the fine-tuning of the engagement strategy to the reactions of consumers.

The screening of the selected projects highlighted some recurring activities employed by project's coordinators; these can be summarized according to the two following objectives:

Objective 1: Observing and understanding the consumer:

- ✓ collecting information on consumption patterns, needs and consumer experiences;
- ✓ exploring consumer response to new regulatory, technical and market solutions (e.g.: response to dynamic tariffs, automatic control schemes, smart metering);
- ✓ identifying consumer segments and early adopters.

These actions are central in gaining insight on consumer behaviour and in evaluating the technical and financial feasibility of smart grid investments, the obstacles to their development and their potential economic and environmental advantages.

Objective 2: Engaging the consumer:

- ✓ providing information to consumers about newly introduced smart technologies/applications;
- ✓ providing information about energy consumption;
- ✓ investigating strategies aimed at behavioural change.

These actions are more focused in interacting with consumers, building understanding and trust and finding the best way to engage them in the long run.

It is worth noting that in some cases, the same activity can contribute to the attainment of both objectives. ‘Providing information about energy consumption’ is one example. On the one hand it contributes to understanding the consumer by enabling the observation of his/her response to new regulatory, technical and market solutions. On the other hand, through the use of marketing techniques, it becomes a crucial tool in the engagement strategy to turn the consumer into an active energy customer.

The questionnaire further asked project coordinators to report the main activities carried out in their project (among those detailed under objective 1 and 2 above or by proposing different ones). Very few project coordinators suggested different activities, and these were all variations or specifications of the ones presented in the provided list.

38 project coordinators out of the 55 that were contacted answered to the questionnaire. The results of this survey have then been processed and analysed to identify the main trends and developments in the field of consumer engagement in smart grid projects in Europe. Even if the number of projects included in this analysis is still limited, they represent about 70% of all projects with a consumer engagement focus reported in the JRC catalogue, 2011. The following section summarizes the main findings.

3.3.3.1.2 Main findings

General findings

The analysis of the results of the questionnaire provides some interesting general findings that can be summarized in the following main points:

Increasing number of consumer engagement projects

Over the years, the number of consumer engagement projects has been increasing (Figure 15). In particular, many new projects started in 2010 and 2011. The share of projects with a focus on consumer engagement over the total number of projects in the JRC catalogue rose from 17% in 2010 to 32% in 2011.

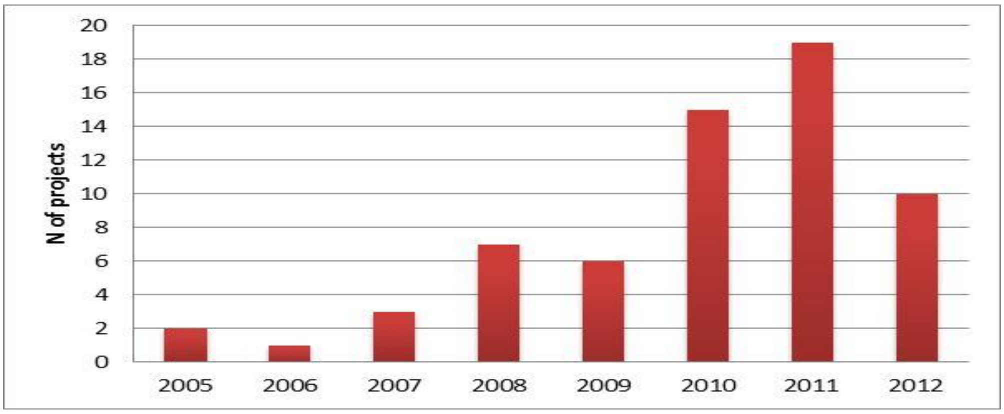


Figure 15. Number of projects with a focus on consumer engagement

Importance of public funding to support consumer engagement project

Projects studying and testing consumer engagement concepts and dynamics are of crucial importance to validate smart grid solutions. Energy utilities and private investors however are not prone to invest in consumer engagement projects, as the uncertainties relating to the response of consumers to the new technical, regulatory and market solutions, heavily affect their business case. Changes in consumers' behaviour are hard to predict, reducing confidence in estimates of long term benefits (International Energy Agency, 2011). Research & development and demonstration activities in this field are therefore more likely to be carried out when co-funded by public authorities or when provided with incentives through regulatory schemes. Over 75% of the projects that answered to the survey have received some sort of funding. About 20% are co-funded by the European Union.

Strong focus on the residential sector

Almost all consumer engagement projects in this analysis (36 out of 38) indicated a focus on the residential sector. In addition, commercial/public services and the industrial sector were simultaneously targeted by 47% and 24% of the projects, respectively. The predominance of the residential sector can be explained by the need for energy providers to target household consumers. Large in number and dispersed in location, residential consumers represent a huge potential for energy efficiency that energy providers can tap into. The consumer engagement projects in this analysis are mainly energy efficiency programmes focusing on behavioural change, dynamic pricing programmes and electric mobility programmes.

Leading organizations in consumer engagement: DSO and Energy Companies

Challenged by the need to integrate increasing shares of variable renewable and distributed energy sources while ensuring the security of the electricity system, Distribute System Operators (DSOs) are inherently interested in enhancing flexibility through energy efficiency and dynamic pricing projects which improve customers' responsiveness. Consumer engagement lies at the very heart of the success of these projects. Not surprisingly, DSOs have started developing projects aimed at getting to know consumers' preferences and behaviours and the impact of their choices on systems' operations. The majority of the consumer engagement projects in our survey are led by DSOs/energy companies (73%) as shown in Figure 16.

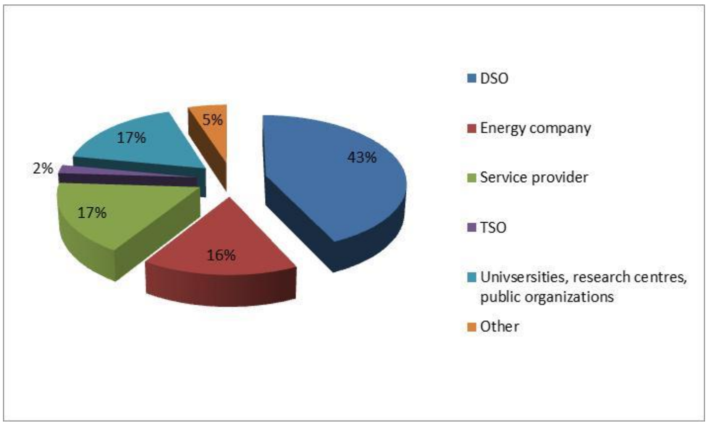


Figure 16. Leading organisations of consumer engagement projects

3.3.3.1.3 Specific findings: projects' objectives and activities

Observing and understanding the consumer

Observation and understanding of consumer behaviour are of crucial importance to elaborate effective strategies for consumer engagement. Most of the projects in the catalogue have a strong observation component, which revolves around three activities: exploring consumer response to new regulatory, technical and market solutions; collecting information on consumption patterns, needs and consumer experiences; and identifying consumer segments and early adopters. This observation component is mainly directed towards understanding consumers' response to new solutions and the values driving this response.

Exploring consumer response and consumption patterns

The observation of consumer response to newly introduced mechanisms and technical solutions is essential for the exploration of their viability as well as their impact on the energy system. Many projects aim at observing consumer reaction to the provision of detailed information on energy consumption and source. Some of them go a step further and explore consumers' response to dynamic pricing and other incentive programs. The concept of consumers actively participating in the energy system by adjusting their load to varying prices is new and project developers are eager to deepen their understanding of consumers' responses mainly by collecting data on real-time consumption.

For example, in the *EcoGrid EU project*, consumers participate with flexible demand response to real-time price signals. The participants are equipped with residential demand response devices/appliances using gateways and "smart" controllers. Installation of the smart solutions allows real-time prices to be presented to consumers and allow users to pre-program their automatic demand-response preferences, e.g. through different types of electricity pipe contracts. "Automation" and customer choice are key elements in the project.

Another interesting group of projects with a strong observation component deals with electric mobility. Electric vehicle (EV) projects are largely in the early phases of exploration as electric mobility is still a very new area. The number of EVs currently on roads is rather limited, hence limited data and experience regarding their performance, impact on the grid and customer preferences and expectations are available. To fill these gaps, the projects in this analysis aim at exploring not only the performance and impacts of vehicles under various (more technical) conditions but also at exploring consumers' behavioural patterns, in particular driving and charging patterns and preferences. In the *Mini Berlin project*, for instance, there are 50 Mini E cars on the street with public access to charging points. The EVs (Mini E) function as energy storage capacity to help balance the grid during periods of high energy feed-ins by renewable energy sources. The project aims at testing the interaction of electric vehicles under everyday conditions and explores the performance of EVs not only from the technical point of view but also through the observation of user's patterns and preferences.

The two main groups of tools used in our projects to investigate consumer behaviour and interaction are advanced metering infrastructure (AMI) - allowing the collection of detailed, real-time information on energy consumption/usage - and consumer interfaces, such as in-home displays (IHDs), web portals, smart phone applications or displays installed in EVs. The provision of information about real time energy consumption, source and price of electricity as well as on driving and charging possibilities is a crucial aspect. The idea is that, having easy access to price and usage data, consumers can make informed and responsible choices concerning their consumption and use.

Consumer segmentation

Besides being used as a means to explore consumer responses, consumer observation has also been used in our projects to take the pulse of consumers, to assess the market and to identify consumer segments and early adopters. Market research has been largely used as an observation means to assess consumers' willingness to save energy, to shift energy use and to adjust to flexible prices, and in general to assess the willingness to engage in an energy-related program. Market research has equally been used to investigate the values that underpin consumer choices. In order to truly understand the consumer, energy providers need to know not only what consumers do, but why they do it. Understanding the values that influence consumer choice, as discussed in the previous sections, is of paramount importance for segmentation of consumers on the basis of non-traditional factors, like attitudes and motivations associated with energy usage (for example environmental awareness, willingness to save money etc.). This sort of analysis will enable project developers to draw conclusions for the development of targeted and effective service offerings (Accenture, 2010a). More generally, customer segmentation along non-traditional factors enables the power industry to maximize customers' level of participation and ensures the design of programmes that are truly beneficial to targeted customers (Gangale *et al.*, 2013). Market research, in the form of surveys or interviews, has been used by several projects in our catalogue as a research tool to analyse consumers' preferences, attitudes and motivations to participate in a programme and to better structure future engagement activities. However, for the most part, the results of these analyses have not yet been included in the projects' engagement strategies.

What needs to be stressed here is that, while surveys can be a very useful means of investigation, real-life behaviours can diverge considerably from the statements made in a survey. How people respond in surveys and how they behave in real life can often be two different things, especially when the behavioural change involves higher bills. A recent IBM study on smart energy consumers, for example, mentions the difficulty of obtaining an accurate barometer of consumers' ultimate uptake of green programmes by simply surveying consumers' interest in green programmes. The complexity derives from the observation that, although many participants express interest in green power, they act in ways that indicate the likelihood that they would eventually not be willing to pay for it (IBM Global Services, 2009) (Smart Grid Consumer Collaborative, 2011b). Moreover, when investigating consumer response in the residential sector, it should also be kept in mind that the actual response to the new technical solutions will depend on the complex interactions between the different members of the households and not on the single individuals included in the survey. Domestic energy consumption is more of a social and collective process than an individualised one (Hargreaves *et al.*, 2010) as discussed earlier in section 3.3.1.

In sum, most of the projects in the JRC catalogue have a strong observation component. Most of them focus on exploring consumer response to innovative regulatory, technical and market solutions (76%) as well as on collecting information on consumption patterns, needs and user experiences (74%). Many projects have started attempting to segment consumers along non-traditional factors, but these efforts are still only at the research level and have, for the most part, not yet been included in the projects' engagement strategies.

3.3.3.1.4 Engaging the consumer

The path to successfully turning the consumer into an active energy customer revolves around the concept of engagement.

Provision of information

A first necessary step towards consumer engagement is raising awareness and providing information about newly introduced smart technologies or mechanisms. Provision of information on green energy is recognized by some authors as crucial for the success of the green energy market (Diaz-Rainey *et al.*, 2008). In the projects discussed here, this is mainly done by means of brochures, energy consultancy services and fairs.

Development of tailored tools and strategies

Following the delivery of this information to customers, the next steps involve exploring ways of securing continuous consumer engagement by means of tailored tools and strategies. In order to change consumer behaviour, consumers need to be aware of their energy use, understand its impacts on the environment and on energy security, and realize the potential for energy and money savings. Generally, the amount of energy use and its impact on the system are largely abstract concepts and for most consumers, especially in the household sector, it may be difficult to link these values to daily energy-using activities (Burgess *et al.*, 2008). The provision of information about energy consumption/usage and source therefore becomes a crucial aspect of any engagement strategy. To achieve consumer engagement, however, the installation of the enabling infrastructure (smart meters, in-home displays) and provision of detailed information alone will not be sufficient. Recent studies suggest that whilst feedback is both necessary and valuable, it is not always sufficient to bring about changes in behaviour as it fails to acknowledge broader social and cultural influences on household energy use (Hargreaves *et al.*, 2010; International Energy Agency, 2011). To actually trigger behavioural change, energy providers need to build confidence and trust and leverage consumer motivations and values putting them at the centre stage of their engagement strategies. It is important to note that successfully engaging the consumer involves iterative rather than consecutive phases, where continuous observation of consumer response allows adjusting the engagement strategy to the feedback obtained. Following an iterative process, project developers in the JRC catalogue have started to develop diversified strategies to find the best way of presenting information to consumers - and possibly to different consumer segments - and observe their reactions to fine-tune them.

For example, the *Ewz-Studie Smart Metering, Zurich* aims at simultaneously assessing the response of consumers to different ways of engaging them, including in-home displays, expert advice, social competition and social comparison. Individual surveys before, during and after the trial allow assessment of consumer response and consumer satisfaction. The *Consumer to Grid Project* aims at testing and measuring behavioural change induced by different feedback means, monthly bills, a smart phone optimized website, in-home displays and an ad-hoc feedback gadget. Behavioural change is assessed by means of data verification (smart meters), questionnaires and interviews.

Many projects focus on one feedback solution only, typically in-home displays, but investigate the importance of using complementary means to engage the consumer. In some cases, in-home displays were coupled with visual recalls such as stickers, magnets, and energy consumption visualization gadgets, which proved to be effective engagement tools. In the *ESB Smart Meter Project* for example, results showed that fridge magnets and stickers achieved 80% recall, with 75% of users finding the magnet useful and 63% finding the sticker useful.

Some projects, also investigate the role of games in promoting awareness and engaging consumers. The *BeAware* - Boosting Energy AWAREness Project uses a system, EnergyLife, which uses wireless sensors and a smart phone to turn energy consumers into active players. This system is based on two pillars: awareness tips and consumption feedback. Awareness tips aim at increasing consumers' knowledge of the consequences of their electricity consumption while consumption feedback makes the actual energy consumption visible to users in terms of the distance to the selected saving goal. In particular, in order to engage the consumer, the EnergyLife system uses an attractive rationale where the pursuit of the savings goal follows a game-like rationale: awareness and consumption are expressed in scores; goals are divided into sub-goals and consumption are expressed in scores connected to different levels of the game, so that the fulfilment of the objective on one level gives access to a higher level; higher levels have greater difficulty and richer functionalities. Finally, knowledge is tested through quizzes and improved through tips, thus further enhancing awareness (Jacucci *et al.*, 2009).

Moreover, the saving activity can be discussed with others participating in the same program, which further reaffirms the importance of social norms information in energy (Allcott, 2011) and of the collective dimension of energy use. Indeed, feedback about individual performance relative to others has proven to be a more powerful non-price intervention to engage the consumers (Allcott, 2011). A comparative feedback may evoke feelings of competition, social comparison and social pressure that may be especially effective when relevant others are used as a reference group (Abrahamse *et al.*, 2005).

In sum, though over 70% of the projects are trying to involve consumers by providing them with information, much less of them (40%) are already actively developing a social marketing strategy for consumer engagement, or investigating ways to best present this information to the consumer. The present findings however seem to indicate an increasing effort among energy providers to search for innovative methods to change the way the electricity commodity is perceived and to build a more consumer-centric relationship with their customers.

3.3.3.1.5 Challenges and success strategies

There are a number of challenges and successful strategies to overcome the difficulties highlighted by project coordinators of the surveyed consumer engagement projects in Europe. Two points most frequently referred to as critical are: i) lack of trust by consumers, and ii) uncertainties regarding the use of different motivational factors.

Trust

Building trust among consumers is a crucial step to overcome consumer resistance to new technical, regulatory and market solutions and to successfully engage them in any (energy related) projects. Trust is a pre-requisite for consumers' cooperation and goodwill. It determines the ability of dialogue and discussion and promotes active involvement of stakeholders (Alvial-Palavicino *et al.*, 2011). When people know little about a technology, as it is argued to be for smart grid technologies (Krishnamurti *et al.*, 2012), acceptance may mostly depend on trust in the actors responsible for the technology (regulators or owners of the technology); trust in actors that are responsible for the technology generally increases acceptance (Huijts *et al.*, 2012). According to a study carried out by the Smart Grid

Consumer Collaborative in the USA, customer goodwill provides a foundation for successful programmes, minimising pushback and increasing customers' receptivity to smart grid initiatives. Utilities that have worked to establish customer goodwill in anticipation of their programmes have faced the fewest issues (Smart Grid Consumer Collaborative, 2011a). Some studies conducted in the USA and UK (IPSOS Mori, 2009; Accenture, 2010b; Accenture, 2010a) have highlighted that consumers do not have much confidence and trust in their electricity providers. For example, the 2009 Consumer Conditions survey in the UK (IPSOS Mori, 2009) which ranks how different markets are perceived by consumers to be performing in terms of their transparency and in generating consumer confidence – lists the electricity and gas markets as the most poorly rated markets. This observation seems to be confirmed by the results of the present analysis, as the need to overcome the lack of consumer trust and confidence was explicitly emphasized by many of the projects surveyed as one of the main challenges.

Many project coordinators reported a high level of scepticism and wariness. Customers tend to seek relationships with more mutual trust and commitment and tend to be less sceptical when trusted organizations or figures, perceived as neutral, are involved in the project. Drawing on this observation, a number of projects started building direct and personal contact with the consumer, using a combination of means ranging from information letters to one-on-one scheduled appointments. Many projects also started approaching customers with an organization or person of trust, i.e. a 'door opener'. Resorting to trusted parties to offset consumers' mistrust has proven to be a successful strategy in several projects included in this study. Examples from our survey include the involvement of representatives of housing associations (*Pilot Project Markisches Vier*tel), consumer associations (*EcoGrid EU*) and local authorities (*Address, eTelligence*). This approach has been identified as a successful one also in other projects outside Europe. The Smart Grid Consumer Collaborative study highlights that very positive results were achieved by those projects that partnered with trusted community groups and persons able to promote messages and programmes to large networks (Smart Grid Consumer Collaborative, 2011a). I will further articulate the importance of trust in section 4.

Motivational factors

As we already pointed out in section 3.2, understanding the values that influence consumer choice is of crucial importance to segment consumers on the basis of non-traditional factors, like attitudes and motivations associated to energy usage. These factors play a fundamental role in actually triggering behavioural change, and are increasingly being used by energy providers as motivational incentives to stimulate consumer engagement and promote their smart grid projects. The results of the survey revealed that the motivational factors commonly used by smart grid projects in Europe are: i) the reduction of/control over electricity bills; ii) environmental concerns, and iii) better comfort, i.e. the provision of technological solutions allowing the optimization of comfort and more control over own energy use (Figure 17). Most of the projects in the present analysis actually combine more than one motivational factor, usually environmental concerns and reduction of electricity bills. This result highlights the fact that electricity providers are not yet targeting single consumer segments, but are approaching consumers as a whole, trying to appeal to them with a combination of different motivational factors.

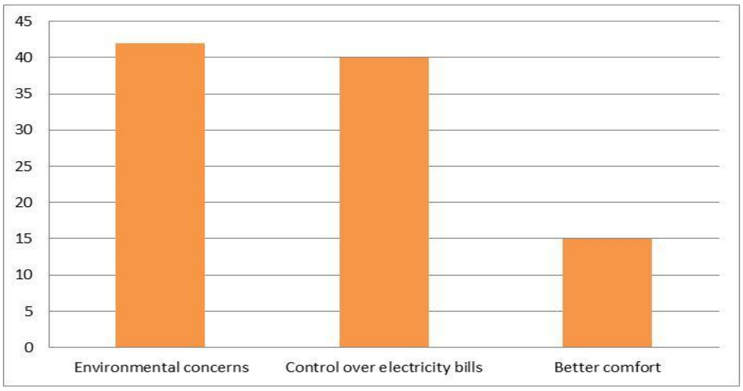


Figure 17. Motivational themes

Reduction of/control over electricity bills

71% of project coordinators specified approaching consumers with the motivational theme 'reduction of/control over electricity bills', indicating the potential of lower electricity bills for consumers. Rising energy costs have made customers more and more sensitive to electricity bill savings. According to the Smart Grid Consumer Collaborative report, messages promoting monetary savings (cost reductions) have broad appeal and have proven more effective in the US at driving participation in energy-related programmes than other messages, at least in untargeted campaigns (Smart Grid Consumer Collaborative, 2011a). Whether this consideration is true also for European customers is unclear. The majority of projects in the present survey are still on-going and limited final results are available. Five project coordinators however, explicitly stated that the economic benefits achievable through behavioural change *are insufficient to motivate consumers to engage* in the project or to maintain the motivation over time. This consideration might further explain the resort to more than one motivational factor at the same time: to trigger and sustain consumer engagement other motivational incentives are also needed.

Furthermore, the difficulty a number of project coordinators have voiced in relation with the motivational theme 'lower electricity bills' is the uncertainty about whether consumers will actually be able to experience those benefits. The danger here is that consumers who will not achieve the expected savings, notwithstanding their behavioural change, might consider the whole experience disappointing and frustrating (Hargreaves *et al.*, 2010). This reaction would constitute a major blow to the consumer engagement process and could severely damage any sort of trust that may have already been established. For this reason it is not sufficient to simply advertise/communicate potential benefits to customers. Proof and assurance that customers will actually experience those benefits equally needs to be provided. This is a difficult communication task and a good way to tackle it could be to involve consumer groups that would act as 'watchdogs' and reassure the consumer about their benefits (Lineweber, 2011).

Environmental concerns

Concerns about the consequences of energy use on the environment and on climate change are growing and messages that refer to these topics have started to resonate with the average consumer (IBM Global Services, 2007). Several studies have highlighted that environmental considerations are becoming an important variable of consumers' choices. A consumer survey by IBM, for example, found that 70% of surveyed consumers stated environmental considerations to be an important factor in choosing energy, as well as other products (IBM Global Services, 2009). Another recent survey confirms that, while consumers consider reliability of supply and tariffs important, they equally place high value on broader environmental and social issues (Ngar-yin Mah *et al.*, 2012).

Nevertheless, some studies emphasize that environmental concerns alone are not enough to engage untargeted consumers. A survey by Accenture (Accenture, 2010b) reveals that the average consumer places a lower relative weighting on environmental impact when deciding to adopt an electricity management programme, compared to other motivational incentives. Similarly, the Smart Grid Consumer Collaborative Report highlights that messages about non-economic benefits, like environmental stewardship, are serviceable with certain segments but have not proven as effective as economic messages in untargeted campaigns (Smart Grid Consumer Collaborative, 2011a). These studies are not specific to the European market and the extent to which their conclusions can be applied to European customers is unclear. The present survey shows that electricity providers' leading consumer engagement projects in Europe consider environmental concerns to be an appealing motivational factor, as it was used by 71% of the projects. About 50% of them, however, used it in combination with reduction of/control over electricity bills, indicating somewhat of a lack of confidence in its effectiveness when used alone in untargeted initiatives.

Better comfort

The motivational factor least referred to by the projects resulted to be better comfort, i.e. the provision of technological solutions allowing the optimization of comfort and more control over own energy use. This factor was used in 45% of the projects but only in one of them was it used alone. The consumer segment, which this factor could most appeal to is that of technology enthusiasts, i.e. consumers who have an interest in the technology itself, either for professional reasons or because it represents 'another gadget' (Hargreaves *et al.*, 2010). Better comfort refers to the use of advanced technology to control and manage electricity use. One main concern about the use of this motivational factor expressed by our project respondents is the limited impact that such targeting would have on other consumer segments.

3.3.3.1.6 Conclusions

The analysis of this DSM pilot project sample reveals some interesting general and more specific findings. General findings indicate an increasing focus on consumer engagement in European smart grid projects, the importance of public funding to support consumer engagement projects, a strong focus on the residential sector and the leading role of DSOs.

Concerning more specific findings, the analysis of objectives and activities characterizing the selected projects reveals a strong focus on observation, highlighting the widespread need to increase knowledge of consumers, to understand their reactions and the drivers of their behaviour. Many projects in the JRC catalogue focus on collecting information on consumption patterns, needs and user experiences and on exploring consumer response to innovative regulatory, technical and market solutions. A number of projects have also started attempting to segment consumers along non-traditional lines, but these efforts are still only at the research level and have not yet been included in the projects' engagement strategies.

While many projects are trying to involve consumers by providing them with information, fewer have reached the stage of investigating ways to best present this information to the consumer and of actively developing social marketing strategies for consumer engagement. The present analysis, however, seems to indicate an increasing effort among energy providers to search for innovative methods to change the way the commodity electricity is perceived and to build a more consumer-centric relationship with their customers. In this regard, most project representatives indicate that successful strategies for consumer engagement need to be focused on building trust and confidence among consumers.

Having provided a general overview of how consumer engagement strategies are increasingly being employed in EU DSM pilot projects, I will now proceed with a more specific analysis of the kind of feedback solutions, feedback information and feedback visualization are used in DSM pilot projects, providing some examples from successful projects.

3.3.3.2 What feedback for the energy consumer: feedback solutions, information and visualization

Consumers' responsiveness to demand-side reduction interventions varies according to a variety of different factors, e.g. demographic, behavioural and situational factors, and it is deeply influenced by the technology used and by the strategies adopted to engage the consumers. Some studies have pointed out that energy use in identical homes can vary up to 250-300%, indicating that the behaviours of the occupants have strongly impact the overall energy use (Karlin *et al.*, 2015) (Hargreaves *et al.*, 2010) (Gram-Hanssen, 2011) . One promising intervention that may promote consumer behavioural change is the provision of feedback to individual or groups about their energy use. *Feedback* refers to the process of providing people with information about their behaviour that can have the effect of reinforcing and/or modifying future behaviours. Feedback is considered an important dimension of behaviour change and has been used in many fields (Karlin *et al.*, 2015) (Hargreaves *et al.*, 2013). Karlin et al. (Karlin *et al.*, 2015) carried out a meta-analysis of research on the effects of feedback on energy conservation; they found significant evidence that feedback is an effective strategy for promoting energy conservation behaviour in particular when it is combined with goal-settings or external incentive interventions. Based on the assumption that information is key to behavioural change, smart metering technologies can encourage consumers to become more aware of their energy consumption – i.e. how much energy they have been using and ideally on what uses - and possibly change their energy-related behaviours. As discussed in section 3.3.2, very often people have only a vague idea of how much energy they use for different purposes and what kind of difference they could make by changing their day-to-day behaviour.

In order to increase consumers' awareness and promote behavioural change, it is necessary to provide consumers with detailed and accurate information on their energy use. To this aim the mere installation of the smart meter might not suffice. In many pilot projects the installation of the smart meter is accompanied by the installation of a user interface, mainly an In-Home Displays (IHD), to explore and maximise consumers' response to different kinds of feedback and signals. Other **feedback solutions** – e.g. websites, ambient displays, informative billing – have also been used, often in combination with one another.

Providing accurate **feedback information** however is not enough to trigger consumer response. In order to make consumers change behaviour it is important to understand and meet their motives. As discussed in section 3.3.3.1, the pilot projects in the JRC database show that consumers' attitudes and beliefs are increasingly being used by energy utilities to motivate consumers to engage with smart grid technologies.

Finally, smart meter data need to be presented in an easy to understand and engaging way (e.g.: numbers, tables, charts, etc.). Pilots have tried different **feedback visualization** tools and strategies to find the best way to trigger and maintain consumers' response.

In this section, I will provide examples of how these challenges have been met by different pilot projects in Europe and will review the solutions which seem to have been most successful in engaging consumers. In particular, I will analyse the measures taken to get consumers' attention, motivate them to take action and finally change their behaviour in the long term. To assess the success of a measure I will try to refer to the quantitative results achieved through them; in case quantitative results are not available I will focus on the qualitative results. The analysis presented hereafter is an extract and elaboration of the activities performed by JRC within the H2020 AnyPlace project (AnyPlace H2020 Project, 2015) and is based on an updated version (2014) of JRC database (Covrig *et al.*, 2014).

By looking at some representative pilot projects, and taking stock of the findings of European surveys (section 3.3.2), I will try to address the following questions that will help me shedding more lights on attitudes and preferences of electricity consumers:

- Which feedback solutions are most used? Which ones are the most effective?
- What kind of feedback information is needed to engage the consumer?
- What are the best ways to visualize feedback information to consumers?

3.3.3.2.1 Feedback solutions

There are several feedback solutions available, with different characteristics and impacts on consumer's behaviour. Some solutions are easy to implement, carry little information and normally require a more active participation from the consumer's side, e.g. informative billing. Some others are more complex and technologically advanced, make more information available to the consumer at the time when it is needed and make the consumer interaction easier, e.g. web portals, in-home displays, ambient displays, TV, etc. Which solution is more effective is still open for discussion, and it is a subject that several pilot projects in Europe are investigating.

As most pilot projects often test different feedback channels in combination with one another, it is difficult to tie changes in behaviour to specific interventions. Furthermore, behavioural change depends not only on the measures adopted but also on how they are delivered. Projects in the JRC database (Covrig *et al.*, 2014) have tested different solutions to deliver smart meter data and have shed some light on their effectiveness with European consumers.

Among the different feedback channels and devices used, the ones which have been most commonly tested by the projects in the database are:

- *Web portals*: a web portal allows the consumer to access smart meter data via his/her computer, smart phone or tablet;
- *In-Home Displays* (IHDs): devices that show smart meter data and that can also support additional functions and information. They can widely vary in complexity, from simple wall-mounted displays to touchscreens;
- *Informative billing* (paper): more frequent (generally monthly) and accurate invoices giving advice and information on the household's energy consumption with the aim of increasing consumer awareness.

The **EDRP project**[3] for example, used both IHDs and web based services. The web applications were used to provide advice, billing information and historic feedback, delayed by one day (not real-time feedback). The project showed that, when combined to the installation of a smart meter, IHDs are more effective in engaging consumers and influencing their electricity consumption behaviour than web-based services. While providing an IHD allowed savings which were generally 2-4% higher than with a smart meter only (with a full range of 0-11% for some periods and customer groups), the web based services did not show any effect on consumption (Raw *et al.*, 2011). The trials that tested the web-based service solutions showed that a major reason for failure is likely to be a lack of engagement with the web sites, not necessarily a lack of effect among those who did use the sites. Although web interventions were unsuccessful in EDRP, the project highlighted that information on the web could work for consumers more engaged with such forms of information and particularly if they receive tailored information, including real-time feedback and online audits (Raw *et al.*, 2011).

The effectiveness of different feedback channels was studied also by an Austrian project, **Consumer to Grid** (C2G)[4]. The project aimed at testing and measuring behavioural change induced by different feedback means, i.e. monthly bills, a smartphone optimized website, in-home displays and ad-hoc feedback gadget[5]. The results of the year-long trial showed no significant reduction in energy consumption that could be clearly tied to one of the tested feedback channel. Compared with the

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[3] The **Energy Demand Research Project** (EDRP) was a suite of large scale trials across Great Britain to test consumers' responses to different forms of information about their energy use. Four energy suppliers (EDF, E.ON, Scottish Power and SSE) each conducted trials of the impacts of various interventions (individually or in combination), involving over 60,000 households, including 18,000 with smart meters. The interventions used were primarily directed at reducing domestic energy consumption, with a minority focused on load shifting. The trials began in 2007 and finished at the end of 2010.

[4] **Consumer to Grid** (C2G) is an Austrian project that aimed to test and measure behavioural change induced by different feedback means. Behavioural change was assessed by means of data verification, questionnaire and interviews. The project started in July 2010 and ended in December 2012. 288 households participated to the trial, 73 of which received an annual energy statement; another 73 received monthly billing, 72 had access to a web portal, 30 had an IHD installed and 40 received Wattson Energy Monitors. The trial involved also a control group of 68 households with a yearly bill. During the projects there were some drop-outs, mostly due to the relocation of the test subjects, leaving the projects with 249 participants.

[5] A commercial product that delivers real-time feedback based on current-transformer measurements.

previous year, the average reduction in electricity consumption across all groups (including the control group with a standard yearly bill) was 6.7 %, with a minimum value of 2.5 % and a maximum value of 10.9 %. Due to the high level of variance, these savings were not sufficiently separable from each other statistically (Smart Grids Model Region Salzburg, 2013). Even if the trial could not accurately measure the behavioural change associated to different feedback means, it was however successful in highlighting some interesting dynamics of the interaction between consumers and the new technology. One interesting finding of the project is that the constant and physical presence of a feedback solution - as in the case of an IHD – can act as a reminder to use the feedback, supporting consumers' interaction and response. IHDs reduce any extra effort required to access electricity-use feedback from a cognitive standpoint (no need to remember) but also from a logistics standpoint (no need to turn on the computer) (Smart Grids Model Region Salzburg, 2013). The consumers involved in the C2G project increased their level of awareness about electricity consumption, and this awareness spread also to related fields (e.g. sustainable mobility) which were not a direct target of the feedback. This new awareness led them to change their patterns of consumption, but their engagement and interest in the feedback decreased over time. This loss of interest might be explained by the fact that after the introductory phase, residential customers experience very little increase in knowledge and cost savings (Smart Grids Model Region Salzburg, 2013). One way to prevent or minimise this trend and maintain consumers' interest over the long term could be to provide additional functionalities besides the consumption feedback, e.g. through tailored advice, prompts or challenges.

Several projects in the JRC database (Covrig *et al.*, 2014) focused on one feedback solution only, typically web portals or IHDs, but they investigated the importance of using complementary means to engage the consumer. In some cases, the main user interface was coupled with visual recalls such as stickers, magnets, and energy consumption visualisation gadgets, which proved to be effective engagement tools. In the **ESB Smart Meter Project**[6] for example, results showed that fridge magnets and stickers achieved 80% recall, with 75% of users finding the magnet useful and 63% finding the sticker useful (Gangale *et al.*, 2013).

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[6] The aim of the **ESB Smart Meter Project** is to help stakeholders understand how information, incentives and new services supported by smart meters could best help customers manage their use of electricity. The trial includes the installation of in-home displays and aims to determine the best technology option for the ESB's smart metering deployment.

Feedback solutions - Recommendations

- Several feedback solutions are possible, each one with different characteristics and impacts on consumer behaviour. However, constant and physical presence of a feedback solution - as in the case of an IHD – seems to have the potential to act as a reminder to use the feedback, supporting consumers' interaction and response.
- Effective engagement solutions require consumer segmentation and tailoring to the different segments' attitudes and needs. In particular, web based service solutions seem to work better with consumers more engaged with such forms of information, particularly if they receive tailored information, including real-time feedback.
- In order to maintain consumers' interest over the long term, additional functionalities besides the consumption feedback (e.g. through tailored advice, prompts or challenges) could be provided.

3.3.3.2.2 Feedback information

A smart meter can provide key data and a user interface can present that information to the consumer in an easy-to-understand and engaging way. Many pilot projects have confirmed that in order to trigger consumer response and maximise the impact of feedback, information needs to match the motives of the consumers. These findings are consistent with the literature, which confirms that acceptance of and engagement with the new technology is affected by a variety of factors, among which consumers' motives play an important role (Huijts *et al.*, 2012) (Alabdulkarim, 2013) (Abrahamse *et al.*, 2011). Consumers' behaviour is driven by a variety of motives and it is therefore important to understand them and to address them with a tailored and effective information strategy. Empirical evidence from a meta-analysis of experimental studies (Delmas *et al.*, 2013) indicates as commonly used information strategies: environmental concerns (conservation strategies), monetary savings (monetary information) comfort (i.e. the provision of technological solutions allowing the optimization of comfort) and more control over own energy use.

Projects in JRC database (Covrig *et al.*, 2014) are aligned with these findings (Gangale *et al.*, 2013) and use a variety of information strategies to motivate the consumer to engage with smart grid technologies. Amongst the different motivational factors, economic savings/more control over electricity bills appears to be the most used. Rising energy costs have made customers more and more sensitive to electricity bill savings. However, increasing research in sustainable energy consumption argues that the economic benefits achievable through behavioural change are insufficient to motivate consumers to engage with smart grid technologies (Delmas *et al.*, 2013). Moreover, the uncertainty about the actual reduction in the electricity bill can lead to disappointment and frustration in case the expected savings are not achieved. This consideration might explain the employment of more motivational factors at the same time; in order to trigger and sustain consumer engagement other motivational incentives are also needed. In particular, strategies that provide information to the consumers on the environmental effect of their energy consumption activities are increasingly seen as effective to promote sustainable behavioural change and are increasingly being used by energy utilities to motivate consumer to engage with the smart grid technologies.

In several projects in the JRC database (Covrig *et al.*, 2014), as discussed in section 3.3.3.1, the motivational factor 'reduction of electricity bills/control over energy use' is used in combination with environmental concerns. In some projects environmental and economic motivations are combined with comfort issues and social welfare. As argued in section 3.3.3.1, this finding highlights the fact that electricity providers are not yet targeting single consumer segments, but are approaching consumers as a whole, trying to appeal to them with a combination of different information strategies(Gangale *et al.*, 2013). It also implies that in many cases it is difficult to tie changes in behaviour to specific interventions as most projects use more than one strategy at a time.

In the **eTelligence project**[7] two different motivational factors were employed to engage consumers: CO_2 emission reduction (environmental) and reduction of energy bill (economic savings). The project tested the saving and load shifting potential of residential consumers using customer-specific tariff incentives and real time feedback. In particular, the event tariffs are based on T*ime of Use* (ToU) combined with bonus or malus events; *bonus events* occur when there is abundance of energy available; *malus events* occur when electricity consumption is unusually high and there is little energy available. The price range in these events can vary from 0.0 €/kWh to 0.8 €/kWh. The project results show that on average, electricity consumption was reduced by 11% with the real-time visualisation, which corresponds to lower costs and lower CO_2 emissions. However, the project shows some interesting findings concerning the potential of economic incentives as drivers. In some cases of malus events with extremely high prices, there was a decrease of consumption of around 20% in the time period of the event while in bonus events with free electricity there was an increase in consumption of up to 30% within the period of the event. It may be concluded that the incentive to use more electricity when prices are low is significantly more effective than the incentive to refrain from using electricity when prices are high. If all tariff events are viewed as a whole, more electricity was used in total over the entire period of events than would have been the case had there been no events (eTelligence FP7 Project, 2014). It can be argued that in case of high electricity prices, other drivers than the economic one could play a role in directing people to reduce energy consumption.

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[7] **E-Telligence** is a German project which explores various approaches of using modern ICT and advanced operation to improve the current energy supply system and to enable broad integration of renewable energy sources like wind, photovoltaic and biomass. In this context, the savings potential and load shift potential in private energy use were investigated in 650 households.

In the **EDRP**[8] project, consumers were equipped with user interfaces that provided them with live data on energy consumption (kWh and cost) and with information such as CO_2 emissions and energy consumption over specified periods. Customer surveys conducted to assess the customer appreciation of the interface functionalities showed that cost information was used and valued more than energy unit information (kWh). Interestingly, the display of information over CO_2 emissions was generally not noticed or used or perceived as useful (Raw *et al.*, 2011). This finding does not necessarily mean that monetary information are more effective that conservation strategies. It can be argued that CO_2 emissions are not the most effective environmental information to engage the consumer in energy conservation behaviour.

Another interesting element highlighted by the EDRP project is the need to find the right balance in the quantity of information supplied to the consumer. It is important to avoid information overload. For example, regular small pieces of information appear to be more effective than a single delivery of comprehensive information.

Feedback information - Recommendations

- Well-designed information strategies can contribute to consumer engagement and may induce behavioural change. However, attention should be paid to tailoring the feedback information to different consumers' segments.
- Feedback information other than economic/monetary information can help to engage different consumer segments and to maintain consumers engaged over time.
- It is advisable to avoid information overload. Regular nuggets of information seem to be more effective than single extensive and comprehensive information.

3.3.3.2.3 Feedback visualization

The visualization of information on energy consumption is seen as a key element in engaging the consumer. Some authors consider visualization as a means for overcoming the energy's so called invisibility: energy can neither be seen, nor easily associated to every day routines (Burgess *et al.*, 2008) (Hargreaves *et al.*, 2013). Feedback visualization solutions can help to make energy visible to consumers through the provision of various kinds of feedback, thus supporting consumers in changing their energy related behaviour.

As discussed above, IHD, smart energy monitors, web portals or smart apps represent the most typical physical interface between the consumer and the smart meter. They can provide real-time feedback to householders about their energy consumption and use and the associated CO_2 emission,

[8] See footnote 5.

enabling them to monitor and manage their energy consumption in order to save money and reduce their carbon footprint (Hargreaves *et al.*, 2013). However, it is argued that there is still a surprising lack of understanding or empirical evidence about how feedback from visualization tools will be used by consumers and how it will be translated into changed consumption patterns that are durable over time (Hargreaves *et al.*, 2013).

Likewise, discussion is open about what visualization features are likely to be most effective at encouraging behavioural change (Anderson *et al.*, 2009). Several research and pilot projects are investigating the ways consumers engage with different feedback visualization and the value to the users of different types of functionalities. The key questions to consider in the design phase of the visualization tool relate to the kind of information that can trigger consumers' reaction and behavioural change and to the best way of presenting them. Several possibilities are available, with different levels of complexity and required consumer interaction.

The information presented by the feedback solution for example can be quantitative (e.g. current or historic consumption[9]) or qualitative (e.g. consumption exceeding a set level) and could include a variety of options, for example warning lights, audible alerts and tips and tricks to save energy. Consumption levels can also be expressed in several ways, e.g. in kWh, in Euro or in avoided CO_2 emissions. Their historic trend can also be visualized in different forms, e.g. using tables or different kinds of charts. In this regard, several projects highlighted that units of energy consumption, like the kWh, are not easily understood by consumers, while their conversion in money spent/saved offers an effective and straightforward alternative for consumers.

The level of complexity of the visualization tool is an important issue especially for IHDs and web applications. Establishing the ideal balance of complex functionality and simple, attractive products is one of the main challenges to address in the design phase. The user-friendliness of the interaction application must be considered as an essential requirement to avoid the risk of deterring users who lack the confidence to interrogate the device. Also, combining different visualization features can help in appealing to different consumer segments, but it is important to keep the interaction simple. This is

[9] Regarding historical feedback in particular, pursuant to Directive 2012/27/EC on energy efficiency, consumers who have been provided with meters installed in accordance with Directive 2009/72/EC, shall have the possibility of easy access to complementary information on historical consumption allowing detailed self- checks. In particular, such information should include:

(a) Cumulative data for at least the three previous years or the period since the start of the supply contract if this is shorter; and

(b) Detailed data according to the time of use for any day, week, month and year. These data shall be made available to the final customer for the period of at least the previous 24 months or the period since the start of the supply contract if this is shorter.

a lesson which has been highlighted in several pilot projects, for example the **Jouw Energie Moment**[10] project, the **Linear** project[11] and the **3e-Houses project**[12].

Many projects are also testing the use of prompts, gaming and peer comparison. In the **Modelec**[13] project for example (Figure 18 and Figure 19), consumers have access to a web interface (personal space) where they can verify their consumption (on an hour/day/month basis in kWh and €), have an historical and peer comparison of their consumption, check the consumption of individual appliances and manage each appliance from remote (via mobile phone or tablet). In addition, the interface visualizes a system of challenges, rewarding consumers for the adoption of sustainable practices.

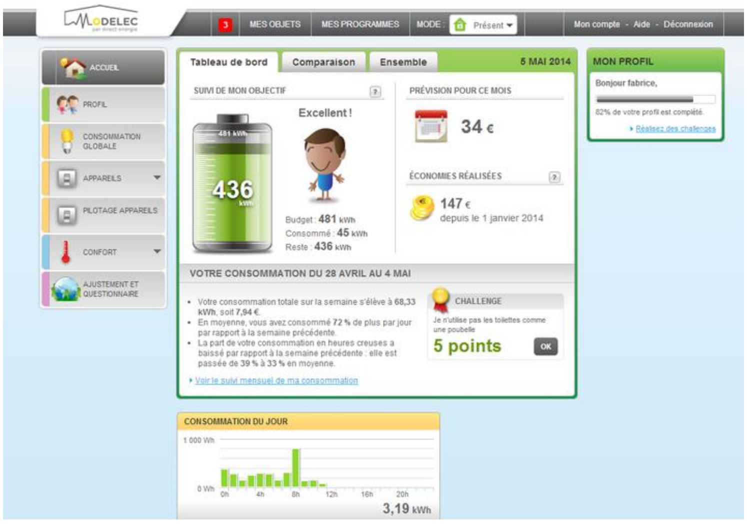

Figure 18. Feedback visualization interface (Modelec Project)[14]

The project however has not yet provided an evaluation of the effectiveness of the visualized information on the consumer energy consumption behaviours. This is the case in many pilot projects,

[10] The **Jouw Energy Moment** project (NL) is a demand response demonstration project which aims at mobilizing flexibility in the use of electricity, giving participants financial and/or emotional incentives to shift their use in time. The project involves about 250 residential participants who have been provided with products and services to enable them to choose their preferred times to use electricity. Equipped with a special In-Home Display (IHD) and a smart washing machine, users will be able to choose whether they want to run their washing machine during times when their local sustainable electricity is produced by PV panels or at those when the cost of electricity is low on the wholesale market. Participants can enter their preferences and constraints and the energy computer does the rest autonomously. The project team dedicated lot of work and effort to the design of the interface to ensure that the information is presented in an attractive and easily understandable way.

[11] The **Linear** Smart Grid (BE) project focuses on solutions to match residential electricity consumption with the availability of wind and solar energy. The Linear system is a research platform designed and deployed by the partners to investigate user behaviour and acceptance. One of the findings of the project was that to limit response fatigue, the effort of participants in configuring appliances needs to be limited to a minimum.

[12] The **3e-Houses** project (ES,DE,BG,UK) aims at integrating the most established ICT technologies in social housing in order to provide an innovative service for energy efficiency, real time monitoring and management of the energy consumption and the integration of renewable energy sources. The project has tested several smart devices to observe the interaction with the end-users.

[13] **Modelec** is a French project that proposes a complementary solution for flexible generation that allows the reduction of peak load through load shedding and load management at residential level. The solution is tested with 500 households. Energy providers, having access to the management of the consumer consumption can manage the main electrical appliances connected to the smart metering (e.g.: electrical heating, water heating) and switch them off for short periods in order to avoid load peaks.

[14] Available in http://www.projet-modelec.fr/le-pilote/interface/

since most of them often combine different visualization features, making it difficult to tie changes in behaviour to specific interventions.

In this regard, a recent project, the **TBH Alliance** project[15] aims to test different feedback visualization methods and to compare the energy savings potential of each tool. Five different types of visualization are being compared;

- *Local visualization of consumption*: energy consumption data are automatically collected and locally visualized (monochrome vs. graphic vs. tactile)
- *Web visualization of consumption manually measured*: energy consumption data are manually collected by the consumer and consumption patterns are remotely displayed (via web or smartphone);
- *Web visualization of consumption data remotely collected*: energy consumption data are automatically collected and consumption patterns are remotely displayed (web or smartphone);
- *Visualization of consumptions detailed for each utility*: remote display of consumption (web or smartphone) detailed per usage (heating, hot water, lighting)
- *Eco-coaching*: raising awareness through online games, quiz/personalized plan with targets/ tools for peer comparison/ forum, blog.

The project aims to demonstrate that through a directed and well developed visualization of energy consumption data it is possible to achieve substantial energy savings.

Figure 19. Energy consumption visualization (Modelec Project)

In conclusion, there is no one-fit-all design solution, as the effectiveness of the display design depends on several circumstances, most importantly on the end-users characteristics. A key principle that should be kept in mind, however, is the need to balance complex functionality and simple, attractive

[15] **TBH Alliance project** is a French project whose aim is to compare the energy savings potentials of different energy consumption visualization tools. It aims at characterizing the consumers' acceptability of different visualization tools and at identifying the most user-friendly and effective (for energy savings) functionalities. The solutions are tested on a sample of 4000 French consumers.

products. To enable behavioural change it is necessary to engage consumers with simple and easy to understand feedback information and to guide them telling them what they need to do.

Feedback visualization - Recommendations

- Empirical evidence about how feedback from visualization tools will be used by consumers and how they will affect energy consumption patterns is not yet available.
- There is no one-fit-all design solution but empirical evidence suggests to keep the information provided to consumers simple, providing complex functionalities in a straightforward and attractive way;
- To enable behaviour change it is important to guide consumers, providing them with simple and actionable information.

3.3.4 Recommendations from international studies and conclusions

In this section I will briefly present the recommendations to foster consumer acceptance and engagement as elaborated by two different comprehensive studies carried out by IEA-DSM[16] and the S3C[17] projects. To be consistent with the previous paragraphs, I have grouped these recommendations into four main categories, i.e. feedback information, feedback solutions, feedback visualization and consumers' concerns.

Feedback solutions: in order to capture the consumer's attention and effectively deliver smart meter data, the feedback solution needs to be easily accessible and understandable by the end users:

- The technology solution needs to match the technology literacy/maturity of the target (Mourik *et al.*, 2013).
- The technology, products and services supplied to the consumers need to meet their expectations to keep them committed and engaged (S3C Consortium, 2014).

Feedback information: to engage consumers and trigger behavioural change it is necessary to develop solutions that address consumers' needs, demands and expectations:

- Providing the technology is not enough. To engage consumers in smart metering solutions it is necessary to create multiple benefits for the consumers (Mourik *et al.*, 2013) and to investigate the

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[16] The **IEA Demand-Side Management Programme** is an international collaboration of 16 countries working together to develop and promote opportunities for demand-side management (DSM). The work of the programme is organized through a series of Tasks and reported in a number of publications. It is managed by an Executive Committee (ExCo). More information on the Programme can be found at: http://www.ieadsm.org/.

[17] The **S3C project** aims to provide a better understanding of the relationship between the design, implementation and use of particular technology and end user interaction schemes and the promotion of smart energy end user behaviour. One of the aims of the project is to establish an understanding on whether and how the design, implementation and use of certain user interaction schemes (as part of a smart grid pilot/test) contribute to the formation of new 'smart' end-user activities and behaviours in their different roles as consumers, customers and citizens. The results were based on the investigation of 32 European smart grid pilot projects through in-depth case study analysis. More information on the project can be retrieved at: http://www.s3c-project.eu/.

added value for end-users (S3C Consortium, 2014). Consumers' needs, demands and expectations should be taken into account when designing products and services (S3C Consortium, 2014).

- In many instances it is clear that economic gains or losses are not necessarily the only trigger to induce behavioural change (Mourik *et al.*, 2013). In many cases the business case for pricing schemes seems not to be very viable. Generally, the price spread between high and low peaks is too small to be a valid (financial) incentive for participants, and for DSOs they do not reflect economic reality. Without the development of solid business models for residential and commercial consumers full-scale rollout is not likely to be feasible(S3C Consortium, 2014).
- When the advantages of renewable energies and of smart grids are in the foreground, end users may be more likely to adopt a sense of urgency that increases their motivation to participate actively (S3C Consortium, 2014).
- Including playful challenges and competitions enhances consumers' participation and engagement (S3C Consortium, 2014) (Mourik *et al.*, 2013).The experiences with gaming interfaces and competitive elements are promising and inspiring, both in terms of engagement and in terms of outcomes. However, a challenge regarding gamification is to capture the interest and attention of end users in the long run(S3C Consortium, 2014).

Feedback visualization: the information provided to the consumer needs to be comprehensible and appealing:

- Consumers want to know where they stand and how they are doing compared to previous periods and/or their neighbours (Mourik *et al.*, 2013). Therefore, easily understandable historical usage feedback information and social comparison feedback can be considered a success factor(S3C Consortium, 2014).
- Feedback solutions need to be easy to use and understand. When consumers do not have a real understanding of how to use the devices, they do not use the interfaces to their full potential.

Consumers' concerns: Consumers' concerns can have a negative impact on consumers' acceptance of the metering technology and on their engagement with the new solutions. In order to prevent opposition and disengagement, these concerns should be addressed at the early stage of products and services development:

- The new solutions should keep consumers' comfort at least at the same level as before their adoption. Many consumers are particularly concerned about the possibility of being without heating or hot water should the devices malfunction, or altering consumption so much as to interrupt services.

These recommendations are well aligned with what emerged from the empirical analysis of pilot projects discussed in section 3.3.3.

Table 3 summarises and compares the findings from the EU surveys, EU pilot projects and international recommendations.

	EU Surveys	EU pilot projects	Recommendations from international studies
Feedback solutions	-web portal (+) -smartphone/tablet (+) -IHD (+) -informative paper billing (-)	Constant and physical presence of feedback solution to maintain engagement; Tailor the solutions to needs and attitudes (segmentation); Additional functionalities help to maintain interest.	The technology solution needs to match the technology literacy/maturity of the target; The technology, products and services need to meet consumers' expectations Include playful challenges and competitions to enhance consumers' engagement (e.g.: gaming interfaces).
Feedback information (consumer's attitudes)	-monetary (+) -environmental -social responsibility	Tailor the information strategies to different consumers segment (segmentation); Other information than economic can work for different segments; Avoid info overload.	Create multiple benefits for the consumers and investigate the added value for end-users; Economic aspects are not the only trigger for behavioural change; Make clear the advantages of renewable energies and of smart grids to increase end users engagement and adoption.
Feedback visualization	-tables and numbers -charts	Lack of empirical evidence about how feedback from visualization tools will be used and how it will affect consumption behaviour; Keep the information provided to consumers simple and attractive; Guide consumers, providing simple and actionable information.	Historical and comparison feedback information and are successful strategies; Make visualization solutions easy to use and understand;
Consumers' concerns	-privacy and security (+) -loss of control -change in comfort level		New solutions should keep consumers' comfort at least at the same level as before their adoption.

Table 3. Summary of findings: EU surveys, EU pilot projects and international studies

3.4 The social electricity consumer: evidence from DSM projects and group discussions

In this section I will present and discuss the collective dimension of energy consumption presenting results from the analysis of DSM pilot projects and the results of focus group discussions. The work presented hereafter is an elaboration of research presented in a conference paper: "*Consumer and community in the Future Electricity Network: an Insight from Smart Grid Projects in Europe*" (Gangale *et al.*, 2014) and a peer reviewed article: "*Exploring Community-Oriented Approaches in Demand Side Management Projects in Europe*" (Mengolini *et al.*, 2016).

3.4.1 The collective dimension of energy use: evidence from DSM projects

As argued in the previous sections, the two-way information and power flow enabled by smart metering systems can allow consumers to become more aware of their energy consumption and to take more informed decisions on their own energy supply. Moreover, the deployment of smart grids can enable the efficient integration of different services – electricity, gas, heating and cooling – in a single shared architecture, fostering conservation and a more efficient use of resources. To accelerate their deployment it is argued (Goedkoop *et al.*, 2016; Koirala *et al.*, 2016) that consumers' participation and engagement should be promoted not only at individual level, but also taking into consideration the wider social context in which consumers live and operate.

The functioning of the future electricity system will rest on the interaction of a multiplicity of social players who operate as independent decision-makers driven by personal goals and attitudes as well as social interactions. Emerging electricity systems will bring forward a radical technological, environmental and economic transformation of the old system, affecting the way consumers live their lives and how they interact socially and culturally (Verbong *et al.*, 2013).

This is particularly true in the DSM domain, where consumers play a fundamental role. In this field, the current debate still focuses mainly on technological issues and economic incentives, mostly addressing energy demand issues with an individualistic approach to attitudes and choices (Verbong *et al.*, 2013) (Geelen *et al.*, 2013) (Goulden *et al.*, 2014). This traditional approach concentrates primarily on individual feedback mechanisms, neglecting the complex social dimension of shared practices, goals and attitudes associated to energy consumption (Shove, 2010; Wolsink, 2012; Goulden *et al.*, 2014). This individual-oriented approach appeals to the consumer self-enhancing values, and reflects a key concern with one's individual interests and well-being, e.g. in terms of comfort or economic savings (Steg *et al.*, 2014).

A more recent stream of research however, is investigating ways to activate consumer's response by leveraging more on collective dynamics, suggesting a shift from an individual approach to energy management to a collegial one where consumers are seen and approached in their social context. This approach builds more on self-transcendent values and reflects a key concern with collective interests; it aims at building a sense of community and of shared values and goals (Steg *et al.*, 2014) . Growing attention is given to strategies to promote active participation of end-users at community level, and on the role that communities can play in the transitioning energy system (Alvial-Palavicino *et al.*, 2011; Anda *et al.*, 2014; Dóci *et al.*, 2015; van der Schoor *et al.*, 2015; Burchell *et al.*, 2016; Olson-Hazboun *et al.*, 2016).

Community-based energy initiatives can produce energy, reduce energy use, manage energy demand and purchase energy; they may therefore play an important role towards self-sufficiency and sustainability. These collective actions can develop solutions to meet local needs involving local people while contributing to energy security, reducing greenhouse gas emissions and keeping costs down for consumers (Department of Energy & Climate Change, 2014). Doci et al. (Dóci *et al.*, 2015) view these initiatives as "*social niches*" capable of introducing social innovations in the electricity market resulting in new forms of organizations, business models and institutions.

As highlighted in Chapter 1, the collective dimension of energy use is increasingly recognised also at European level. According to the European Commission, European consumers engage more and more in self-generation and cooperative schemes in order to better manage their energy consumption (European Commission, 2015b). Regional and local energy initiatives are seen as facilitators of consumer participation in the energy market and in the effective governance for the Energy Union. According to (European Commission, 2015b), such initiatives should be supported as they can provide a valuable link between decision-makers, citizens and innovators, opening new opportunities for local communities to play an active role in the energy transition.

The transition to a more participatory energy system however, requires a shift from an approach based on individual-oriented strategies to a more comprehensive and integrated approach based on community-oriented strategies where inclusivity and a collective sense of purpose and values are the drivers to transition (Barr *et al.*, 2012; Rae *et al.*, 2012; Wirth, 2014; Koirala *et al.*, 2016). A more integrated approach, that leverages on collective dynamics and on the integration of different actors and sectors (such as electricity, water, gas, heating and cooling), can enhance consumer participation (Koirala *et al.*, 2016).

In this context, the aim of this section is to investigate if the theoretical trend and socio-political acknowledgement of a more collective dimension of energy use are reflected in the design and development of DSM projects in Europe. Several studies have analysed consumer engagement strategies in smart grid projects in Europe (Gangale *et al.*, 2013; S3C Consortium, 2014; Kessels *et al.*, 2016) and in the US (Hewitt *et al.*, 2005; Smart Grid Consumer Collaborative, 2011a; U.S. Department of Energy, 2013). This topic is emerging also as a field of investigation in other countries, among which China (Jiang *et al.*, 2013), Japan (Ngar-yin Mah *et al.*, 2013) and Australia (Anda *et al.*, 2014). However, it appears that there are no comprehensive studies on the use of community-based approaches as a tool to increase consumer participation in demand side management projects. The analysis of recent developments in this field can help identify best practices and lessons learned from real life experiences, thus supporting effective policy making.

3.4.1.1 Methodology

As argued earlier, pilot projects provide an important means to monitor the direction Europe is taking and to understand what works and what doesn't in real-life experiences. The JRC inventory offers a valuable tool to explore the changing role of consumers in the evolving energy system: with this aim in mind, I screened the 2014 JRC database (Covrig *et al.*, 2014) and singled out the demonstration projects with a clear focus on residential demand side management (DSM). DSM aims at matching demand with the available supply, allowing for larger integration of intermittent generation. It helps network operators to manage their grids in a more flexible and efficient way and to defer investments in network reinforcement and expansion (Warren, 2014) (Zhang *et al.*, 2017). It also helps consumers to better manage their energy consumption by changing their behaviour and energy consumption practices. Given its broad scope and reach, different definitions of demand side management exist in the literature. For the scope of this analysis, and building on recent analyses of the term (Warren, 2014), I included in the definition both projects that aim at shifting consumption to another point in time (*demand response*) and projects that aim at reducing the level of energy consumption while providing the same service and without affecting the level of comfort (*energy conservation*).

I focused on DSM projects as they are inherently centred on consumers and allow for the investigation of new trends in the strategies for consumer engagement. Expanding on my previous work (Gangale *et al.*, 2013) (Covrig *et al.*, 2014), I looked at DSM projects in the JRC database to capture signs of a new attention towards the wider context in which consumers live and towards the social dimension associated to energy consumption.

Out of 459 smart grid projects in the 2014 JRC database, I identified 67 DSM projects. For each one of them I collected additional information on the project's scope and on the engagement strategies used to address the individual and social dimension of energy consumption. I investigated the scope of the projects to see to what extent they take into consideration the multiplicity of actors and factors having an impact on consumers' attitudes and consumption habits. Specifically, the elements I looked into are the *range of project partners*, the *targeted end-use sectors* and the *targeted services* (electricity, water, gas, heating and cooling). I investigated these aspects as I believe they are key to characterize the socio-economic scope of the project and its inclination to build on community dynamics to impact on consumers' attitudes and consumption habits. I also investigated the consumer engagement strategies used to activate consumer's response and the dynamics on which they are grounded to verify if a trend exists from an approach focused on consumers as individual agents to an approach that addresses consumers as socially situated individuals, part of a wider community.

The analysis is limited to the identification of emerging trends from DSM innovation projects in the JRC database. These projects feature multiple interventions which play out in an interactive way and it is therefore not possible to disentangle the effects of one intervention from the contribution of other factors. At this stage of the research it is therefore not possible to use the results of the projects to evaluate the effectiveness of the adopted engagement strategy. Even if I cannot yet confirm the effectiveness of initiatives characterized by a more inclusive approach, I can however present the evidence of an emerging interest for collective dynamics and multi-stakeholder partnerships. Further research should be devoted to investigate this topic as well as the scalability and replicability potential of community engagement projects.

3.4.1.2 Results

3.4.1.2.1 Project's scope

Project Partners

Though most of the projects are still led by distribution system operators and energy companies (over 40% of them), DSM projects increasingly attract the participation of intermediary organizations, i.e. local project partners that work closely with the concerned community/territory and operate mostly at local level. Table 4 shows the different kinds and the occurrence of local project partners, while Figure 20 presents their participation in the projects over time.

Local project partner	No.
Municipalities	10
Housing associations	9
Public agencies	6
Consultancies	4
Local development organizations	2

Table 4. Local partner organizations in DSM projects

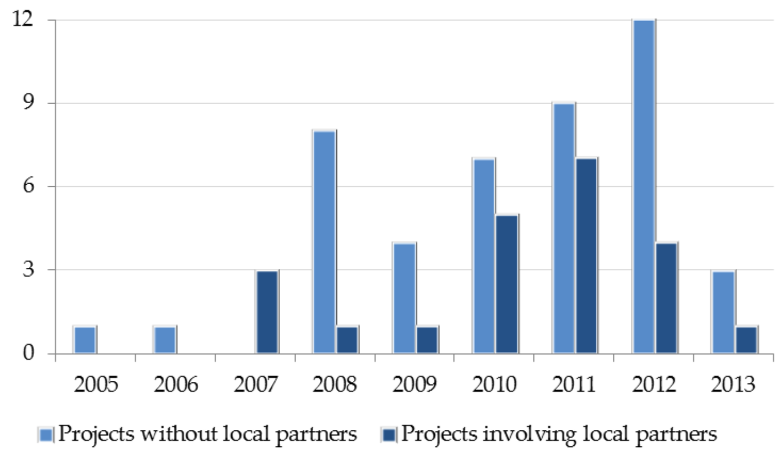

Figure 20. Evolution in the participation of local partners over time

Municipalities are increasingly active in DSM projects. Other public sector organizations, such as public agencies for resource efficiency and housing associations, also participate in an increasing number of projects. This trend reflects the literature on the role of public and local partners to engage consumers (Department of Energy & Climate Change, 2014) (UK Power Networks, 2013) (Goedkoop *et al.*, 2016) and highlights the emerging interest of DSM projects in building on existing local partnerships to reach a wide range of consumers. Several studies recognise the critical role of public and local partners to engage consumers, specifically to reach those that are the hardest to reach, e.g. vulnerable consumers (UK Power Networks, 2013). Local partners, such as social housing providers and local community centres, benefit of a good knowledge of the local environment and in many cases of a high level of trust. They are therefore the best-suited parties to engage with local communities and reach both the mainstream group and the most vulnerable groups (UK Power Networks, 2013).

End-use sectors

The analysis of the projects reveals a trend towards the inclusion of different kinds of consumers within the scope of the project (Figure 21). Overall, 63% of the projects address exclusively the residential sector, while 37% of them address the residential sector in combination with the commercial, industrial or public sector. The inclusion of different sectors seems to point in the direction of addressing households within a wider context where public, commercial and industrial entities are also included. Bringing together more end-use sectors promotes the idea of a larger community effort fostering social and economic benefits for all the actors involved.

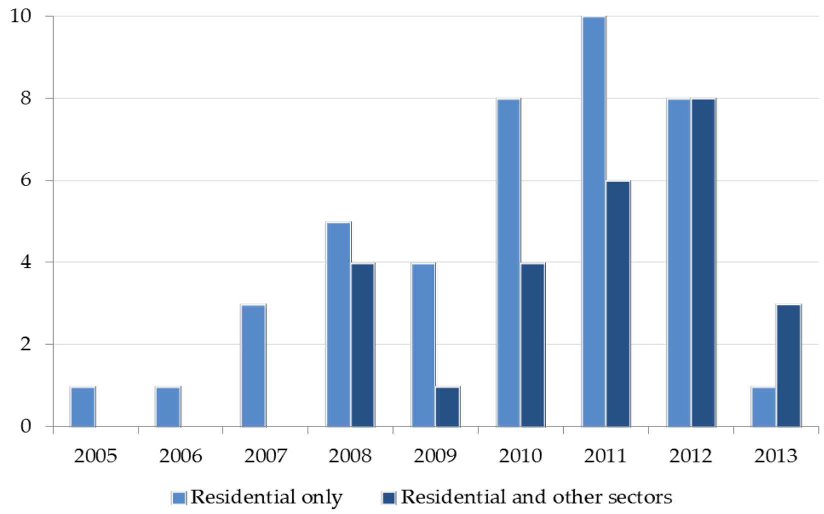

Figure 21. End-use sectors

Targeted services

Out of the 67 projects, 16 projects (24%) present a cross-service approach, i.e. the inclusion of other services - water, gas, heating and cooling - in the scope of the project (Figure 22). This development is in line with the idea of integrating multiple utilities in a single shared smart grid platform. DSM projects offer the opportunity to exploit synergies, scale and scope economies with other services. The same communication infrastructure can serve multiple meters, as well as devices providing different services (Cervigni *et al.*, 2014). At the same time, this trend is in line with the idea of a multi-stakeholder, municipally-based partnership, which is at the core of the concept of smart communities. Including other services in the scope of the project can also help maximising benefits and opportunities for consumers, thus contributing to technology acceptance and consumer engagement.

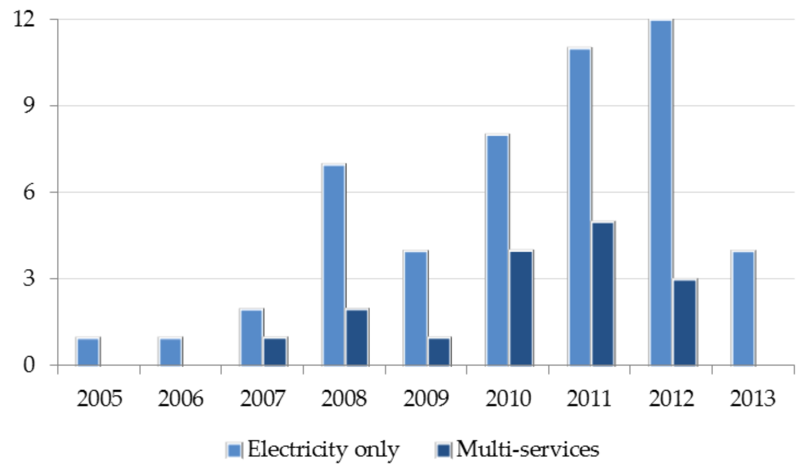

Figure 22. Evolution of multi-services projects

3.4.1.2.2 Consumer engagement strategies

To verify the argument that consumers are increasingly approached in their collective and community dimension, I also analysed the engagement strategies and tools used by all 67 projects. The analysis shows that the engagement strategies are characterized according to two main approaches: *individual-oriented strategies*, i.e. strategies focusing mainly on mere economic feedback mechanisms, and *community-oriented strategies*, i.e. strategies that adopt a more diversified and participatory approach and aim at building a sense of community and of shared goals and values. About 48% of the projects resort only to individual-centred mechanisms, while the rest of the projects mainly use a combination of the two strategies, complementing the economic feedback with the use of messages appealing to the collective interest and with the implementation of other community engagement tools. Figure 23 shows the share of projects resorting to the different approaches. In the following paragraphs, the analysis of the projects allows a deeper characterization of the two strategies and of the tools used to engage the consumers.

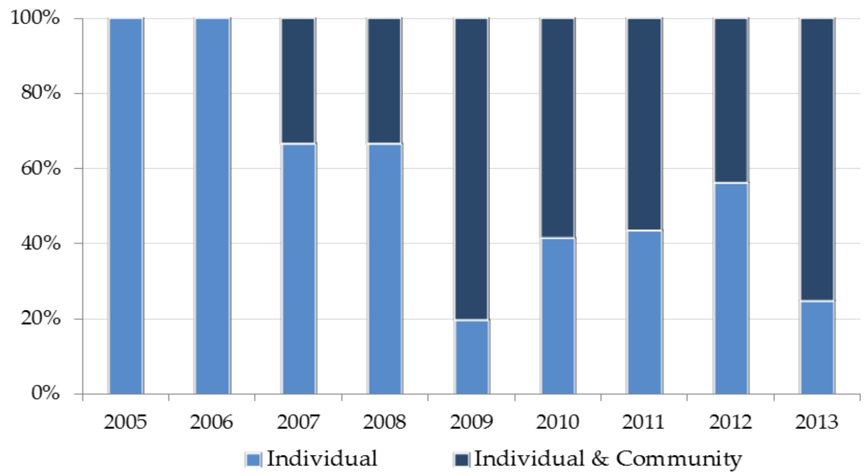

Figure 23. Engagement strategies used in the projects

Individual oriented strategies

Individual-oriented strategies appeal to the self-enhancing values of the consumer that reflect a key concern with one's individual interests, i.e., hedonic and egoistic values (Steg *et al.*, 2014). They mainly provide individual feedback on energy consumption, in terms of energy or monetary savings. In some projects these strategies are coupled with engaging tools, e.g. historical comparison, expert advice/home visits, hints and tips, goals, targets and rewards (Figure 24).

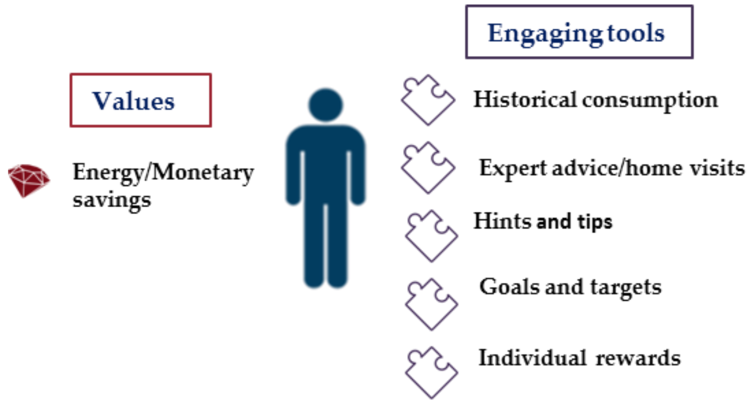

Figure 24. Individual-oriented engagement strategies

Only in one project (*Nice Grid*) the consumer also receives information on the availability of energy from renewable energy sources (RES), a kind of information that is more typically used in community-oriented projects, as it appeals to more self-transcendent values. In this case however, this kind of information can still be seen as appealing to the self-enhancing values, as the consumers in this project are also prosumers; the availability of RES energy, i.e. self-generated electricity, is translated in economic gains. In two projects (*Intrepid* and *3e-Houses*) social comparison strategies for individual user engagement are used. In these projects however, the use of peer comparison seems to appeal mainly to the consumer's self-enhancing dimension ("my neighbour is saving more"), without stressing the sense of a community achievement.

Community-oriented strategies

Community-oriented strategies are strategies that appeal to self-transcendent values reflecting a key concern with collective interests, i.e., altruistic and biospheric values (Steg *et al.*, 2014). These strategies adopt a more participatory approach and aim at building a sense of community and of shared values and goals. In particular, I found that the most addressed values are environmental protection, improvement of the general welfare and being part of an innovative project. These strategies increasingly make use of social norms marketing messages and non-price interventions.

The most frequently used tools for community-oriented consumer engagement are summarized in Figure 25, while in the rest of this paragraph I will present some practical examples of projects where they were used.

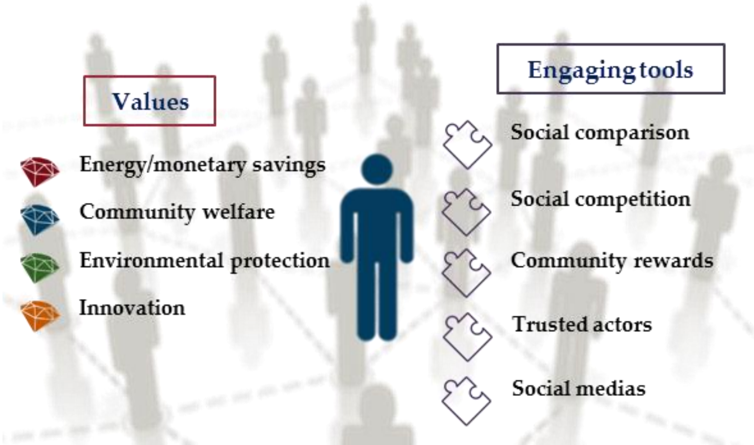

Figure 25. Community-oriented engagement strategies

Social comparison (22/67 projects). 22 projects used social comparison, a tool which compares a household's energy use to that of similar neighbours to provide a point of comparison for an individual's own behaviour. Interestingly, in order to avoid the possibility of boomerang effects - i.e. that the same message may actually serve to increase the undesirable behaviour among individuals who perform that behaviour at a rate below the norm (Schultz *et al.*, 2007) - some projects added an injunctive message, i.e. a smiley face or a green light, indicating that the desired behaviour was approved. Adding an injunctive norm that conveys the message that energy conservation is good for the community can substantially reduce the risk of the boomerang effect (Allcott, 2011).

The *SMARTSPACES* project provides the possibility to compare buildings against each other using colour-coded smileys that greet participant when they switch on their monitors. Another interesting project is the *eSESH* project, which also offers the possibility of comparison with other tenants in the same buildings and living in similar dwellings. Red, orange and green lights are visualized in the web portal, indicating a comparatively high, average or moderate consumption.

Social competition/community rewards (5/67 projects). Including playful challenges and competitions enhances consumers' participation and engagement (Efficiency, 2013; S3C Consortium, 2014). The experiences with gaming interfaces and competitive elements are promising and inspiring, both in terms of engagement and in terms of outcomes. However, a challenge regarding gamification has to capture the interest and attention of end users in the long run (S3C Consortium, 2014). In the JRC database, the *DEHEMS Project* employs a social competition strategy based on teams of households - the Energy Team Challenge - which is designed to encourage a reduction in electricity usage by leveraging on team dynamics. Electricity usage reduction is rewarded with EcoPoints that can be redeemed in exchange for "eco positive" goods and services (e.g.: discount on A++ white goods for households or low energy device) that could be shared across the community (DEHMES Project, 2011). This approach based on competition is meant to drive change, help engagement and provide a way of linking different stakeholders towards common societal (energy saving) and community (community reward) goals. On the same note, the *Energy Demand Research Project* (EDRP) applies advanced community engagement strategies where each community participating to the project can compete for a Community Project Prize (in monetary term and beneficial to the community) for achieving a certain reduction in electricity consumption over a time period that is compared with the same time period in the previous year.

Community based social marketing strategies (14/67 projects). Social marketing is an approach that seeks, through marketing techniques, to identify the barriers that people perceive when attempting to change behaviour. Community based social marketing merges this approach with insight into the importance of social norms and community engagement in behavioural change (Jackson, 2005) (Anda *et al.*, 2014). The organization of community events where project participants can meet face-to-face with local residents are an effective means to reinforce community dynamics (S3C Consortium, 2014). The present analysis reveals the resort to this tool, with many projects using community based events to inform and engage consumers. Community events are very often used in the recruitment phase, as for example in the *EU-EcoGrid* project; however, they are also organized in the course of the project to strengthen community dynamics after recruitment and to carry participants over to the installation and demonstration phases (e.g.: green picnic and winter fairs, EDPR project).

Some projects (e.g. *DEHEMS project*) also employ community based social marketing to engage participants through continuing conversation and active debate (DEHMES Project, 2009). An innovative form of community marketing is promoted by the *DEHMES project* where project users are organized in Living Labs. Living Labs are composed of groups of people who are actively involved in the creation and evaluation of technologies which they will ultimately use. In taking this approach, the project embraces the idea that changes in behaviour are often best carried out in a group or community context rather than at individual level. The presence of other people with the same interest and motivation can help to reinforce the change in behaviour (descriptive social norm: "I do what others do") and to eventually turn it into an accepted and shared habit (it becomes the new accepted injunctive social norm: "I do it because it is good for the community") (DEHMES Project, 2009). It is however important to underline that the effectiveness of community engagement strategies may be also due to the specific characteristics of the community where the project is implemented (as for example the Island of Bornholm in the EcoGrid project and the winning community of EDPR project). These communities are strongly characterized by community-oriented consumers whose goals are related to innovation, environmental protection and community welfare (self-transcending values). Furthermore, some projects (e.g. EcoGrid) show that in small communities, people influence each other in favour of the adoption of technologies that they see beneficial for the community (Eco Grid EU Project, 2015).

Community trusted actors (9/67 projects). Establishing a trusted relationship with the consumer is a crucial step to overcome resistance and fully engage the consumer. Often scepticism and wariness are reported as barriers to successful project development (Gangale *et al.*, 2013). Recent studies on stakeholder's influence on the development of community renewable energy schemes (Ruggiero *et al.*, 2014) have highlighted the importance of two stakeholders: intermediary organizations acting as "trusted authorities", which we have already addressed above, and local champions. Local champions are actors who have significant non-material resources in term of individual values, skills and competencies (Ruggiero *et al.*, 2014); therefore they have the ability to easily persuade their peers and encourage behavioural change. On this note, several projects in the JRC database report as best practice the use of local champions for engaging with the community and building a trustworthy relationship. The *eSESH Project* reports the resort to 'champions', i.e. fellow tenants who show a strong interest in technical and energy-saving matters and who can act as multipliers by 'spreading the message' and helping neighbours in case of questions. They are highly motivated people well known by the neighbourhood (eSESH Project, 2013). In the *eSESH Project t*he communication among tenants was improved to the extent that 'champions' became known experts acting as energy managers helping others and potentially learning skills that can finally be of benefit to the community. Also the *DEHEMS project* promoted active involvement through the recruitment of community champions, i.e. proactive members of the local community, selected from the living lab population, that fulfilled both a community marketing role and a supporting role.

Social media (11/67 projects). Social media tools can also be useful for various types of campaigns, but their use requires time and dedication. An interesting example from the JRC database is the *SMARTSPACES project*, where some pilots made effective use of social media tools using the cascading effect of twitter messages. These tools allowed the project to reach a wide audience, informing and engaging consumers who could pose questions and start conversations.

Table 5 lays out the main engaging tools used by community-oriented strategies, the objectives they serve to achieve, and some examples of practical applications from the projects in the JRC database.

Engaging tools	Objective	Examples from the projects
Social comparison	Comparing consumption level with that of a similar household; indicating that the desired behaviour is approved	Red, orange, green lights; colour-coded smileys
Social competition / community rewards	Leveraging on team dynamics; linking different stakeholder; rewarding the community	Energy Team Challenge; EcoPoints; Community Project Prize
Community based social marketing	Identifying barriers to adoption; reinforcing community dynamics; exploiting potential for behavioural change in a community context; informing on the progress of the project	Community events (e.g: green picnics, winter fairs); Living Labs
Community trusted actors	Overcoming resistance and scepticism; building trustworthy relationship; exploiting non material resources of local actors	Intermediary organizations; fellow tenants; proactive local community members ("local champions")
Social media	Reaching a wide audience; addressing questions and concerns; providing information	Twitter messages

Table 5. Community-oriented strategies: tools, objectives, examples from the projects

3.4.1.3 Conclusions

In this section I have investigated if the current theoretical and socio-political acknowledgements of a more collective dimension of energy use are reflected in the design and development of DSM projects in Europe.

The analysis shows that DSM projects are increasingly being designed and developed having in mind a collegial approach to energy consumption, where consumers are considered in the wider socio-economic context in which they live and operate. Although the evidence of this new trend is still fragmented, there are signs of a more inclusive approach, increasingly based on community dynamics, both in the projects' scope and in the engagement strategies used therein.

The diversification of organizations, with an increasing number of local organizations participating in DSM projects, underlines the emerging interest of DSM projects in building on existing local partnerships to reach and engage a wide range of consumers. Local organizations, having a good knowledge of the local environment and benefitting of a high level of trust, are the best suited parties to engage with local communities. DSM projects also increasingly include different end-use sectors (residential, commercial, industrial and public sector) in the scope of the project, promoting the idea of a larger community effort fostering social and economic benefits for all the actors involved.

Furthermore, a growing number of projects integrate multiple services (electricity, gas, water, heat and cooling) in the project proposition, thus building on the concept of a multi-stakeholder, municipally-based partnership that can maximise benefits and opportunities for consumers.

Signs of a new attention to the wider context in which consumers live and to the social dimension associated to energy consumption are also found in the increasing use of engagement strategies and tools addressing the consumer as part of a wider community. An emerging trend exists from an approach that aims at changing individual behaviours - such as the provision of consumption feedback appealing mainly to the economic self-interest - to an approach more focused on changing community's behaviours towards goals that benefit the community at large. Many projects try to mobilise consumer's response using a more participatory approach that builds on a sense of community and of shared values and goals.

While the projects in the JRC database resort to different combinations of partners, end-use sectors, services and consumer engagement strategies and tools to increasingly engage consumers, an integrated approach is still missing. These projects are still testing a variety of interventions which play out in an interactive way according to concrete local circumstances. It is therefore not yet possible to disentangle the effects of one intervention from the contribution of other factors and to link these trends to project results, thus supporting the conclusion that initiatives characterized by a more inclusive and community-oriented approach deliver better results. Further research and analysis are needed to explore this link, as well as the scalability and replicability potential of community engagement projects.

3.4.2 The collective dimension of energy use: evidence from group discussions

The aim of this section is to explore how "alternate" discourses of sustainable energy consumption and critical social science research may suggest an alternative answer to the dominant approaches based on an efficiency-focused rationalisation discourse that still mainly focus on technological issues and economic incentives as enablers of smart grid successful deployment. Using data from a group discussion and applying a critical discursive psychology perspective, this section presents three main interpretative repertoires that consumers draw on and explores consumers' social practices and meanings related to energy. The findings are in line with the recent literature on sustainable energy consumption and further support the idea that the way electricity and technology are embedded in daily household practices should be more central in the research and development of emerging electricity systems. If the required changes in social practices that the further electrification of the home will require are not well understood, the energy efficiency benefits derived from smart electricity grids might be offset.

3.4.2.1 Background

As argued in previous chapters, successful implementation of smart grid will require consumers' adoption of smart home technology and in particular of smart meters. These meters "will provide consumers with real-time information on their electricity use to help them control their consumption, save money and reduce emissions" (Department of Energy & Climate Change, 2009). Through smart meters, consumers will be capable of interacting with real time displayers or smart energy monitors adjusting their consumption patterns in response to supply conditions. However, the development of these smart home technologies is still surrounded by uncertainties as well as risk, particularly in relation to social aspects (Darby *et al.*, 2012). As argued by some authors, the only aspects of the smart grid that can be truly smart are the people within it (Honebein, 2012). In other words, consumer action is the fundamental driver. Therefore consumers, their daily routines and the social context in which they operate, should be more central for the grids utilities, where the focus is still mainly on technological issues and economic incentives (Wolsink, 2012; Geelen *et al.*, 2013; Verbong *et al.*, 2013). Jackson (Jackson, 2005) argues that sustainable consumption and consumer behaviour are key issues to the impact that society has on the environment. However, he acknowledges the challenges and difficulties of changing consumption behaviours. Consumption (of goods or services) is important not only for its functional uses but also because it plays a symbolic role in peoples' lives as it conveys discourses about status, identity, social norms and social cohesion. Moreover, consumers are mostly locked into unsustainable consumption patterns influenced by routines, social norms and expectations as well as incentive structures, institutional barriers and restricted choice.

Many studies have been recently published where consumers have been involved in interviews, workshops and focus groups to assess their perceptions and understanding of smart girds and smart metering technology as tools to accelerate a sustainable energy transition. While recognizing a general consumer positive attitude towards smart grid technologies, they acknowledge the need to further explore consumers' social and cultural practices related to energy use.

In a recent study Naus (Naus *et al.*, 2014) challenges the mainly positive cultural framing of smart energy technology where "citizen participation" is a key term. The focus is shifted to the changes in domestic energy practices connected to the use of different information flows involved in smart grids and to their effects on social relations within and between the households. The methodological approach employed is based on mix-method: orientating interviews (one), semi structured interviews (four, with residents sampled form 45 households which participated in a one-year smart meter trial) and observation at workshops organized by local energy cooperatives (four). The perspective used to analyse data is the *theory of social practices*. The article concludes that new information flows may not produce more sustainable practices in linear and predictable way. Indeed, behavioural changes are contextual and emergent and give room to new social practices.

In another study, Hargreaves (Hargreaves *et al.*, 2010) explores how householders interact with feedback on their domestic energy consumption. It argues that social and cultural practices of households and their associated energy use are influenced by a number of factors which may have no direct link with energy use or the environment. In order to find evidence for this claim, the paper reports the findings of fifteen digitally recorded semi-structured interviews with households on their use of smart energy monitors. The data are analysed using a *grounded theory-approach* in order to identify common themes across different households and devices. The findings show that there are gender and age specific styles of engagement with the devices and what they communicate. They also points to the fact that smart energy monitors can lead to greater cooperation and greater conflict among members of the household leading to the conclusion that domestic energy consumption is a social and collective rather that individualised process.

Finally, Verbong (Verbong *et al.*, 2013) presents an analysis of practices and perceptions of stakeholders (specifically, 37 interviewees with stakeholders representing governmental organizations, public and private research organization, energy utility companies and other organization's including NGO's) on users' perspectives in current and future smart grids experiments. The paper argues that there is the need to pay attention to changing social practices resulting from the further electrification of the home. These changes in social practices might offset energy efficiency benefits derived from smart grids. The paper uses as methodology of research in-depth interviews with relevant stakeholders as well as analysis of smart grid projects using a *Strategic Niche Management framework*. The results show that, though users have become more central in smart grid projects, the focus in the smart grids community is still mainly on technological issues (e.g: smart meters roll out) and economic incentives (e.g: price incentives in order to lower energy use at times of peak load). The article conclude that the domestication of technology, that it to say the way it is embedded in daily household practices is central: users, their daily routine and their social context should be taken more seriously.

These recent studies show an interest in exploring how energy is embedded in every day social practices through a methodological approach mainly based on semi structured interviews directed to either energy stakeholders or users that are taking part to trials on a voluntary base. Therefore the results may be biased towards a segment of the population that has knowledge and acceptance of the new technology and may not be scalable to the whole population. In this light, the aim of the present section is to transcend this specificity using a group discussion setting where people will freely express themselves about beliefs, attitudes and meanings on sustainable energy consumption and analysing attitudes as fluid constructions rather than psychological entities capable of predicting behaviours. I argue that the *critical discursive psychology perspective* used to analyse the data provide a complementary perspectives to those presently used in the literature. In this section, I am interested in investigating ***what kind of discourse on sustainable energy consumption and new smart home technology is connected to every day consumer social practices, meanings and attitudes***. The aim is to shed more light on how people make sense of their everyday energy consumption and how they negotiate and construct beliefs, meanings and social practices in energy consumption.

3.4.2.2 Method

The study of attitudes can be approached with two different perspectives, namely cognitive social and discursive. Their different ways to approach attitude derives from the different ways they understand the person and how the person relates to the world. The *cognitive social perspective* assumes that attitudes are distinctive entities linked to an "object of thought" that can be located on "dimensions of judgement" in some ways (e.g. questionnaires) (Taylor, 2012). Attitudes, according to the cognitive social perspective, endure beyond the moment; this implies that a person holds an attitude before encountering the specific object in a particular situation. The *discursive psychology perspective* (DP) challenges the social cognitive approach at two levels: methodological and theoretical. From the methodological point of view, DP argues that attitude measurements such as questionnaire take responses out of the context and ignores the way meanings are constructed. From the theoretical point of view DP challenge the concept of an attitude as '*an enduring, underlying state expressed in talk and behaviour*' (Taylor, 2012) and the assumptions that an attitude or its object could be the same for different people. Discursive psychology is interested in how meanings, like attitudes, are constructed in talks. The discursive psychological perspective will be the perspective used in this section. Critical social psychology and in particular discursive psychology use alternative research methods and questions to generate alternative visions of the individual; in particular discursive psychology sees the individual as positioned in social available meanings and practices. Discursive psychology researches the role that language and discourse play in constructing social reality. Discourse processes are seen as a form of social action and talks as a means of constructing social reality rather than simply a way of communicating ideas and experiences. Speakers draw on already existing cultural ideas in their discourse. The methodology applied is a discourse analytic methodology which is qualitative through textual and conversation analysis. In discursive psychology the focus of analysis is the external world discourse and its meanings and effects. The interest of this piece of research is to see how "alternate" discourses of sustainable energy consumption and critical social science research may suggest an alternative answer to the dominant approaches based on an efficiency focused rationalisation discourse that presents distinct theories of the environment, the state and the individual (Hobson, 2002). The discursive psychology approach is interesting since it involves a social exploration of new alternatives, social practices and meanings at the group and eventually community level.

The research method employed to collect data is group discussion. The use of group discussion is a popular means of data collection in the social sciences. There are two different research traditions which enlighten the use of group discussion in social sciences: the positivist and the interpretivist traditions. The *positivist tradition* take a scientific approach to the study of social phenomena and assumes that social objectives can be studied objectively and in ways that produce reliable data that can be established as scientific laws (Horton-Salway, 2012). In this light, the outcome of the group discussion is seen as the sum of the individuals' ideas and opinions. The *interpretivist approach* instead has as main interest the individual in its active role in the construction of the social reality. The interpretivist approach focus on the process of negotiating and constructing meanings between people and is interested in examining meanings as socially shared. The attention is on multiplicity of understandings within a specific context. In this perspective, group discussion is considered the most appropriate methodology to approach the research question being investigated in this section since its interest is in exploring how attitudes towards sustainable energy consumption are constructed and negotiated in everyday life.

The research data consists of series of group discussions organized within the framework of a research activity aimed at exploring consumer's perception of smart home devices: "*Exploring consumer's perception of smart home electricity devices in Europe: Public concerns with a focus on health*" (Debarberis, 2015). The participants were informed, prior to the day of the discussion group, of the general subject and aim of the discussion, of the fact that the discussion would be recorded and of the possibility of withdrawal from the research at any time. The participants were asked to sign a consent form prior to the start of the discussion where the aim of the study was clearly stated. Further, they were reassured about confidentiality ("what is said in this room stays here") and on the fact that the recording will be erased once the research will be finalized and assessed. Finally, they were reassured that the interest of the discussion was essentially on hearing experiences and opinion and not on seeking right or wrong answers. The researcher followed a series of leading questions and statements that brought the discussion from the general (electricity consumption) to the more specific (attitudes and perceptions of smart electricity technologies). The discussion was facilitated by two supporting visual representations of smart energy systems and smart homes. For the scope of this thesis, I elaborate the script of one group discussion.

3.4.2.3 Analysis

The collected data are presented in the form of transcript that reports the exact discussion that took place between the participants and the researcher. The first aim was to find regularities and patterns in participants' talk about electricity use and practices exploiting the dynamic nature of the talk in a group discussion that is not available in individual interviews. The search for patterns was guided by three analytic concepts characteristics of critical discursive psychology: *interpretative repertoires*, *ideological dilemmas* and *subject positions* (Reynolds *et al.*, 2003). *Interpretative repertoires* are the recognizable routines of arguments, descriptions and evaluations found in people's talk. They are building blocks of conversations through which people develop accounts and versions of significant events and through which they perform social life. They are part of common sense explanations that provide a basis for shared social understanding and consist of what everyone knows about a topic (Reynolds *et al.*, 2003). However, repertoires can be polarized and inconsistent since different repertoires construct different versions and evaluations of events according to the rhetorical demand of the context. This variability in interpretative repertoires allows for *ideological dilemmas* to arise. Ideological dilemmas represent dilemmatic nature of lived ideologies as opposed to intellectual ideologies. Lived ideologies are composed of beliefs, values and practices of a given society or culture. They are characterized by inconsistency, fragmentation and contradiction that represent discrepancies between the intellectual ideology and the lived ideology. In terms of *subject positions*, these can be defined as subject's "locations" within a conversation. It is how participants take up or attribute identities made relevant in specific ways of talking. These "ways of talking" can change within and between conversations due to the use of different interpretative repertoires or discourses.

I first present the main interpretative repertoires participants drew on to make sense of their electricity consumption:

- ✓ Electricity as integral part of the daily social practices (as a given for granted resource/service)
- ✓ Electricity as comfort and control (individualistic dimension)
- ✓ Electricity as a common limited resource (social dimension)

The first two of these repertoires were strongly put forward and underlined during the first part of the discussion while the second came forward in the development of the discussion. They represent a sort of polarization between an individualistic view of everyday comfort and control over daily social practices and routines and the realization that electricity represents a limited common resource that requires a move towards more sustainable consumption behaviours.

Electricity as integral part of the daily social practices (as a given for granted resource/service)

This repertoire clearly emerges at several points in the discussion:

Extract 1

P1: Yes, on my side I think that electricity is something that is in my life and I cannot live without electricity. …. It is something that is granted. I have electricity, it is normal to have electricity and it impossible to live without electricity.

P2: I would also like to say that I always use electricity when I need it. I use it to my benefit and I am not like a slave of electricity, like oh I shouldn't make this or oh I shouldn't do that just because I will use more electricity.

Here both participants underline how electricity is integral and essential elements of daily life that is *available when needed*.

Extract 2

P1: If I need some more (electricity), if something changes and there are more people at home for example, I know that the consumption will rise and it is not a problem.

Extract 3

P2: If it can be adapted to for example not switch on at night, but switch on during the day according to the peak and the low of the energy rates then that would be a good solution. That the machine would get the information and can switch on when it is a good time and it fits within the habits of the owner. Like an oven, which consumes a lot, you use when you want to eat, so it is difficult to only use it in the night because you want to eat during the day.

P1: Yes, I think it has to be really strongly related to the habits of the owner. For example for the washing machine or may be just every appliance.

These extracts point to the electricity lived as an integral part of everyday life, something "we cannot live without", something given for granted that is part of household daily practices and routines (eating, washing, cooking) and something that has to adapt to the consumer needs and behaviours and not vice versa.

Electricity as comfort and control (individualistic dimension)

A second repertoire is electricity as provider of comfort and as something we can control.

Extract 4

P1: So I can take care of what I do, so I know exactly what I do, I know that there is room for improvement but I consider that my comfort is more important than my consumption. …I have my level of acceptance for the discomfort that it will bring in reducing my consumption.

Comfort is clearly seen as something that has priority also on other important issues as consumption (and therefore costs) and something the participant is not ready to give up on.

Extract 5

P1: The problem is when the provider would tell you to please disconnect this or please disconnect that. That is really what I would not be in favour of, because it could reduce my level of comfort. The consumption is not a problem. The thing is that they have to propose to me smart things to reduce my consumption without reducing my comfort.

Extract 6

P2: but then it is about having the house warm, not to save costs let say by doing that. So it is about the comfort of the user….. I would not like to have the washing machine running in the night when electricity is low price, because I don't want to stay up all night listening to the washing machine.

Once again, the importance of comfort is underlined as having priority on costs.

Extract 7

P1: I don't iron, because I hate ironing. So when the washing machine is done, I immediately take the clothes out and hang them so that I don't have to iron them. So I don't want the washing machine to end when I am not at home.

Extract 8

P1: So I am concerned about management, but mostly I want to manage my electricity use myself, definitely I don't want that any machine is managing these things for me.

P2: They can like, suggest it maybe. Or say it might affect your energy plan and financial…Say how it affects your energy costs. So maybe say this affects your energy costs, and they should inform you on that. But then it should be your decision to live your life how you want to.

These extracts present electricity as something over which the consumers want control in order to accommodate their needs and wishes (comfort). Participants seem not to be ready to give up some of the control they have on their energy use because this would mean adapting behaviours to electricity availability, thus losing comfort. One of the participants positions himself in relation to energy providers ("*they have to propose me smart things*") as those that will have to devise ways in which consumers will not lose comfort. The emphasis is on the individualised processes of energy consumption and on the individual daily routines and practices.

Electricity as a common limited resource (social dimension)

In contrast to the first two repertoires, where electricity is experienced as an individualised process, and is considered a given for granted resource, this repertoire constructs electricity as a limited resource that should not be wasted.

Extract 8

P2: But I never leave light switched on in a room when I am not there, I never leave TV on when I'm not watching. It is a habit of mine to always switch on the lights when I enter a room and switch off the lights when I exit a room.

And when questioned by the researcher about the reasons for this behaviour

P2: I take these measures to reduce electricity consumption, from a financial point of view but also because I find it a waste of resources to use something without the need to use it. So I find a pity to make use of something when actually I don't need it.

Extract 9

P1: It is very difficult. I think that the society has to first adapt the highest consumers to reduce their consumption. And I don't consider myself as someone who wastes the energy. I'm using the energy, I am concerned about energy, and I'm not wasting energy.

Here the participant constructs energy (electricity) as a common limited resource, while positioning him in opposition to other consumers that have higher energy consumption. He clearly states his position as a *concerned consumer* that is *not wasting energy*.

Extract 10

P1: Yes because I think we are human beings in general, we are smart and we can adapt. The thing is that we have to know, to have the information that maybe we are not in line with all the other ones and then have our own reflections about why we are not in line with the other ones.

Once again the participant constructs energy as a social limited resource but this time position himself in alignment with the other consumers (adopters of smart technologies) and is willing to find out the reasons of not being in line with those consumers that are adopting the new technology. This clearly depicts the dilemmatic nature of lived ideologies (the social practices of seeking comfort and control of our lives) as opposed to intellectual ideologies (not wasting common resources) and the need to align ourselves with social norms and strive for common social goals.

The importance that both participants attribute to the contribution they may give to societal goals (sustainable future) and thus their readiness to adapt and change behaviour is further articulated in the following extract:

Extract 11

R: so it makes a difference for you what other people do?

P1: Yes, I want that the society joins together to reach something. Being the first one, no I want that this is something everyone does together.

R: so comfort is important, but if you see that all the people are doing something that you are not doing you are ready to adapt?

P1: Yes, exactly. I want to contribute to the goal.

P2: as a general thought, I think that, my idea is that people should go together with their time, and be modern, so. If you want to keep up life and not be left behind then you have to adapt and be flexible to continue with things.

3.4.2.4 Discussion

The data analysis presented above sheds lights on the kinds of representations circulating in everyday discourse about electricity. These interpretative repertoires identify electricity as an "entity" that is an integral part of the daily social practices of households, it is a given-for-granted resource that helps the individual to move in his/her daily social routines (first interpretative repertoire). Moreover, electricity is functional to comfort, over which consumers want control in order to accommodate their needs and wishes (second interpretative repertoire). In the light of these two constructions of reality, the participants appear not to be ready to give up some of the control they have on their energy use because this would mean adapting behaviours to electricity availability, thus losing comfort. The participants position themselves in their daily household practices, where electricity has an individual and self-enhancing dimension that facilitate and smooth their daily routines. However, in contrast to the first two repertoires, the discourse analysis shows the emergence of a repertoire that constructs electricity as a limited resource that should not be wasted. Here the participants construct electricity as a common limited resource. Both participants position themselves as consumers that do not waste energy as opposed to the "highest consumers" who are the first, according to the participants, that have to reduce their consumption. They both clearly state their positions as *concerned consumers* that are *not wasting energy*. The analysis further shows that participants want to align themselves with the best consumers (those with a lower consumption). This clearly depicts the dilemmatic nature of lived ideologies (the social practices of seeking comfort and control of our lives) as opposed to intellectual ideologies (not wasting common resources and the need to align ourselves with social norms). They both are ready to adapt their behaviours if this can contribute to the societal goals of a sustainable future. The findings are in line with the recent literature on sustainable energy consumption. In particular they strengthen the idea that the way electricity and technology are embedded in daily household practices should be more central in the research and development of smart grids. The changes in social practices that the further electrification of the home will require need more attention and analysis. If not well understood, the energy efficiency benefits derived from smart grids might be offset. Finally, my results show that smart home technology support the claim that domestic energy consumption is a social and collective *as well as* individual process.

In regard to the perspective used for analysing the data, I think that critical discourse psychology fits very well the purpose of the research question which is to explore consumers' attitudes, perceptions and social practices related to electricity. Indeed a critical discursive psychology approach helps in shedding light on the kinds of representation circulating in every day discourse about electricity (*discourse resources*: electricity as granted and essential, electricity as comfort and control) and in identifying how these resources are used to construct and reconstruct the idea of electricity as an individual right as well as a social good that should be cared for in a socially fair way ("*you are very good, but I want that the level (of data security and electricity consumption) is the same for everybody"*) (*discourse processes*). The discourse analysis performed highlights how values and preferences are not fixed, but fluid and dynamic, constructed and negotiated in a social context that can vary from household level to community level. I will build on these results to develop the framework presented in Chapter 5.

3.5 Maintaining full protection for consumers

Consumers are concerned about a broad range of issues that include cost, loss of control (including utilities' ability to arbitrarily or accidentally shut off the service), health effects of radio frequency, safety, privacy and data protection, fairness, uneven distribution of effects and the impact that smart grid may have on vulnerable groups such as fuel poor, elderly or people who are less familiar with IT. These concerns have been reported worldwide (Krishnamurti et al., 2012; Ngar-yin Mah et al., 2012; Broman Toft et al., 2014) and have also emerged from the analysis of surveys at EU level (section 3.3.2). As I have discussed in Chapter 1, the internal energy market legislation clearly established, together with common rules for the generation, transmission, distribution and supply of electricity, consumer protection provisions, with a view to improving and integrating competitive electricity markets in the Community. Consumer protection has further being addressed in the New Deal for the energy consumer and the recent Clean Energy Package. In this section I present the main consumer's concerns that emerge from the literature review and the findings presented in Chapter 3. The analysis of pilot projects does not provide sufficient evidence to draw conclusion on consumer's concerns and on how they have been addressed in the projects.

3.5.1 Consumer's concerns

3.5.1.1 Data privacy and security

An indirect risk of smart grid is the violation of consumer's privacy. AlAbdulkarim (Alabdulkarim, 2013) defines privacy as the right of electricity consumers to be guaranteed adequate measures of protection of their personal data maintained by the system, to prevent disclosure of this data to unauthorized parties and prevent unlawful deduction of further information from the data, which can reveal private aspects of consumers' behaviour and habits. The consumers are not only concerned with confidentiality, but also with data sharing and retention. These concerns are linked to the possibility of identifying consumer general behaviour patterns from their appliance usage (individual patterns), to monitor consumer behaviour as it happens (real time surveillance), to sell consumer information to third parties to profile individuals (information detritus) and to determine whether a person is at home (physical invasion) (Krishnamurti *et al.*, 2012).

The data privacy issue has served as an argument for the Dutch government to renounce plans for mandatory implementation of smart meters in the Netherlands (KEMA, 2010). The report states that from a legal standpoint smart meters pose a legal dilemma since the frequent readings threaten the respect for private and family life according to the Convention for Protection of Human right and Fundamental Freedoms (KEMA, 2010). This resulted in granting the consumers with an opportunity to opt for a smart meter under "administrative-off", assuring no data can be exchanged with the DSO or any third party and thus disabling the possibility of remote control and disconnection. Therefore, the ability of regulators and companies to control and secure data privacy will have a large influence on how willing consumers are to move towards smart grid deployment. The EU Commission's Expert Group 2, Smart Grid Task Force argues that the data privacy and security should be addressed at the design phase of the smart grid, i.e. prior to the development of the smart grid systems and processes. One of the key features of the "privacy by design" strategy is the approach towards data handling, namely: data control and access rights, data use, data storage and data sharing. In addition to the "privacy by design principle", mechanisms shall be implemented for ensuring that, by default, only those personal data are processed which are necessary for each specific purpose of the processing and are especially not collected or retained beyond the minimum necessary for those purposes, both in terms of the amount of the data and the time of their storage.

Furthermore, it must be clear whether and what data processed for smart metering are the personal data and thus whether the EU data protection framework applies. Two types of data are processed within smart metering: - personal data, defined in accordance with the Data Protection Directive and - technical data, that is to say any data needed for maintenance of the grid.

Related to the issue of data privacy is the grid cyber security. While the two-way consumer-utility communication and internet-transferred data will account for sustainable and efficient delivery of electric energy, while placing the consumers in the focal point, it also makes the grid vulnerable to external attacks. These attacks could range from remotely disconnecting customers to hacking a network to adjust load conditions, which could ultimately result in electricity network instability. Securing the electricity network requires protecting a variety of devices connected to the grid that heavily rely on wireless technologies.

3.5.1.2 Health concerns

Several studies (Krishnamurti *et al.*, 2012; Alabdulkarim, 2013; Consumer Futures, 2013) report on consumers concerns regarding the adverse impact on health caused by the electromagnetic waves emitted by the meter. While many consumers are willing to adopt technologies that emit electromagnetic wave such as mobile phones or Wi-Fi communication, some still object to wireless smart meters due to fear of prolonged exposure to the radiofrequency emitted by the smart meter. Although evidence to date suggests that exposure to radio wave produced by smart meters do not pose a risk to health, it is important that consumer's anxieties about the health impacts of smart systems are taken seriously. In addition, anxiety about possible health impacts of smart systems could cause delays or threaten their installation (Consumer Futures, 2013). Moreover, increased awareness of adverse health effects has resulted in numerous activist-campaigns demanding that the consumer be given the right to choose (Alabdulkarim, 2013).

3.5.2 Consumer's protection

3.5.2.1 Vulnerable consumers

Vulnerable consumers are consumers that have difficulties in accessing products and services that suit their needs due to their particular conditions such as, for example, long term ill health, age or financial situation (Consumer Futures, 2013). The 2009 internal energy market legislation introduced an obligation for Member States to take appropriate measures to protect vulnerable consumers. In particular, each Member State shall define the concept of vulnerable customers which may refer to energy poverty and, inter alia, to the prohibition of disconnection of electricity to such customers in critical times. The legislation recognizes the diverse situations of energy consumers in different parts of the EU; the European Commission does not consider it appropriate at this stage to propose a European definition of energy poverty or of vulnerable customers (INSIGH_E, 2015). Therefore, each member state has different approach strategies to the vulnerable consumer and respective issues to be tackled with.

For instance, the UK 'Safety Net' initiative guarantees to never knowingly disconnect a vulnerable customer at any time of year, where for reasons of age, health, disability or severe financial insecurity that customer is unable to safeguard their personal welfare or the personal welfare of other members of the household (Eurelectric, 2013).

3.5.2.2 Energy poor

A fuel poor household is defined as a household that cannot afford to keep adequately warm at reasonable cost. The World Health Organisation (World Health Organization, 2007) notes that the term "fuel poverty" does not necessarily mean that a household is 'poor' in the traditional sense, and suggests to consider a definition that is less based on a concept of poverty and is more targeting the home. It argues that the main risk factor is inadequate housing and that fuel poverty is to be seen as a result and not as a cause of that. At national level, definitions of fuel poor household exist in the UK and Ireland where it is considered to be a household which needs to spend more than 10% of its income on all fuel use and to heat its home to an adequate standard of warmth. This is generally defined as 21ºC in the living room and 18ºC in the other occupied rooms - the temperatures recommended by the World Health Organisation (Darby *et al.*, 2012). Smart grid technology may present some positive aspects in relation to fuel poor: - smart meters can facilitate prepayment and avoid higher unit prices; - energy displays can help consumer to visualize their energy use and alert them in case of unusual patterns, - benefit of preferential access to cheap electricity (in case of abundant supply) (Darby *et al.*, 2012). However, smart grids are still surrounded by uncertainty, in particular for what concerns social and economic factors. This uncertainty strongly suggests a need to involve a wide spectrum of system users, including the fuel poor, in the trials of new technology and even in the design of those trials (Darby *et al.*, 2012). For example, it is not yet clear what kind of direct or indirect impacts the EU policy on smart metering may have on household in fuel poverty.

Figure 26 shows the regional distribution of the share of the population at risk of energy poverty. Southern and Eastern regions of Europe are at higher risk of energy poverty (INSIGH_E, 2015).

Figure 26. Share of population at risk of energy poverty in the EU (INSIGH_E, 2015)

Other proxy indicators for energy poverty can be used, as for example: dwellings with leakages and damp walls, having arrears in account, ability to keep the home comfortably cool, ability to keep home adequately warm. This is represented in Figure 27.

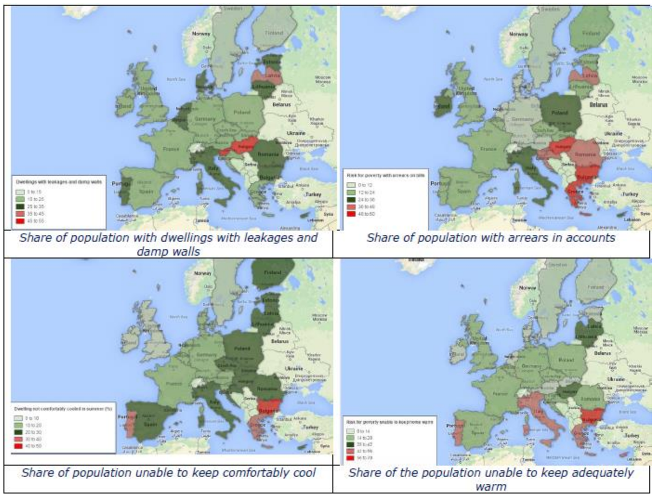

Figure 27. Share of population at risk of energy poverty in the EU (INSIGH_E, 2015)

Recent literature recognizes that energy poverty is caused by an interaction between high energy bills, low income and poor energy efficiency, in addition to supplementary determinants such as housing tenure and quality of energy supply (Thomson *et al.*, 2013) (Bouzarovski *et al.*, 2012) (Bouzarovski *et al.*, 2015). Possible indicators for measuring these aspects are suggested in Figure 28 (INSIGH_E, 2015).

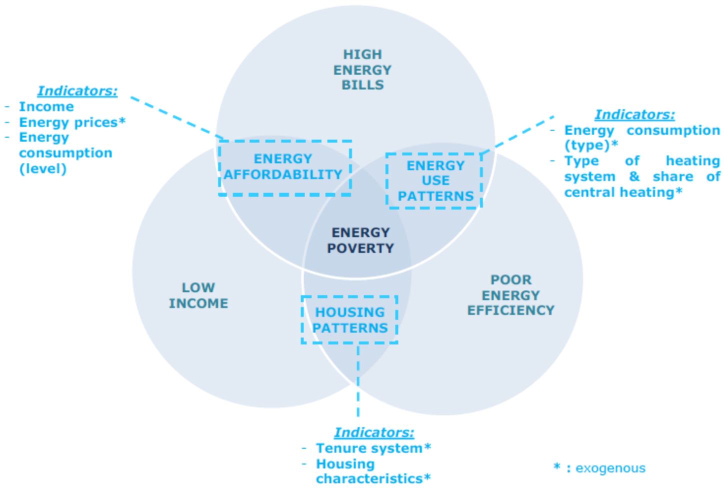

Figure 28. Drivers of energy poverty and key indicators (INSIGH_E, 2015)

The same study (INSIGH_E, 2015) suggests the following definition of energy poverty as "*a situation where individuals or households are not able to adequately heat or provide other required energy services in their homes at affordable cost*". However a commonly agreed definition of energy poverty is still missing at European level. Less than a third of Member States explicitly recognise concepts of energy poverty, and only four countries have legislated definitions (UK, Ireland, France, Cyprus).

The concept of energy poverty is often associated with that of vulnerable consumers, yet the second notion is wider and includes broader vulnerability issues not only related to affordability, e.g. disability, unemployment, age, etc. To address the energy vulnerable and energy poverty challenges actions should be taken in a variety of fields, including technical, financial, social, consumer protection, information provision, etc. This integrated approach is essential for the definition of a clear policy framework.

3.5.3 Fairness in energy

An increasing number of energy policy documents underline the importance of fairness and participation, without further developing these concepts (European Commission, 2015a) (European Commission, 2015b; European Commission, 2015d). The concept of energy fairness is strictly related to the concept of energy justice. The work on energy justice to date has been framed mainly within the literature on environmental justice (Jenkins *et al.*, 2016) (Ottinger, 2013). However the relevance of justice or equity in energy emerges as one of the three cores dimensions of the definition of energy sustainability provided by the World Energy Council that reads: *"Delivering policies which simultaneously address energy security, universal access to affordable energy services, and environmentally sensitive production and use of energy is one of the most formidable challenges facing government and industry"*. (World Energy Council, 2016)

Therefore there is the need to ask new questions of energy research, concerning participation, cooperation and motivation. Recent studies (Jenkins *et al.*, 2016) (Jenkins *et al.*) (Heffron *et al.*, 2015) have tried to bring some clarity and insight in the concepts of justice and fairness in energy.

Fairness questions related to energy could be answered through a three-level approach. The first level concerns the **fulfilment of basic needs**. One needs to have access to energy in order to participate in society and this energy has to be affordable. The second level concerns **distributive fairness** that is to say how benefits and burdens are distributed. These benefits and burdens include market mechanisms, network costs (how should the network costs be distributed?), non-local and local externalities linked to energy production and transportation. The third level concerns participation in decision making (**procedural fairness**). Participation can be related to general policy matters or specific technology implementation (e.g. siting of wind farm, smart meters deployment). How people evaluate a specific technology or policy implementation and how they will respond to it are influenced by the perceived fairness of the decision process that led to that implementation(Huijts *et al.*, 2012).

The **fulfilment of basic needs** relates to the issue of energy poverty. *Energy poverty* is about a structural deficit regarding the accessibility and affordability of energy, e.g. the rate of energy price rises versus income growth, the ability to have access to cheaper energy prices, the household energy needs, the lack of efficiency of energy use, the efficacy of social policy interventions.

3.6 Conclusions: towards an integrated approach to energy communities

The scope of the present chapter was to understand, through the review of social psychology theories and the analysis of evidence from EU surveys and DSM pilot projects the attitudes, preferences and concerns of the electricity consumer. It emerges that energy consumption is an individual as well as collective process that need to be understood and tackled in its complex dimension and may benefit of community-based local approaches.

Local energy systems are increasingly being recognized as having a crucial role in the energy transition as they are important both for self-sufficiency and sustainability and are expected to in a better position over profit-seeking traditional utilities to tackle the issue of energy poverty (Koirala *et al.*, 2016) and fairness in energy. Research on local energy systems has increased significantly in recent years. However these studies still lack a comprehensive and integrated approach for local energy systems. As argued by Koirala the various available approaches " *are designed to adapt to an existing blueprint of a centralized energy system*" (Koirala *et al.*, 2016). There is a need for a shift to an integrated approach that captures all the benefits of distributed energy resources and increases the local as well as the global welfare (see

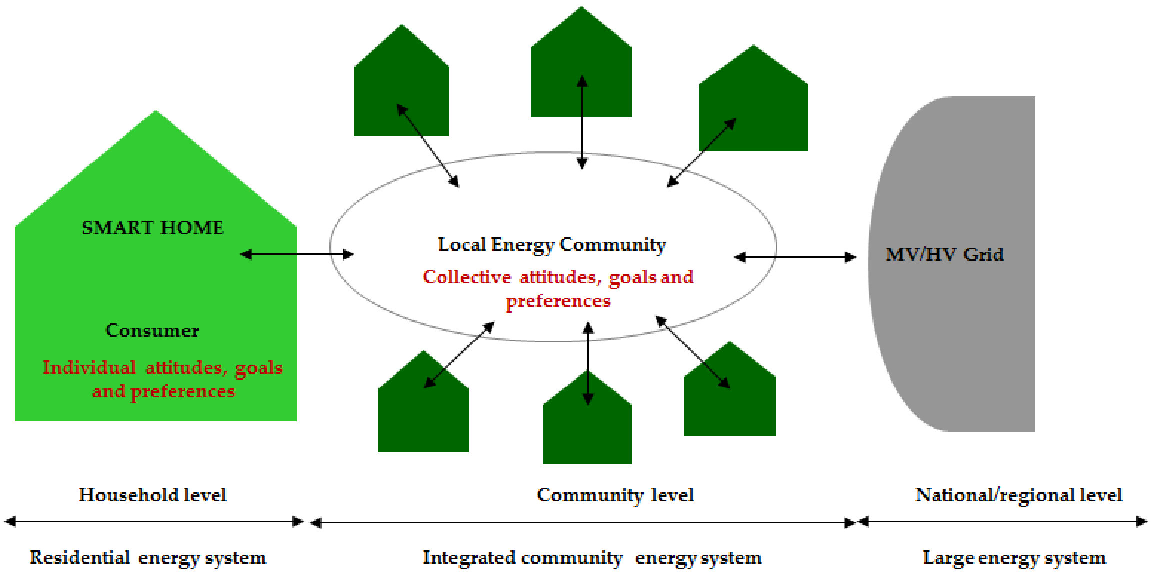

Figure 29. An integrated community energy system (adapted from (Koirala *et al.*, 2016))

4 Subjective Individual Model of Prosumer

4.1 Introduction

In this chapter I will present an agent based model – **Subjective Individual Model of Prosumer (SIMP)** - that simulates interacting energy end-users. This model aims at providing insights into prosumers distinctive behaviours at micro-level, while observing emergent behaviours of the overall system at macro level. I will use a broader understanding of the term *prosumer* as discussed in Chapter 1, where the term prosumer "*includes all consumers that not only passively consume energy, but are also actively participating in the market (through energy efficiency measures and demand-side response), thus generating value for themselves or for the other players in the market".* The model is mainly aimed at investigating the energy prosumer behaviour when prosumer is exposed to different energy contracts that present different levels of technology development. Self-generation and the inclusion of the electricity network are not included in this first version of the model.

I am interested in capturing emergent prosumer's behaviours in terms of contract choices (technological choices), switching rate, sustainability and attitude satisfaction while they interact with their peers and social networks under different EU policies and interventions at macro level. The model conceptualization is based on the findings of the previous chapters where, through the analysis of social psychology theories and evidence from energy consumer surveys, focus groups and demand side management projects I have characterized the electricity prosumer. The EU surveys and studies have shown that energy consumers still lack awareness of their energy consumption and of smart metering technologies, though significant differences at national level exist. Moreover, from the analysis of DSM pilot projects emerges that consumers have different drivers and motivations to engage with smart metering technologies and do have concerns that my hinder their adoption. This is also what emerges from the analysis of focus groups discussions, where, however, the influence of social dynamics shows the fluidity of interpretations and views on the emerging electricity systems. The importance of the collective dimension of energy use is also confirmed from additional analysis of the engagement strategies used in EU demand side management projects. The analysis of the theoretical approach to sustainable energy consumption behaviour has shown a variety of approaches. For the development of the model that I will present in this chapter I combine elements from the Theory of Planned Behaviour, Goal Framing Theory and the concept of "homophily" (Rogers, 1983) (McPherson *et al.*, 2001) that were discussed in Chapter 3.

The findings of Chapter 3 represent the inputs to SIMP as shown in **Error! Reference source not ound.**.

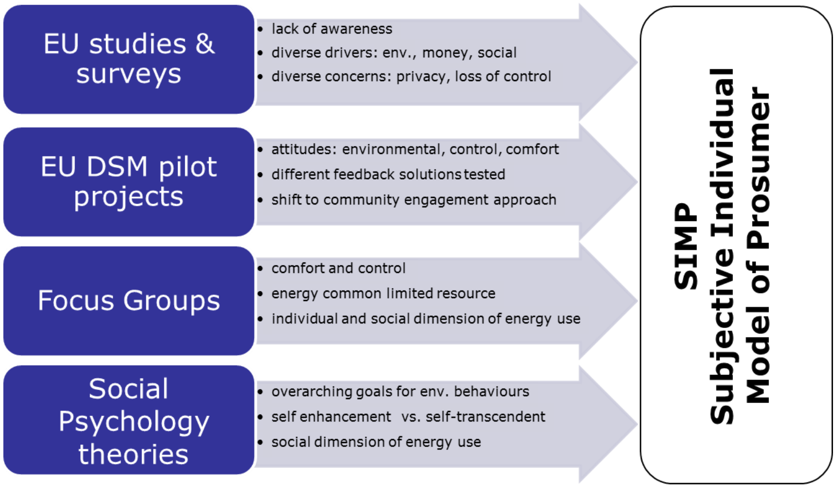

Figure 30. Inputs to the model architecture

As discussed in Chapter 1, agent based modelling is a suitable tool to address the complexity of socio-technical systems where human interact heavily with the technical system. ABM, generating phenomena in a bottom-up approach, allows a better reflection of the complexity of socio-technical systems than standard techno economic modelling approaches (Epstein *et al.*, 1996; van Dam *et al.*, 2013; Boero *et al.*, 2015). ABM can be considered as a 'virtual laboratory' for simulating interactions among large numbers of human and non-human actors providing advantages over traditional simulation models. ABM allows the researcher to run a wide range of virtual experiments to gain greater understanding of complex, non-linear systems (Loomis *et al.*, 2008). In recent years there has been an increasing trend in using agent based simulation in residential energy research (Zhang *et al.*, 2011; Chappin *et al.*, 2012; Kowalska-Pyzalska *et al.*, 2014) that is contributing to the understanding of both scientific and applied aspects of the demand side of energy use (Rai *et al.*, 2016). The idea is to model in a virtual environment the electricity prosumer who, while acting in a smart grid technology context, behaves and interacts with other actors at household, community and societal level. In particular, Zhang and Nuttall (Zhang *et al.*, 2011) have developed an agent-based model of a market game involving two parties: residential electricity consumers and electricity suppliers. The aim of the model is to evaluate the effectiveness of UK policy on promoting smart metering in the UK retail electricity market. The Theory of Planned Behaviour (Ajzen, 1991) (see Chapter 3) has been chosen to formalize the behaviour of residential electricity consumer agents. This theoretical choice is driven by the consideration that the Theory of Planned Behaviour emphasizes the role of psychological (attitudes), sociological (subjective norms) and environmental factors (perceived behavioural control) in the consumer's decision making process. However, a limitation of the proposed model is consumer's personality characterization. It suggests that consumer's intention to perform certain behaviours is essentially driven by consumer's personality trait "price sensitivity". However, the range of "attitudes" that jointly determine a person's intention to perform a behaviour is certainly broader than the purely sensitivity to "price incentives" as I have discussed in Chapter 3. A schematic view of the consumer characterization that I will use in the present chapter is presented in Figure 31.

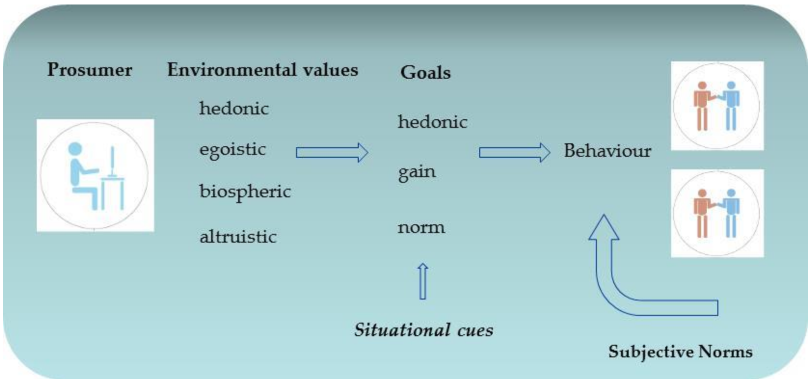

Figure 31. Consumer characterization

Building on the work of Zhang and Nuttall, on the findings of Chapter 3 and on the conceptual steps sketched by Rai (2016) (Rai *et al.*, 2016) in Chapter 2, I develop an agent-based model of electricity prosumers interacting with an energy supplier through a series of electricity contracts, each contract characterized by a different type of service(s) offered to the prosumer. The model foresees only one energy supplier who however has a wide portfolio of contracts available for the consumers.

My aim is to explore the diffusion of smart grid technologies enabled services among a population of interacting electricity prosumers and to evaluate the impact of such diffusion on individual and societal performance indicators.

The SIMP model, implemented in NetLogo, can be used as a tool or "reasoning machine" that can contribute to the understanding of diffusion patterns of energy services (in the present case, represented by contracts) and associated switching rate.

The work presented hereafter is an elaboration and extension of the research presented in: *"An agent based-model of electricity consumer: smart metering policy implications in Europe"(Vasiljevska et al., 2017).*

4.2 Model architecture

The model consists of a number of agents (i.e.: electricity prosumers) and a portfolio of electricity contracts offered by the electricity supplier. The agents are characterized by attitudes and concerns. The agents, their relevant others (e.g.: reference groups, peer groups) and their interactions through electricity contracts with the electricity system, represent the socio-technical system I am interested in modelling. Each contract is characterized by a type of end-user service (defined in the contract and enabled by the smart meter) and time duration. The *prosumer-agents* gain experience with a certain type of contract and retain this experience in their memory. The prosumer-agents also communicate their experience to other similar agents (according to the concept of *homophily*) and this may influence their decision on the type of contract they will adopt. An overview of the model architecture is presented in Figure 32

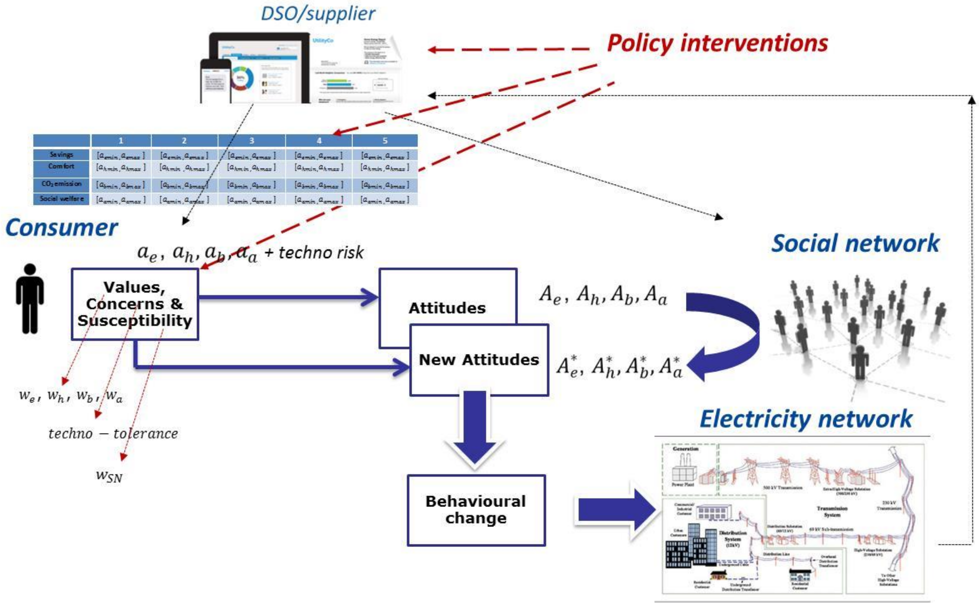

Figure 32. SIMP model architecture

Furthermore, prosumer-agents behaviour may be influenced by governmental policy (e.g.: national roll-out of smart metering systems with opt-out option for the prosumers), national/local authority initiatives (e.g.: environmental campaigns) or business case driven initiatives from the DSO/supplier. While policies and institutions are influenced and shaped by actors' behaviours (DSO, consumers, markets, etc.) and change over time, for the purpose of this model they are assumed to be exogenous and fixed.

The socio-technical system as a whole evolves based on the decision of individual agent. These decisions influence the overall system level performance indicators defined as:

- ✓ Adoption of contract types;
- ✓ Energy savings;
- ✓ CO_2 emission savings;
- ✓ Comfort change;
- ✓ Social welfare.

I will further explain these performance indicators in the following sections.

The model is simulated for a period of 10 years with time steps of one month and in each simulation run the system behaviour is a combined result of the actions of all agents.

4.2.1 Agent characterization

The central entity of the model is the *electricity prosumer-agent*, representing individual households. Prosumer-agents have personal goals and preferences determined by their own personal values. The literature on environmental values (Steg *et al.*, 2012; Steg *et al.*, 2014), as presented in Chapter 3, defines *self-enhancing values* as those values that reflect a key concerns with one's individual interest and well-being, i.e.: egoistic and hedonistic values and *self-transcendent values* as those values that reflect a key concern with collective interest i.e.: altruistic and biospheric values. These self-enhancement and self-transcendent values characterise the prosumer-agents' weight factors w_e, w_h, w_b , w_a and describe the agent's relevance (Menanteau *et al.*, 2000) towards four criteria that I define as follows: *financial savings* (related to egoistic values), *comfort change* (related to hedonistic values), *CO_2 savings* (related to biospheric values) and *social welfare* (related to altruistic values). The weights are randomly assigned to each agent, following a uniform distribution [0,1], as defined in Table 4.1 (see section 2.3). The highest weight factor determines the "*archetype*" each agent belongs to (e.g.: agents belonging to egoistic archetype have the highest weight factor for the egoistic criterion), which indicates that the agents are heterogeneous for what concerns the archetype. The weights are normalized so that the sum of the weights equals 1. The four values (egoistic, hedonistic, biospheric and altruistic) that characterise the consumer's weight factors also characterize each contract and will be used by the prosumer to evaluate the contracts.

The four criteria for financial savings, comfort (thermal comfort), CO_2 emission reduction and social welfare are defined hereafter.

For **financial savings** I consider as criterion the monetary value of saved energy defined as follows:

Box 4.1: Financial savings

$$a_e[€] = E_{average\_saved}[kWh] * price[\frac{€}{KWh}]$$

$E_{average\_saved}[kWh]$ is the average monthly energy saved and $price[\frac{€}{KWh}]$ is the electricity price.

For **comfort** I consider as criterion the change in thermal comfort defined as follows:

Box 4.2: Thermal comfort

$$a_h\,[\%] = \frac{T_{final}[°C] - T_{set}[°C]}{T_{set}\,[°C]} * 100\ \%$$

T_{set} [°C] is the target thermostat temperature set by the agent and T_{final}[°C] is the actual temperature occurred due to behaviour change.

For **CO_2 emission reduction** I use the following:

Box 4.3: CO_2 emission reduction

$a_{\mathrm{h}}\,[t_{CO2}] = E_{average\_saved}[kWh] * e_{rf}\left[\frac{t_{CO2}}{KWh}\right]$

$E_{average\_saved}[kWh]$ is the average monthly energy saved and $e_{rf}\left[\frac{t_{CO2}}{KWh}\right]$ represents emissions reference factor.

For **social welfare**, I use demand factor as a proxy of how efficiently the consumer is using electricity during defined time period (e.g. month) and define it as follows:

Box 4.4: Social welfare

$a_{\mathrm{a}}[\%] = \left(1 - \frac{P_{max}[kW]}{P_{peak}[kW]}\right) * 100\%$

$P_{max}[kW]$ is the maximum load used in a given time period (*i.e.* month) and $P_{peak}[kW]$ is the peak power during time period of one month, corresponding to the contracted capacity of the household. Low demand factor means less system capacity is required to serve the connected load.

Each time step (one month), the prosumer-agent has a certain contract and based on the experience it has with that contract, develop an attitude towards the contract. Furthermore, the *prosumer-agent* memorises the experience it has with all past contracts and communicates this memorised experience to other similar agents, potentially influencing their decisions. When an agent is not satisfied with the current contract it decides to opt for a new one. The satisfaction level of each agent is measured relatively to an agent specific variable defined as *threshold-attitude.* When the agent is satisfied with the current contract, but the contract has ended (contract duration = 12 months) the agent considers the present contract in the portfolio of contracts to be evaluated at the following time step. The decisions on what type of contract the agent opts for is based on the scores on contract criteria a_{e}, a_h, a_b and a_{a} weighed against weight factors w_e, w_h, w_b and w_a and modelled as multi-criteria problem, as consumers evaluate multiple electricity contracts against the given set of criteria.

As emerged from the analysis of EU surveys and pilot projects (Chapter 3) electricity *prosumer-agents* also have technology concerns, in terms of data privacy, security and health. To take these concerns into consideration, each agent is characterized as having a "*techno-tolerance threshold*". Figure 33 summarizes the electricity *prosumer-agent* characterization. Finally, I introduce the variable w_{sn}, defined as *susceptibility* factor, that represents a measure of agent's personal beliefs about what relevant others (e.g.: reference groups, peer groups) might think of its actions (subjective norms).

Figure 33. Electricity prosumer-agent characterization

4.2.2 Agent's activities

Agents have a certain contract α_j with the electricity supplier. Each contract communicates range of values (a_{cmin}, a_{cmax}) relative to the four criteria (Box 4.1-4.4) and expected to be achieved with that contract. The average of that range is the communicated score of contract α_j on criterion c, i.e.:

$$a_{c,communicated} = \frac{a_{c,max} + a_{c,min}}{2} \qquad (1)$$

To combine the scores across criteria when evaluating single contract, the scores are normalized as follows:

$$a_{c,norm,communicated}(\alpha_j) = \frac{a_{c,max\,max} - a_{c,communicated}}{a_{c,max\,max} - a_{c,min\,min}} \qquad (2)$$

where $a_{c,maxmax} = max_k(a_{cmax})$ and $a_{c,minmin} = min_k(a_{cmin})$ are the best and worst communicated score of α_j on criterion c among all k communicated contracts. This way, $a_{c,norm,communicated}$ will always be a value between 0 and 1.

The agent's decision making process is presented in Figure 34.

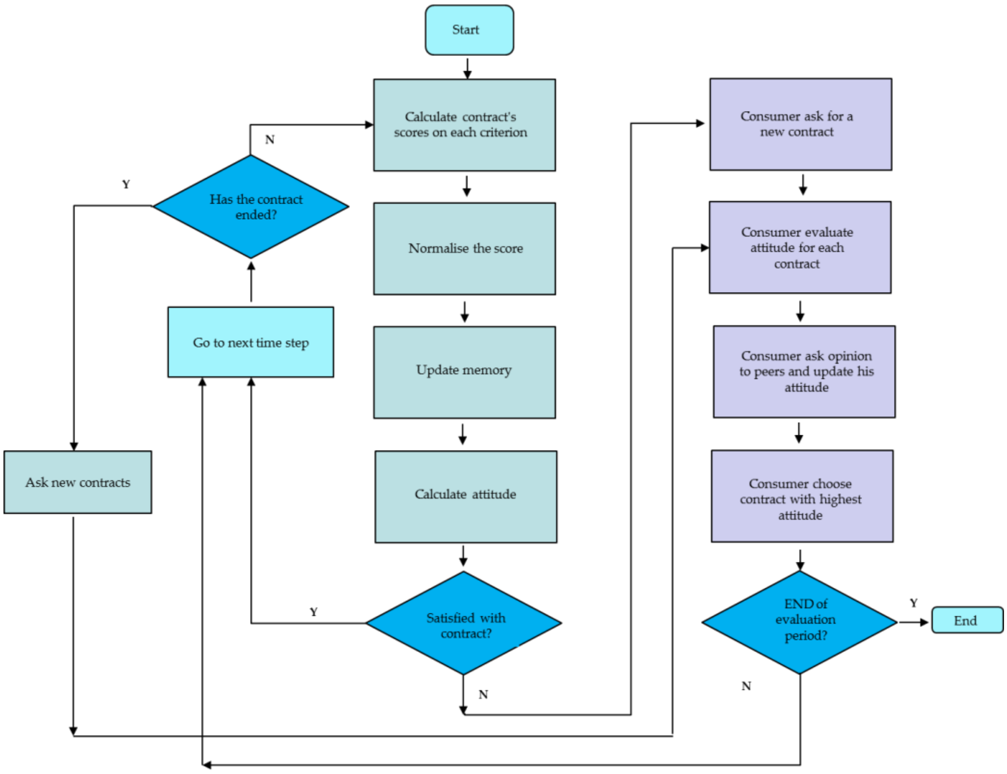

Figure 34. Flow chart of consumer's decision making process

How prosumers update their memory

Positive consumer's experience would certainly result in the diffusion of more advanced smart grid technologies. While EU currently progresses towards nation wide deployment of smart metering systems, the real impact of smart grid technologies enabled services is still uncertain and consumers' experience with smart metering systems is limited. However, some observations on potential impacts (energy savings, monetary savings, CO_2 reduction, comfort change, etc.) of using smart metering systems (smart meter and feedback devices) is already reported in the literature. I therefore use a range of these impacts for deriving the experienced scores (see Table 4.1 in the following section). With this in mind, at each time step agents gain experience with contract α_j and the experienced score on each criterion c is derived as a random value from the communicated range, i.e.:

$$a_{c,experienced} = rand(a_{cmin}, a_{cmax}) \qquad (3)$$

Next, the experienced score is normalized, as follows:

$$a_{c,norm,experienced}(\alpha_j) = \frac{a_{c,max\,max} - a_{c,experienced}}{a_{c,max\,max} - a_{c,min\,min}} \qquad (4)$$

where, $a_{c,norm,experienced}(\alpha_j)$ is the normalized experienced score of contract α_j on criterion c and $a_{c,maxmax}$ and $a_{c,minmin}$ are defined as in (2).

Consumers update the existing values in their memory with the current experience they have by calculating the average of the past experienced score and the new experienced score as in (5). At the initial time step and in case of no previous experience: $a_{c,memory}(\alpha_j) = a_{c,norm,communicated}(\alpha_j)$.

$$a^*_{c,memory}(\alpha_j) = \frac{1}{2} * a_{c,memory}(\alpha_j) + \frac{1}{2} * a_{c,norm,experienced}(\alpha_j) \qquad (5)$$

where $a_{c,norm,experienced}(\alpha_j)$ is calculated as in (4) and $a^*_{c,memory}(\alpha_j)$ is the updated memory value.

How prosumers calculate their attitude

Next, each agent calculates the attitudes towards contract α_j by multiplying the scores on criterion *c* with the criteria-specific weight factor w_c and summing the result, i.e.:

$$A_{c,experienced}(\alpha_j) = w_c * a^*_{c,memory}(\alpha_j) \qquad (6)$$

with w_c being the weight factor, as a measure of relative importance the agent gives to criterion *c* and it is randomly drawn from a uniform distribution between 0 and 1.

The total attitude towards contract α_j is the sum of all individual attitudes relative to each single criterion *c*, where *c € [e, h, b, a]:*

$$A(\alpha_j) = A_{e,experienced}(\alpha_j) + A_{h,experienced}(\alpha_j) + A_{b,experienced}(\alpha_j) + A_{a,experienced}(\alpha_j) \qquad (7)$$

Based on this attitude and agent-specific satisfaction threshold, the agents decide whether to switch to a different contract or keep the contract they currently have.

How consumers choose their contract

Personal preferences

At each time step (t = one month), the agent may consider switching to a different contract if one of the following reasons is true:

- ✓ agent is dissatisfied with the current contract or
- ✓ contract has expired.

In each of these cases, agents ask for new available contracts from the supplier and perform an evaluation of the portfolio of the received contracts. If the agent was satisfied with the current contract and the same has ended, the agent reconsiders it for evaluation, along with the new received contracts. The decision making process is modelled as a multi-criteria problem as presented in Figure 4.5.

Technology concerns, in terms of data privacy and security, health, etc. have been highlighted in several EU smart grid pilot projects and national roll-outs of smart metering technologies. For example, in the case of the Netherlands, the original legal obligation to accept the meter was revoked due to data privacy concerns. This resulted in granting the consumer with the possibility to either refuse the smart meter or accept it while blocking the remote reading option (so called "administrative off" option). To introduce such concerns in the model, I have characterized each agent with a "*techno-tolerance threshold*" and each contract with a level of perceived concerns: "*techno-risks*". For each contract that the agent receives, the agent considers only those contracts that have a "*techno-risk*" value that is below the agent's "techno-tolerance threshold".

The total attitude towards each contract under evaluation is the sum of each single attitude relative to each single criterion c, where *c € [e, h, b, a]:*

$$A(\alpha_j) = A_{e,communicated}(\alpha_j) + A_{h,communicated}(\alpha_j) + A_{b,communicated}(\alpha_j) + A_{a,communicated}(\alpha_j) \qquad (8)$$

$$A_{c,communicated}(\alpha_j) = w_c * a_{c,norm,communicated}(\alpha_j) \qquad (9)$$

Peer influence: relevant others

Each agent have a circle of relevant others (e.g.: reference groups, peer groups) that may influence its choices. The circle of peers is generated in such a way that each agent communicates with *n* other peers in a circle of 200 agents. Half of those peers belong to the same archetype – people tend to associate with others who are similar according to the principle of "homophily" (McPherson *et al.*, 2001) and the rest are randomly chosen from different archetypes. This choice introduces some *heterogeneity* in the model and it is defined as the number of peers with whom the agent communicates that belongs to a different archetype than the one of the agent.

Based on the experience each agent shares with this *n* peers, agents update their attitude as follows:

$$A_c^*(\alpha_j) = A_{c,communicated}(\alpha_j) + \left(\frac{\sum_{i=1}^{n} A_{ic,experienced}(\alpha_j)}{n} - A_{c,communicated}(\alpha_j)\right) * w_{SN} \qquad (10)$$

where $A_{ic,experienced}$ presents the attitude of the i-th neighbour among n neighbours the agent communicates with and it is calculated as in (6); w_{SN} stands for the susceptibility factor, as a measure of the importance the agent gives to the opinion of its peers and $A_{c,communicated}(\alpha_j)$ represents the personal attitude the agent has towards contract α_j and relative to the score on criterion c, calculated as in (9).

The agent behaviour, in terms of adoption of the electricity contract α_j, is determined by the agent's personal attitude towards a certain contract (first term in (10)) and by the difference between agent's own personal attitude and the attitude of the peers taking into consideration the agent's susceptibility (second term in (10)).

Finally, the agent elaborates an overall attitude $A^*(\alpha_j)$ towards contract α_j, i.e.:

$$A^*(\alpha_j) = A_e^*(\alpha_j) + A_h^*(\alpha_j) + A_b^*(\alpha_j) + A_a^*(\alpha_j) \qquad (11)$$

The agent will choose the contract that maximizes its attitude:

$$A^* = max\left(A^*(\alpha_1), A^*(\alpha_2), \dots, A^*(\alpha_j), \dots, A^*(\alpha_k)\right) \qquad (12)$$

Figure 35 provides a snapshot of the model interface as implemented in NetLogo.

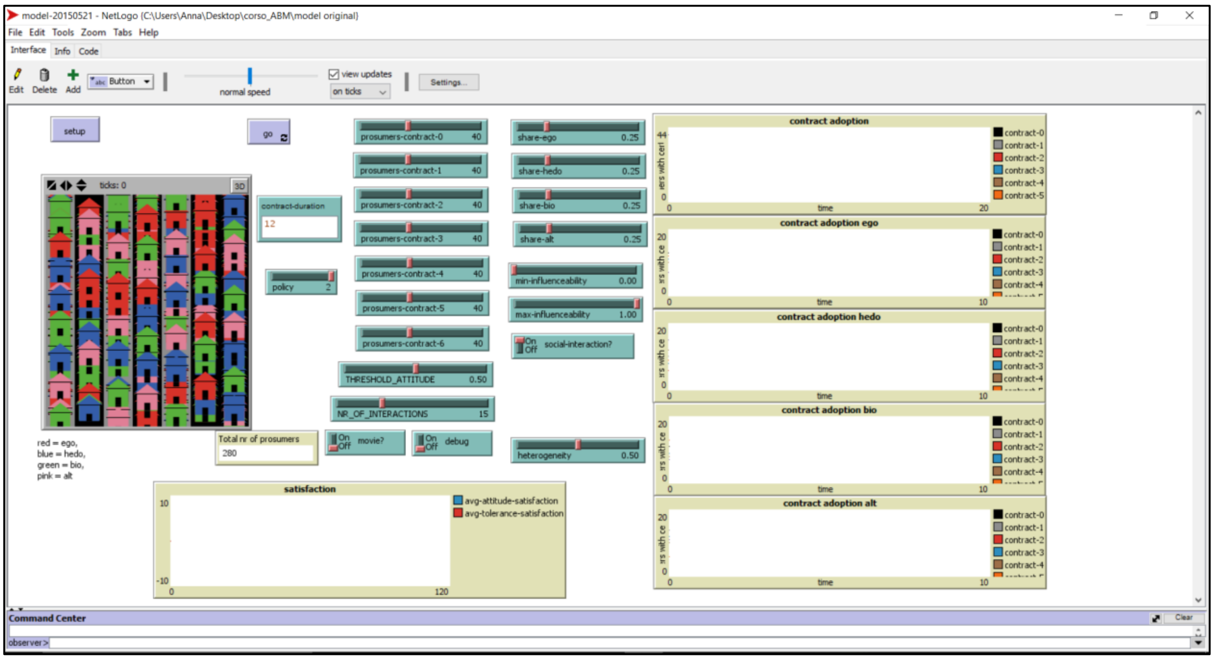

Figure 35. Model interface in NetLogo

4.2.3 Characterizing the contracts

The contracts have been defined based on the existing type of contracts offered by major EU suppliers and potential future ones. In particular I have considered as a base for developing the different contracts offered the case of smart meter roll out in the Netherlands (see Box 4.5). All the agents are offered the same contract options. According to the type of service they provide, available contract options can be represented by the following:

A. *Indirect feedback with own historical and peer comparison once a year*: this type of feedback option allows for historical analysis of consumer's electricity consumption and peer comparison at the end of each year;

B. *Indirect feedback with historical and peer comparison once per two months*: this type of feedback option allows for historical analysis of consumer's electricity consumption and peer comparison every second month. Such feedback provision is in line with the requirements in some EU Member States (e.g.: Sweden, the Netherlands) for smart metering data reading and energy billing six time per year;

Box 4.5: Smart meter roll out in the Netherlands (extracted from (European Commission, 2016e))

The bill to amend the Electricity and Gas market law, which aimed at incorporating the Energy End-Use and Energy Service Directive (ESD) (European Parliament and the Council, 2006) in the Dutch legislative system, was proposed in 2007 in the Dutch Parliament by the Minister of Economic Affairs. The bill included a mandatory smart meter rollout. However, strong concerns about data privacy were raised by the main consumer protection association of the Netherlands, *Consumentenbon*d, which opposed the policy and led a campaign against mandatory installation. As a consequence, the Dutch government decided not to proceed with the initial bill as originally designed, and introduced new measures to address the concerns of the consumer association. A final compromise was reached in 2011, when the legal scheme for the rollout was approved by the two chambers of the Dutch Parliament. Specifically, the new framework involved:

- voluntary installation;
- voluntary automatic meter reading, with three separate possibilities:
    - no automatic meter reading ("administrative-off");
    - fixed settings for automatic reading on pre-scheduled basis; and
    - full automatic smart reading (i.e.: anytime automated readings).

Through this framework, the consumer was given the freedom to choose not only to install the smart meter, but also the smart meter's online connection to the network, which is the crucial difference between smart and traditional meters (i.e. without automatic reading, the functioning of the smart meter is similar to that of traditional meters). In 2014, the Parliament approved the measures which enabled a large-scale deployment of smart meters.

The first phase of the smart meter rollout has been concluded in the Netherlands. This first small scale rollout phase was initiated in 2012 (now being followed by the large scale rollout, initiated in 2015 and currently ongoing) and has now been evaluated.

A noteworthy point is that, during the initial stages of the large-scale deployment, only a small number of households opposed installation of smart meters. This was considered by the involved stakeholders n as an indication of acceptance of smart meters and the rollout policy.

C. *Indirect feedback with own historical and peer comparison once a month*: this type of feedback option allows for historical analysis of prosumer's electricity consumption and peer comparison every month;

D. *Direct feedback with In-Home Displays (IHD):* this type of feedback option allows for analysis of prosumer's electricity consumption on a more granular base (near real-time). This feedback option give the prosumer the right of having access to its metering data without sharing them with the

DSO/supplier or any third party (e.g.: "administrative-off" option in the Dutch national roll-out of smart metering systems);

E. *Direct feedback with Time of Use (ToU / Real Time Pricing (RTP))*: this type of feedback option allows for detailed analysis of prosumer's electricity consumption on a more granular base (near real time) and the possibility of having more advanced pricing mechanisms tailored to prosumer's load profile;

F. *Direct feedback with Home Automation (HA)*: this type of feedback option allows for detailed analysis of prosumer's electricity consumption on a more granular base (near real-time) and the possibility to automate the usage of consumer's home appliances by responding to electricity prices;

G. *Direct feedback with Home Automation, including demand response and renewable energy self-consumption (European Commission, 2015b):* this type of feedback option allows for demand response to electricity price using home automation (as in contract F), but in addition it includes self-consumption of electricity produced at consumer's premises.

As presented in section 4.2.1, each contract is characterized by a "*techno-risk*" that represents the level of perceived technological concerns. Techno-risk varies from 1 for contract A and B (less technologically advanced) to 6 for the more technologically advanced contract G. Each contract is therefore characterised by communicated range for each criterion (a_{e}, a_{h} , a_{h} , a_{a}), perceived technological risk ("techno-risk") and contract duration as presented in Table 4.1

The communicated range for ***financial savings*** varies between 0 and 10% from contract A to G, respectively (Darby *et al.*, 2012) (Van Elburg, 2104). The analysis of electricity prices for households is based on prices for the medium EU standard household consumption band, namely one with annual electricity consumption between 2 500 and 5 000 kWh (Eurostat, 2016). I have considered in the analysis an average annual household consumption of 3600 kWh/year or 300 kWh/month. The average price of electricity for household consumers in the EU-28 (the prices for each EU Member State are weighted according to their consumption by the household sector for 2013) was EUR 0.208 per kWh (Eurostat, 2016).

The ***comfort change*** is expressed as a temperature deviation relative to the target thermostat settings. It is not possible to define comfort in absolute terms; however the World Health Organization's standard for warmth indicates 18°C as suitable temperature for healthy people who are appropriately dressed. For those with respiratory problems or allergies, they recommend a minimum of 16°C; and for the sick, disabled, very old or very young, a minimum of 20°C (World Health Organization, 1990). According to a study by housing expert Richard Moore (Boardman *et al.*, 2005), comfortable indoor temperature lies within a range of 18°C-21°C. I have considered a temperature of 20°C as a target thermostat setting, gradually reducing it at a minimum of 17°C in the case of contract G.

As far as ***CO_2 emissions savings*** are concerned, the EU Covenant of Mayors reports a value of 0.460t CO_2/MWh_e as standard emission factor and 0.578t CO_2-eq/MWh_e), as life cycle assessment (LCA) emission factor[18] for EU 27 (Covenant of Mayors, 2010). In the model I use a value of 0.5 t CO2/MWh_e as standard reference factor.

Finally, demand factor is used as a proxy of ***social welfare***. It should be noted that, for the purpose of this model, I link the social welfare to the security of supply since I assume that lower demand factor leads to more flattened household load profile and this contributes to enhanced energy usage and reduced outages. I have used peak load reduction between 10% due to demand response and maximum 50% due to both demand response and renewable energy self-consumption for contract G (Darby *et al.*, 2012).

The contracts characterization is summarized in Table 6.

Criteria / Contracts	Savings [€], a_e	Comfort %], a_h	CO_2 [t], a_b	Social welfare [%], a_a	Techno-risk	Duration (month)
A	[0; 0.1]	[0; 0.1]	[0; 0.5]	[10; 20]	1	12
B	[0.54; 0.66]	[0; 0.1]	[1; 2]	[10; 20]	1	12
C	[0.54; 0.66]	[0; 0.1]	[1; 2]	[10; 20]	2	12
D	[1.08; 1.32]	[-6; -4]	[2; 4]	[20; 30]	3	12
E	[2.2; 2.6]	[-12; -8]	[5; 7]	[20; 30]	4	12
F	[3.2; 4]	[-12; -8]	[8; 10]	[30; 40]	5	12
G	[5; 7]	[-17; -13]	[12; 16]	[40; 50]	6	12

Table 6. Contract characterization

Figure 36 provides a visualization of the contract distribution in the NetLogo space at t=0. The lines along which the households are distributed represent the seven contracts offered to the consumers (contract A on the left side and contract G on the right side). The colours of the households represent

[18] Method which takes into consideration the overall life cycle assessment (LCA) of the energy carrier, *i.e.* not only the emissions of the final combustion, but also all emissions of the supply chain.

the household archetype; as earlier discussed this is linked to the four different values (red=egoistic; blue=hedonistic; green=biospheric; pink=altruistic).

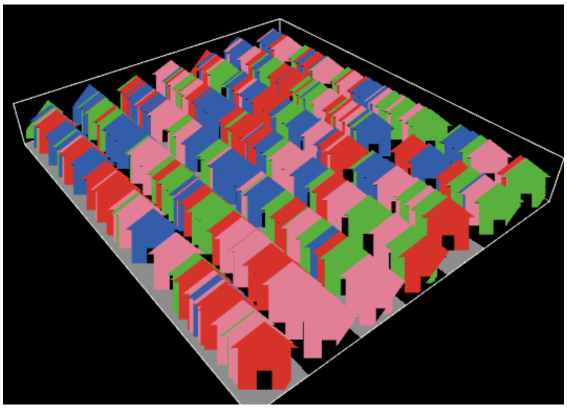

Figure 36. Contracts' distribution among households at t=0

4.3 Policy interventions

As defined earlier, SIMP has been developed in the policy context defined by Directive EU 2009/72/EC on internal energy market for electricity and more specifically, the recommendation EU 2012/148/EU on smart metering deployment (Chapter 1). In this legislative context and being inspired by the Dutch smart meter roll out as presented in Box 4.5, I consider three possible policy interventions.

Mandatory smart metering policy: this policy mandates the Distribution System Operator (DSO) to install smart meters to all electricity consumers. This situation resembles the situation in several EU countries[19], where the consumer is required to accept the smart meter and can choose one of the contracts presented in Table 4.2. Contract A and contract D are not available in this policy context since both these contracts do not foresee the presence of a smart meter (contract A) or the possibility for the smart meter to exchange data with DSO (contract D).

Voluntary smart metering policy: this policy mandates the DSO to carry out nation-wide smart metering deployment, nevertheless, the consumer can choose to refuse the meter or opt for "administrative off". This represents the situation in some EU countries (e.g.: the Netherlands, see Box 4.5) where data privacy concerns resulted in the introduction of the "opt-out" option for the consumer. The types of contract offered to the consumer in this policy are presented in Table 4.2 and include the full range of seven contracts.

[19] http://ses.jrc.ec.europa.eu/smart-metering-deployment-european-union

Environmental smart metering policy: this policy option foresees the same conditions of the voluntary policy; therefore the consumers are entitled to the full range of seven contracts. In addition, it also foresees an environmental campaign by national/local authority launched at a certain time step (t = 40 in SIMP). As a consequence of this environmental campaign, I assume that the consumers will become more aware of environmental issues and therefore the *biospheric value* (represented by w_b) will increase. I assume an increase of 100 % of the weight relative to the biospheric value (w_b). As a consequence, the number of agents with a biospheric archetype will increase. The types of contract offered to the consumers in this policy are presented in Table 7.

The three policy options are summarized in Table 8. In the following section I will proceed to the analysis of possible diffusion rates of smart metering enabled services under the three different policy interventions.

Contract	A	B	C	D	E	F	G
Mandatory policy	No	Yes	Yes	No	Yes	Yes	Yes
Voluntary policy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Environmental policy	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 7. Contract types available for each policy

POLICY OPTIONS		
Mandatory smart metering policy	**Voluntary smart metering policy**	**Environmental smart metering policy**
Governmental policy in place to install smart meters to all electricity consumers.	Policy mandates DSO to carry on nation-wide smart metering deployment. Consumer can choose opt-out or "administrative off" options.	Voluntary policy with environmental campaign, launched by national/local authority (40th month in our model).
Available contracts: B, C, E, F, G	Available contracts: A, B, C, D, E, F, G	Available contracts: A, B, C, D, E, F, G

Table 8. Policy Options

Figure 37 provides an exemplification of contracts' distribution among households for the environmental policy (policy 2) at t=0 and t=12 where the colour of the house represents the household archetype.

Figure 38 provides an exemplification of contracts' distribution among household at t=120 (end of the simulation period) for the voluntary policy (policy 1) and for the environmental policy (policy 2).

a) b)

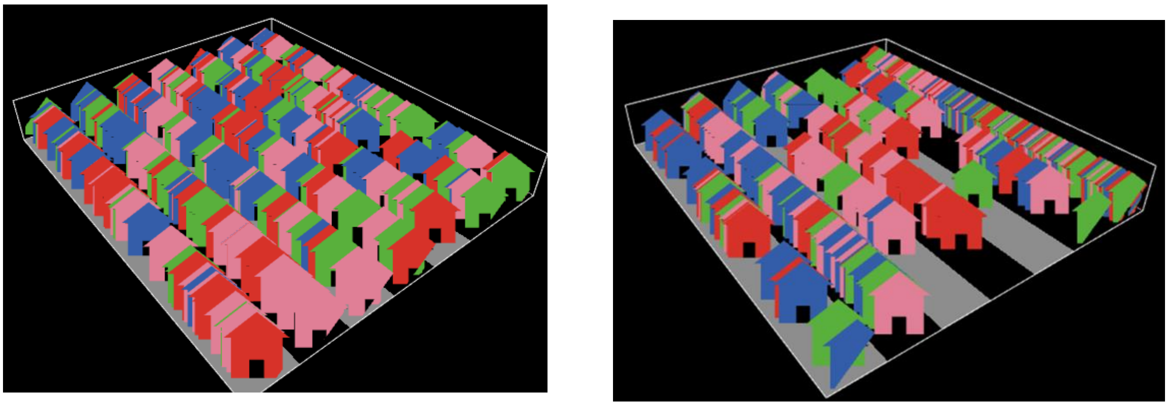

Figure 37. Contracts' distribution among households at a) t=0 policy 2, b) t=12 policy 2

a) b)

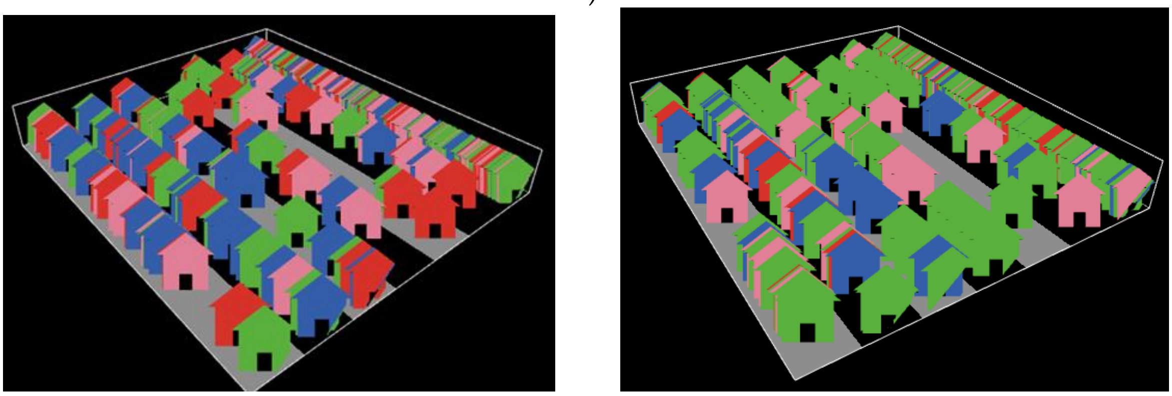

Figure 38. Contracts' distribution among household: a) t=120, policy 1, b) t=120, policy 2

4.4 Simulation and data analysis

The model has been implemented in Netlogo (Wilensky, 1999) and extensively verified using both single and multi-agent testing (van Dam *et al.*, 2013), whereas the programming language R has been used for the data analysis.

4.4.1 Experimental set-up

Data analysis has been performed by building experimental set-up relative to the following variables: relevant others (e.g.: reference groups, peer groups) each agent communicates with (*n*); policy; heterogeneity; initial contract distribution; threshold-attitude and contract duration (see Table 9). Four experiments, relative to the initial contract distribution and contract duration have been developed (as shown in Table 10). The contract types considered reflect possible smart metering enabled services to be deployed in EU. My interest is in observing the impact of initial contract distribution on the final system level contract adoption. Scenario 1 and Scenario 3 are conservative assumption and reflect the current EU situations, whereas Scenario 2 and Scenario 4 represent future settings, where a variety of smart metering services will be available to the end user.

Variable name	Brief description	Value
n	Number of peers each agent communicates with	7 (fixed)
policy	The policy determines what contracts are available, and whether an environmental campaign is introduced at t=40	mandatory, voluntary, environmental
heterogeneity	Level of peers belonging to different archetype then agent's own	0; 0,5; 1
Initial contract distribution	Contract distribution among agents at the beginning of the simulation	Equal distribution or all consumers have contract A or B (depending on the policy)
threshold-attitude	Measure of agent satisfaction with a certain contract. If the overall attitude is lower than the threshold-attitude, agent decides to change contract.	0.5 (fixed)
contract-duration	Contract time duration	12 months or indefinite

Table 9. Simulation parameters

The assumption of having contract duration of 12 moths (this is the minimum contract duration observed in most of the EU member states) and indefinite contract duration is linked to my interest in investigating the effect of "lock-in" periods, during which the consumer would need to pay a penalty for leaving the contract or of other switching barriers, in case of fixed contract duration. Each experiment is tested for each policy separately.

The model runs in an experimental setup of 20 runs for each parameter combination in order to be able to explore the spread in the outcomes, which is caused by randomly determined factors such as the social network layout, weight factors of agents, agent's experience with certain contracts, agents' susceptibility (wsn) and technology threshold. The parametrization for the simulation experiments is given in Table 11-13. Empirical values are not available for most of the parameters and as a result, synthetic data are used, based on expert judgment; these have been extensively varied. Nevertheless, wherever a source is given, the parameter value is empirically based. Each experiment starts with N agents with randomly generated weights. The highest of the four weights (w_e, w_h, w_b, w_a) determines the archetype the agent belongs to.

Scenario	Initial contract distribution	Contract duration
Scenario 1	All agents have the less technologically advanced contract (B in the mandatory policy and A in the voluntary and environmental policy)	12 months
Scenario 2	Equal contract distribution	12 months
Scenario 3	All agents have the less technologically advanced contract (B in the mandatory policy and A in the voluntary and environmental policy)	Indefinite
Scenario 4	Equal contract distribution	Indefinite

Table 10. Contract types available for each policy

Variable name	Brief description	Value	Source
N	Number of household agents; depends on the policy	200 or 280	-
Available contracts	The contracts that are available to the consumers; depends on the policy	[A,B,C,D,E,F,G] or [B,C,E,F,G]	-
Environmental campaign	Determines whether or not an environmental campaign is introduced in month 40; depends on the policy	Yes or no	-

Table 11. Simulation variables (depending on the parametrization)

Variable name	Brief description	Value
w_e, w_h, w_b, w_a	Weight factors, as relative importance agent gives to certain criterion (egoistic, hedonic, biospheric, altruistic)	Chosen from uniform distribution [0,1]
w_{SN}	Susceptibility factor: measure of the importance agent gives to the opinion of relevant others	0.5
techno-tolerance threshold	Acceptance level due to perceived risks associated with smart metering technology	[1,11]

Table 12. Agent-specific variables

Variable name	Brief description	Value	Source
$a_{emin,}a_{emax}$	communicated range for financial savings	See Table 4.1	Eurostat statistics explained
$a_{hmin,}a_{hmax}$	communicated range for comfort change	See Table 4.1	B. Boardman et al.
$a_{bmin,}a_{bmax}$	communicated range for CO_2 savings	See Table 4.1	Covenant of mayors, 2010
$a_{amin,}a_{amax}$	communicated range for social welfare	See Table 4.1	S. Darby et al., 2012
Techno-risk	perceived technological risk	[1, 6]	-

Table 13. Contract-specific variables

4.4.2 Data analysis

The individual decisions of the prosumer-agent to switch to a certain type of contract determine the system level outcomes: *adoption of contract types, average financial savings, comfort change, CO_2 savings and social welfare*. My interest is to monitor the system level performance that emerges from lower-level properties and processes; therefore I focus my attention on these system performance indicators and I analyse the patterns due to change in policies and scenarios. Parameter values vary between runs due to stochastic values used during agents' initialization and model execution. In order to obtain realistic assessment of the patterns observed in the simulated system evolution, it is necessary to perform a statistical analysis of the results of several runs.

Heterogeneity and susceptibility, as represented in the present model, does not prove to have a relevant impact on the average contract distribution. This can be explained by the fact that agents with *egoistic*, *biospheric* and *altruistic* archetypes have objectives which pull in the same direction in term of contract type preference, i.e. agents who belong to these three archetypes will behave similarly, whereas hedonic agents will act differently. As such, more technologically advanced contracts that would yield higher energy and financial savings, would also result in higher CO_2 savings and increased social welfare. Therefore, having observed this, I decide to keep susceptibility and heterogeneity constant in order to focus on other parameters.

In the following sections I will present the results for what concerns contract distribution and system level performance for the four scenarios.

4.4.2.1 Scenarios analysis

Scenario 1

Contract duration	12 months
Contract distribution	All consumer have at t=0 have the less technologically advanced contract (i.e.: contract A or B if mandatory policy)

The results of the simulation for Scenario 1 are presented in Figure 39. The figure shows a slightly higher adoption of the more technologically advanced contract (contract G + contract F) under the environmental policy. Indeed the environmental campaign impacts the consumers' choice. Consumers switch to more technologically advanced contracts that yield better environmental performance in terms of CO_2 emissions. However, such a campaign would be expected to produce better results in term of contract G adoption, while this seems not to be the case. This fact raises doubt on the effectiveness of large scale campaign that are not targeted to specific segments of the population. The figure also shows an adoption of G contract for the mandatory policy slightly higher than the one for the environmental policy. This may be due to the more restricted contract choice that consumers have in the mandatory campaign (contract A and D are not offered).

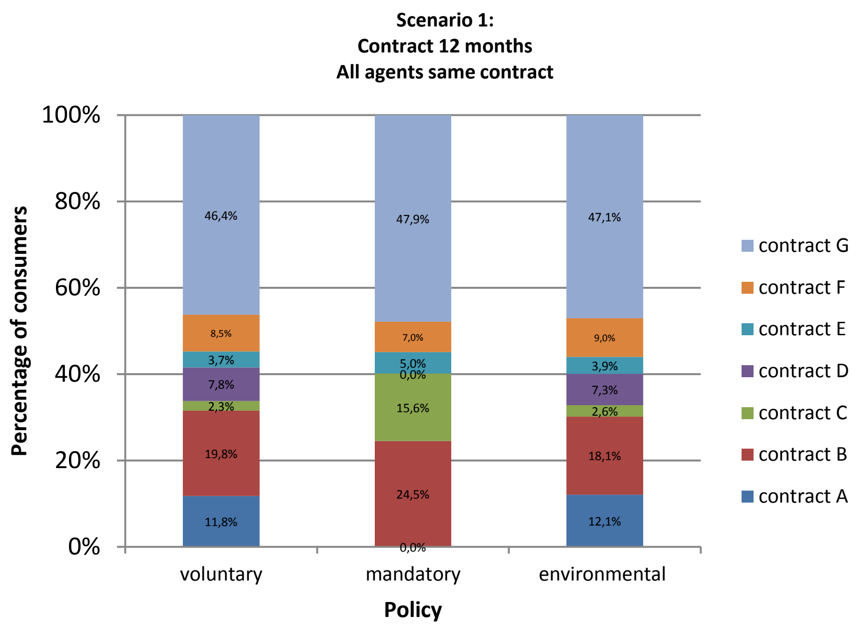

Figure 39. Average contract distribution for Scenario 1

Scenario 2

Contract duration	12 months
Contract distribution	Equal contract distribution at t=0

The results of the simulation for Scenario 2 are presented in Figure 40. The figure shows a similar pattern as in Scenario 1, however the differences between the three policies appears to be reduced in comparison to scenario 1. It appears that the initial contract distribution (scenario 1: all consumers with the less technologically advanced contract vs. scenario 2: equal distribution of the available contract among the consumers) does not influence the final contract distribution.

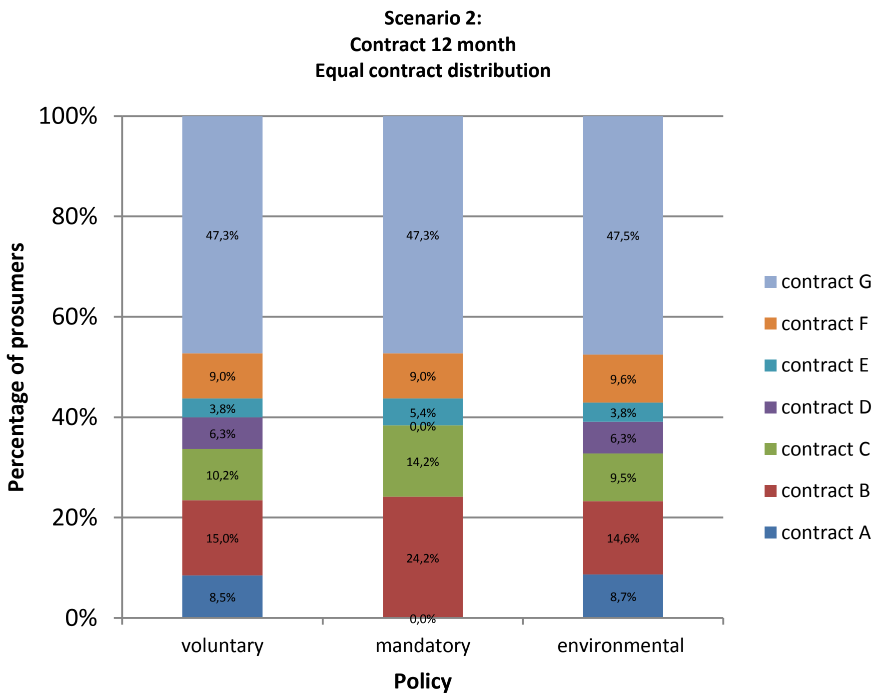

Figure 40. Average contract distribution for Scenario 2

Scenario 3

Contract duration	indefinite
Contract distribution	All consumer have at t=0 have the less technologically advanced contract (i.e.: contract A or B if mandatory policy)

The results of the simulation for Scenario 3 are presented in Figure 41. In this case contract duration is indefinite, that is to say the consumer are not forced to change contract at t=12. The pattern shows similarities with the two previous scenarios in terms of contract adoption, where the environmental campaign policy appears to be the one yielding better results, though the difference is not a substantial one. It appears that contract duration do no impact final contract adoption.

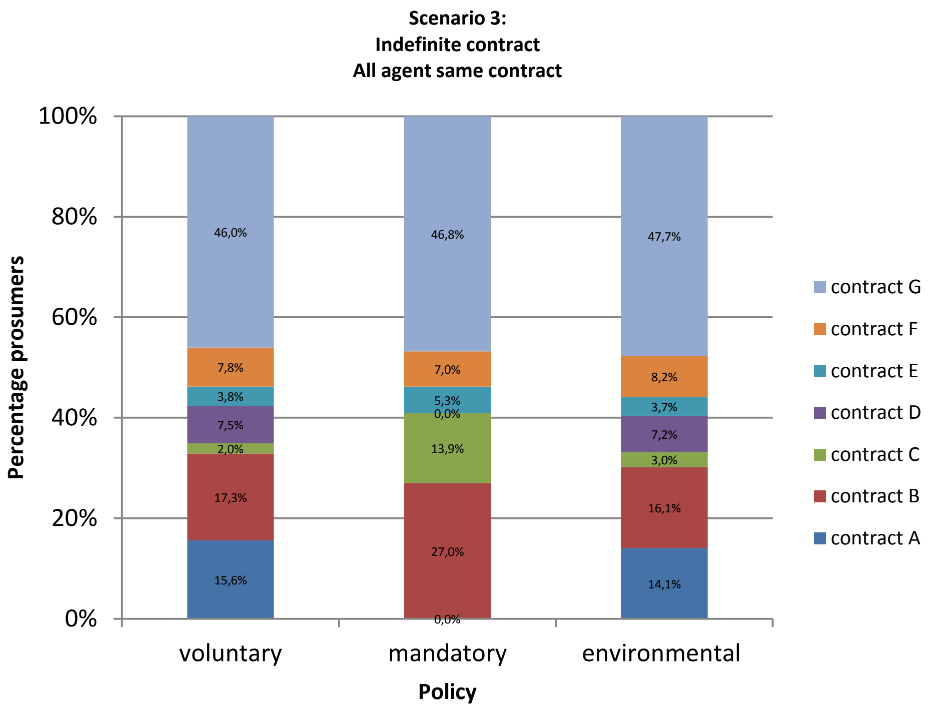

Figure 41. Average contract distribution for Scenario 3

Scenario 4

Contract duration	indefinite
Contract distribution	Equal contract distribution at t=0

The results of the simulation for Scenario 4 are presented in Figure 42. In this scenario we observe a higher adoption of more technologically advance contracts (G and F) compared to the previous scenarios for all three policy options. This result could be ascribed to the maturity of the market where all possible contracts are available (condition of equal contract distribution at t=0) and the duration. Consumers are given the possibility to stay with current contract (indefinite duration), however, being exposed to a more mature market (equal contract distribution) they are more aware of the possible advantages of the available contracts and proactively move to better system performance contract. However, the influence of the environmental campaign remains not significant.

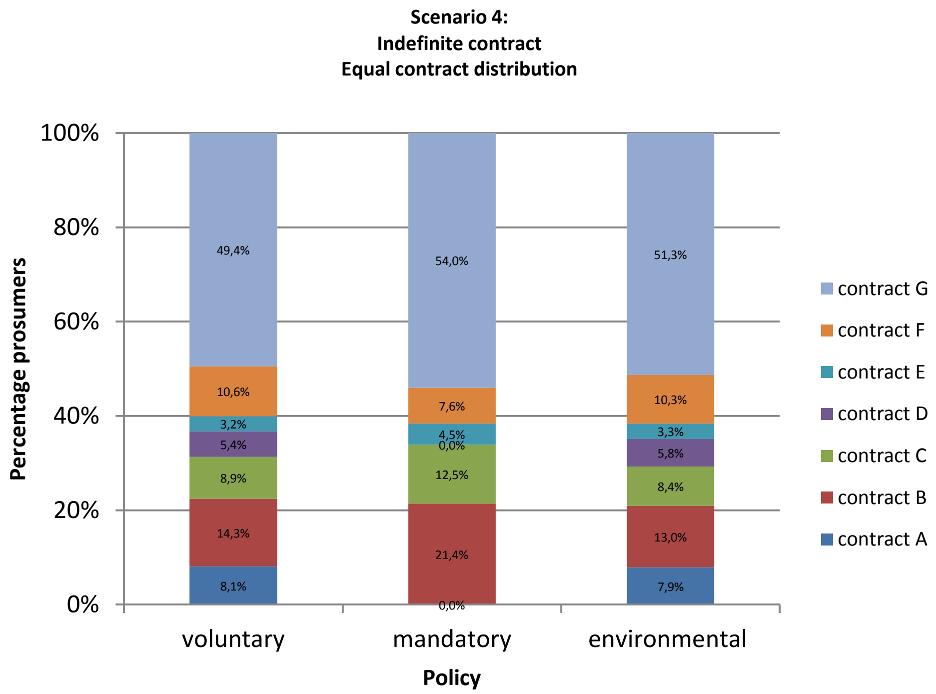

Figure 42. Average contract distribution for Scenario 4

4.4.2.2 Average contract distribution: comparing scenarios

Figure 43 summarizes the four scenarios. From the comparison of the four scenarios I can draw the following overall general observations:

- There is no significant difference in the adoption level of the contract types between the voluntary and environmental policy within a scenario even though one would expect that the environmental policy and the associated increase in the number of consumer with biospheric archetype would yield a higher share of more technologically advanced contracts. One reason could be the influence of *techno-tolerance threshold,* as currently modelled, on consumer's contract choice. This threshold is fixed and do not change over the simulation and for archetype. As a result, the increase in the number of consumer with *biospheric archetype* does not necessarily lead to an increase in the adoption of more technologically advanced contracts, due to the influence of the techno tolerance threshold. Another reason, as mentioned earlier, could be linked to the limited efficacy of large scale environmental campaign that do not target specific needs and desires of specific consumer's segments, therefore do not yield the expected results.
- The more technologically advanced contracts, such as contract F and contract G, are highly adopted in all policies. This can be linked to the fact that these are the most best scoring contracts for 3 out of the 4 criteria that agents consider in their choices.
- For what concerns the voluntary and environmental policy, consumers have a much higher adoption level of contract C when contract are initially equally distributed among agents (2nd and 4th scenarios), then when all agents have initially contract A (1st and 3rd scenarios). This could be explained by the fact that some consumers do not consider switching since they remain satisfied over the course of the simulation.
- The higher adoption of contract F and G in scenario 4 can be explained by market maturity (all contracts are present in the market). Consumers are given the possibility to stay with current contract (indefinite duration), however, being exposed to a more mature market (equal contract distribution) they are more aware of the possible advantages of the available contracts.
- The higher contract adoption of contract B in scenario 3 may be due to the contract unlimited duration that produce "lock-in" patterns where consumers, if not encouraged, tend to stay with the current option.
- Contract A (feedback once a year) and contract D ("administrative off") are not offered in the mandatory scenario and this may affect the different contract distribution for the mandatory policy in all four scenarios. In case of mandatory policy, the consumers have to do with a reduced number of contracts offered.

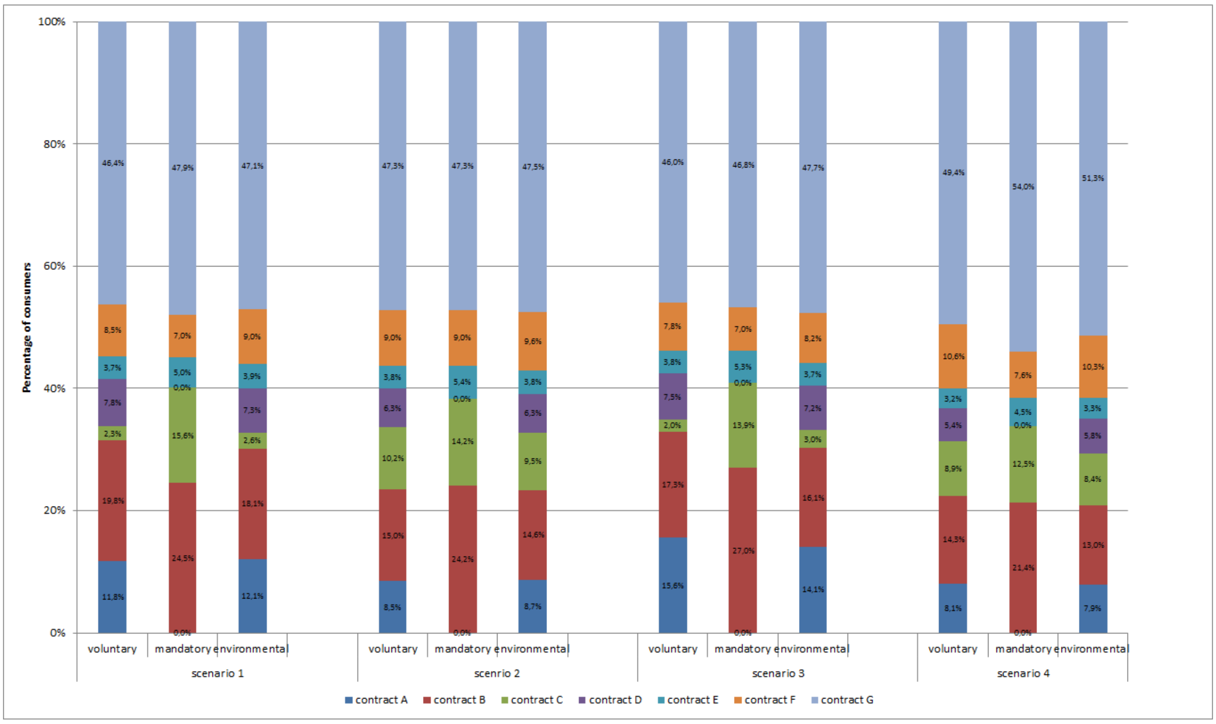

Figure 43. Average contract distribution for the four scenarios

Figure 44 shows an example of the contract distribution for the environmental policy (policy 2) as presented in NetLogo.

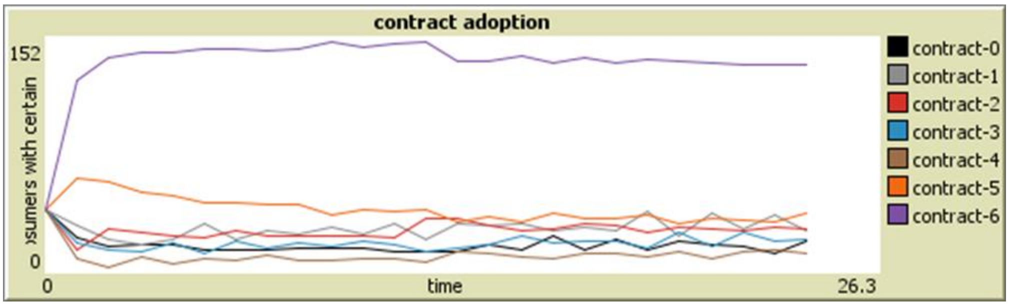

Figure 44. Contract adoption (t=24, policy 2)

4.4.2.3 Analysis of the system level performance indicators

The impact of agent's behaviour on the four criteria: financial savings, comfort change, CO_2 emission savings and social welfare, based on 20 runs, is presented in Figure 45-48. The figures present the average value across the whole simulation period and all simulation runs (continuous line) and the spread around the average value (colour shaded area).

Figure 45 represents the financial savings. These are lowest in Scenario 3, due to the highest average adoption of contract B (feedback ones per two months) in the mandatory policy and both contract A (feedback once a year with no smart meter) and B in the voluntary policy. Highest financial savings are observed Scenario 4, as a result of the highest adoption of contract of the most technologically advanced contract (contract G) and the lowest adoption of both contracts A and B across all three polices. There is no significant difference in the financial savings between Scenario 1 and Scenario 2. This means that when the contract duration is 12 months, the initial contract distribution has not influence. The contract duration does however have an impact if the contracts have an undetermined duration. In Scenario 3, highest financial savings are observed in the environmental policy and lowest in the voluntary one, owing to higher adoption rate of contract F and G in the environmental policy (in comparison with the first two policies) and lower adoption rate on contract A and B. In Scenario 1, Scenario 2 and Scenario 4, the financial savings are highest in the mandatory policy due to high adoption of contract G and low adoption of contract A.

Figure 46 represent the *comfort change.* Differently from the financial savings, the lowest comfort reduction is observed in Scenario 3 and highest comfort reduction in Scenario 4. The same reasoning as for the financial savings holds also here, i.e. lower adoption level of contract A and contract B, combined with higher adoption of contract G in Scenario 4 results in highest comfort change for that scenario.

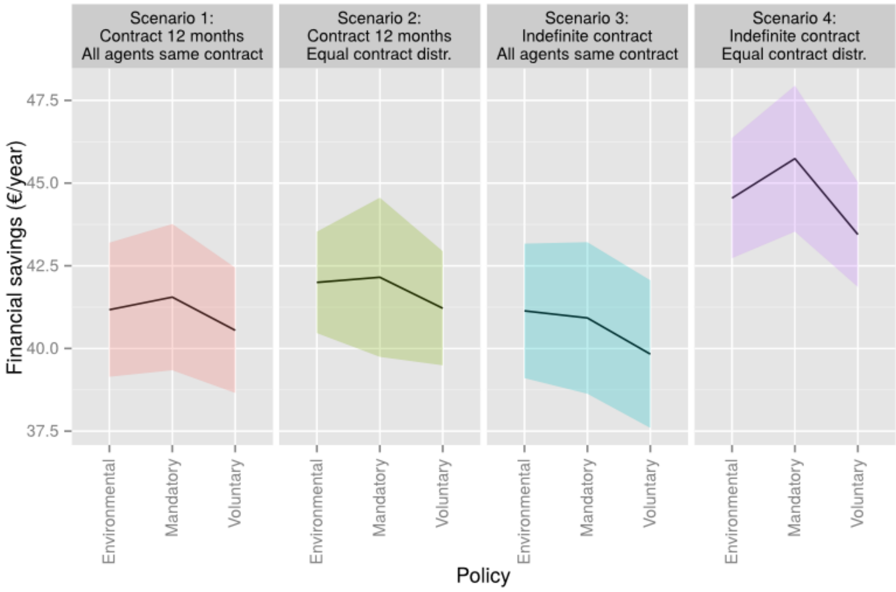

Figure 45. Financial savings

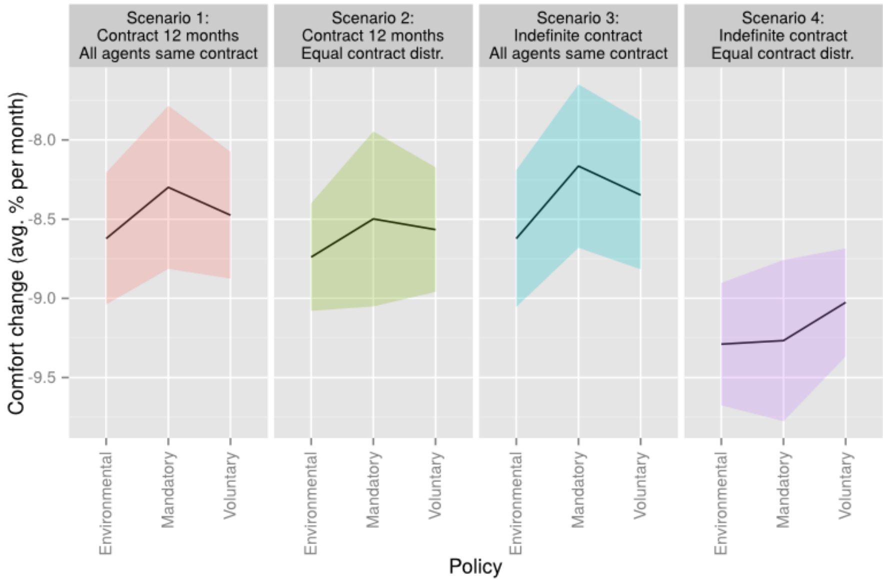

Figure 46. Comfort changeFigure 47 represents the *CO_2 savings*. The same trend as in the case of financial savings is observed. Scenario 4 shows highest CO_2 savings owing to the highest adoption level of contract G and lowest adoption of contract A and B, comparing to the rest of the scenarios. CO_2 emissions savings are lowest in Scenario 3. Scenario 1 and Scenario 2 do not seem to show significant difference in the outcome of this indicator. Furthermore, the mandatory policy leads to highest CO_2 savings in scenario 1, 2 and 3, while the voluntary policy results in best performance of this indicator in scenario 4.

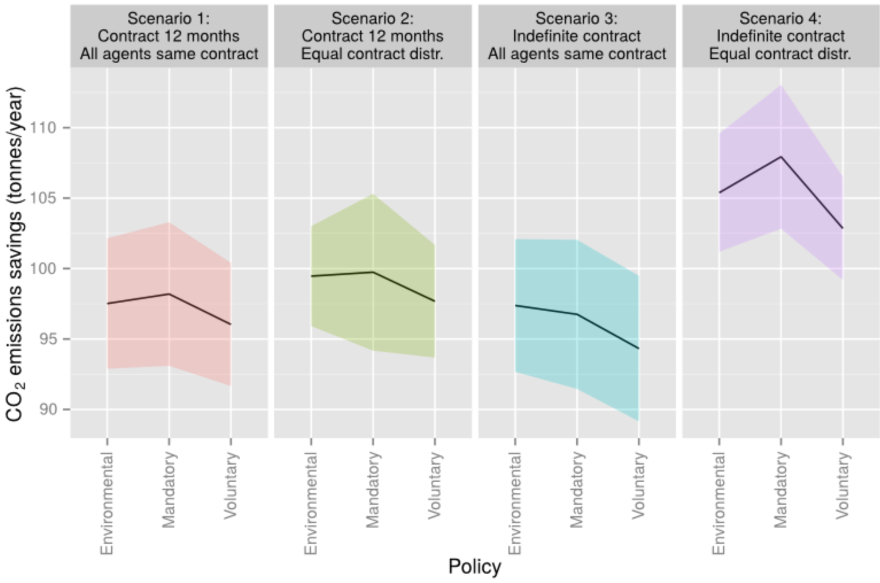

Figure 47. CO_2 emissions savingsFigure 48 presents the *social welfare*. As for the financial savings and for the same reasons, the highest increase in social welfare is observed in Scenario 4. Nevertheless, the difference between this indicator and the financial and CO_2 savings is the increasing trend in the outcome of social welfare as moving from the mandatory policy to voluntary and environmental policy in scenario 1, 2 and 3 (Figure 48). This is due to the fact that contract A (feedback provision once a year with no smart meter) has the same communicated range for the social welfare as contract B and C (see Table 6), i.e. increased adoption level of contract A in the mandatory and environmental policy does not lead to decreased social welfare, as it was the case of financial and CO_2 savings. Additionally, increased adoption of contract D (and to some extent contract E) in the last two policies, comparing to the first one, yields increased social welfare. The adoption level of contract G does not seem to significantly vary among the 3 policies. Scenario 3 shows worst performance of this indicator due to the fact of having highest average adoption level of contract A, B and C (see Figure 43), when comparing to the rest of the scenarios.

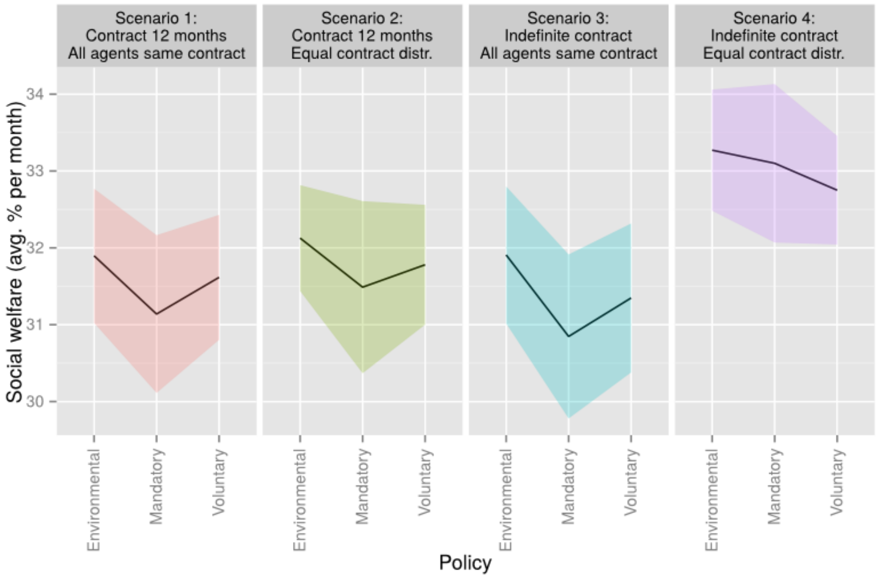

Figure 48. Social welfare

4.4.2.4 Techno-tolerance and Attitude satisfaction

The analysis of the results allows also the exploration of the agents' satisfaction, in terms of their perception towards risks associated with contract type (data privacy and security, health, etc.), and in terms of overall satisfaction.

Figure 49 presents agents' *techno tolerance satisfaction* linked to their perceived smart metering technology risks. This is calculated as the difference between the agent's specific "*techno-tolerance threshold*" and the "*techno-risk*" associated to the adopted contract. It can be observed that agents may be satisfied with their choice, in terms of overall contract performance, but this can be at the expenses of techno-tolerance satisfaction. The techno tolerance threshold is initialized at the beginning as a random number drawn from a predefined set. Future model updates could consider varying the techno-tolerance threshold in accordance with the experience the agent has with the smart metering technology or due to information campaigns or social networks influences. Figure 49 shows that average agent's techno-tolerance satisfaction is worst in Scenario 4. This is due to the higher adoption of contracts F and G that are the most technologically advanced contracts with the highest associated techno-risk. On the other hand, the highest techno-tolerance satisfaction is observed in Scenario 3. This is due to the lower adoption of contracts F and G and higher acceptance of contract A, in comparison with other scenarios. Finally, for all the scenarios, the average techno tolerance satisfaction is the lowest for the environmental policy. Energy savings, CO_2 emission reduction and social welfare have the highest values for the environmental policy (Figure 45, 47, 48) in Scenario 3; this results in lowest techno-tolerance satisfaction, due to higher adoption of contract F and G and lower adoption of contract A. All performance indicators perform the worst for the voluntary policy in Scenario 4

(Figure 45-48) due to lower adoption level of contract G, in comparison with the mandatory and environmental policy and higher adoption level of contract A, in comparison with the voluntary policy. This also leads to higher techno-tolerance satisfaction for the voluntary policy.

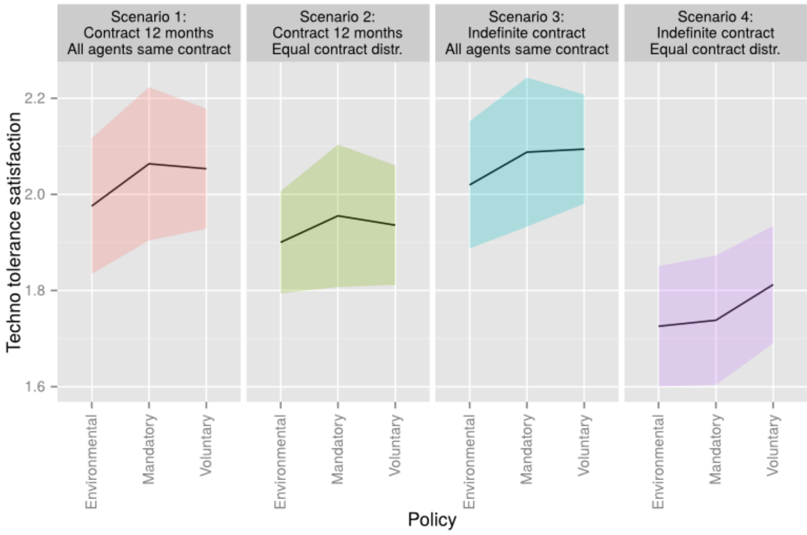

Figure 49. Average techno-tolerance satisfaction

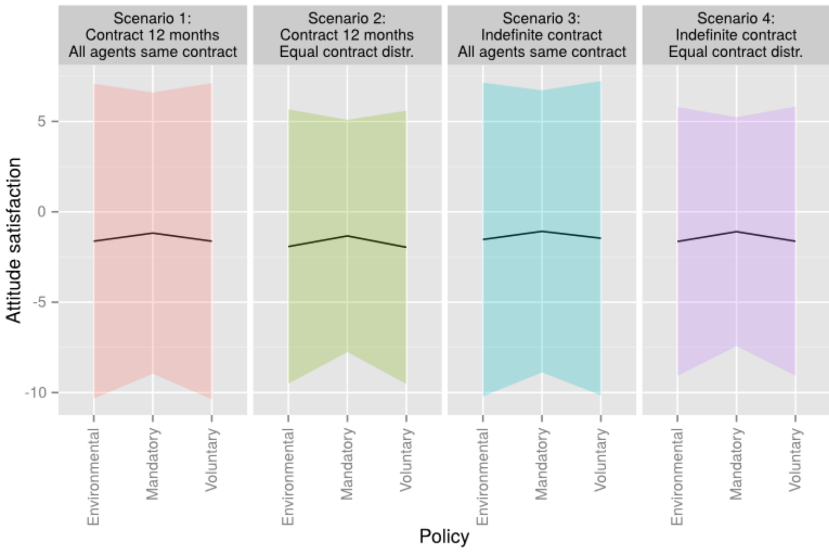

Figure 50. Average attitude satisfaction

Figure 50 represents the average *attitude satisfaction*. This is calculated as the difference between the agent's general attitude towards a certain contract and the agent specific attitude threshold.

4.5 Discussion

The aim of SIMP is to provide insights into how smart metering technologies and enabled services diffusion can be promoted under different policy settings and how this technological diffusion affects individual and societal performance indicators. The outcomes are not meant as predictive, but rather as explorative of the mechanisms at play. SIMP cannot be classically validated since it discusses possible future mechanisms and, as such, it has been subject to expert validation. The main findings emerging from the data analysis are the following:

- It emerges that granting the consumers with opt-out or "administrative-off" options for smart metering system results in an increased number of consumers opting for a less technologically advanced contract (i.e.: contract A or contract D). Given the initial assumptions on population preference distribution, it may be concluded that addressing consumers' concerns (such as data privacy and security) by granting them with more options, does not necessarily lead to higher energy and CO_2 savings and higher consumer's satisfaction. This pattern has been recognized as realistic during expert validation.

- The pattern of an increased number of consumers opting for a less technologically advanced contract when granted with opt-out and "administrative-off" options remains strong also under the environmental policy, where despite significant number of agents becoming more environmentally concerned (i.e.: consumer with higher weight for the biospheric criterion) system level indicators, such as energy and CO_2 savings remain lower in comparison with the mandatory policy. This results from the significant adoption of contracts that do not require data sharing with DSOs and thus do not present additional benefits, such as dynamic pricing (e.g.: contract A and D in the environmental policy). Furthermore, technologically advanced contracts that yield higher benefits may also be subject to technology concerns, as perceived by the consumers. As a result, *average techno-tolerance satisfaction* appears to be the lowest for the environmental policy, which is associated with a high level of perceived technological risk by the consumers for the adopted (more technologically advanced) contracts. It can be therefore argued that giving consumer more contract choices do not necessarily produce better system level results, which is in line with psychological research. Schwartz (Schwartz, 2014) argues that an abundance of choices is likely to produce worst decisions because people tend to simplify their choices to the point that the simplification hinders their capability to opt for a good choice. In this respect, policies may need to target the information to the right segment of population in order to avoid information overload.

- The average *total-attitude satisfaction*, differently from the techno-tolerance satisfaction, does not vary greatly among policies and scenario. For instance, agents experience the highest techno-satisfaction in Scenario 3; this is linked to the high adoption level of contract A. Nevertheless, the total-attitude satisfaction remains similar in the other scenarios. This can be explained by the high diversity of the agent's population (in terms of agents' archetype).

- There is no significant difference in the average total-attitude satisfaction among the policies; nevertheless, it appears to be slightly higher in the mandatory policy. This can be explained by the increased adoption level of contract A in the voluntary and environmental policy, i.e.: agents opt for less attractive contract due to the perceived technological risk for more attractive ones. It can therefore be argued that giving the consumer more options (as in the voluntary policy) does not necessarily lead to higher consumer's satisfaction. Giving consumers too many options (contracts, in the present model) to choose from leads the consumer feeling less satisfied even after taking the decisions (Schwartz, 2014). Therefore risks perceived by the consumers shall be approached at an early stage, clearly communicating how the consumption data will be used, by whom and for which purpose.

- Information strategies (e.g.: environmental campaigns in the environmental policy) for increasing consumer's awareness of the environmental benefits of technologically advanced contracts do not seem sufficient to effectively diffuse the full potential of smart metering services. The risks that consumers associate to technologically advanced contracts (e.g.: data privacy and security) represents an obstacle to the adoption of more advance contracts. Therefore, policy interventions need to simultaneously address adoption barriers and openly communicate potential concerns and address them appropriately (e.g.: reassuring the consumers that they cannot be disconnected without notice; ensuring that "administrative-off" actually means no metering data is being exchanged, etc.)

In conclusion, a good policy should be designed so as to adequately inform (right and complete information) the consumer on the advantages and disadvantages of the offered technological solution. The consumer can therefore be more prone to accept more advanced technologies and lower the concerns linked to the technology (e.g.: lower techno concern for well-designed information campaign). As a consequence, this could lead to the consumer feeling more satisfied.

4.6 Limitations

While there are clear useful insights to be drawn from the results provided by SIMP, there are some important limitations:

- The total attitude satisfaction stays below 0 in all the scenarios, i.e.: agents are constantly dissatisfied. This results in high switching rate. The reasons can be the following: first, in the model, the experience the agents get with each contract is modelled as exogenous variable, each time step randomly drawn from a predefined set of values (defined in the contract) for each indicator. The evaluation of the current contract should be based on learning from past experiences and the current experience should take into consideration this learning process (e.g. through adaptive set for each indicator).

- The attitude threshold and techno-tolerance threshold are exogenous, fixed at the initialization of the model. Fixed techno-tolerance threshold means consumers disregard the contracts that are below their techno-tolerance threshold. Such an approach prevents the agent to consider more "technologically risky" contracts at the expense of a better outcome (in terms of energy savings, environmental impact, etc.). The perception for more "technologically risky" contracts may change over time, owing to the experience an agent have with the contract, which will ultimately result in adaptive techno-tolerance threshold. Similarly, attitude threshold shall consider agents' learning and adaptation and therefore be reflexive and reactive to the environment. This certainly deserves attention in future developments of the model.

- The model should consider more reflexive and reactive institutions, as well as explore institutions emerging from agents' behaviour.

- The possible availability of empirical data constitutes a major route for further development of the model.

- ***The consumer decision making process is modelled as a multi-criteria problem where the consumers maximize their utility (attitude) while interacting with a circle of peers. This produces rather predictable patterns. The interactions with a wider social network that not only includes peers could produce variability and emerging patterns. This will be explored in the following chapter.***

5 SIMP: Introducing the Social Network

5.1 Introduction

As discussed in Chapter 3, a wealth of social psychology theories signals the social embeddedness of environmentally significant behaviours. These theories suggest that behavioural change must occur at the collective, social level. Instead, as argued by Shove, the popularity of the ABC approach (attitude-behaviour-choice) (Shove, 2010), indicates the tendency to ascribe the responsibility for sustainable behaviours to the individual whose behavioural choices will make the difference (Delre *et al.*, 2010). The self-sustaining paradigm that considers behaviour as something that is shaped by factors (infrastructure, history, social situations) does not include issues of societal transformation. Differently from social theory of behaviour that focuses on causal factors and external drivers or barriers, social theories of practice emphasis endogenous and emergent dynamics were people are carriers of practices. Against this background, the aim of the present chapter is to explore the effect of social networks and social theory of practices on consumer behaviour and analyse possible emerging patterns. I know ground my exploration in social practices theory.

I will call this new model version SIMP-N.

5.2 SIMP-N

5.2.1 Coding the social network

In Chapter 4, I have presented the SIMP model and highlighted its limitations. Specifically, I have acknowledge the model limitations linked to the decision making process that is based on a rational choice of utility maximization where prosumers are driven towards contracts that maximize their values satisfaction, while considering the risk linked to the technology. It is this technology risk that limits the adoption of more technologically advanced contracts. This approach is based on more rational choice approach (the so called "ABC framework" (Shove, 2010)) where responsibility for sustainable behaviours are ascribed to individual whose energy preferences in terms of contract's choices will make the difference.

To explore the effect of social influence on consumer's choices I introduce an additional element in the decision-making process. I assume that during the decision making process of contract choice, the consumers may decide to sidestep the current decision-making rules and follow the contract choice of the "community" to which they belong. Each prosumer is now also characterized by a "community" ("prosumer-owns community"). The prosumer will be assigned a number - represented by the slider "communityNumber" in the model interface -chosen within the range defined by the slider (see figure Figure 51) in the following way:

```
ask prosumers [
  set community 1 + random communityNumber
]
```

The "communityNumber" is introduced so that I can now characterize the consumer's involvement ("membership") in a certain number of social networks (e.g.: school, sport, associations, etc.). This "membership" does not necessarily imply that members share common individual values (egoistic, hedonic, biospheric and altruistic as defined in the model). In this way I will be able to explore the effect of social influence on consumer's choices. This is in line with the social theory of practice were endogenous and emergent dynamics are emphasized over causal factors and external drivers. In the code procedure "to choose-contract", the following new lines are introduced:

```
if lookCommunity and random-float 1 <= pOfFollowingMyCommunity
  let myCommunity community
  if count other prosumers with [community = myCommunity] > 0
  let myReference one-of other prosumers with [community = myCommunity]
  set current-contract-nr [current-contract-nr] of myReference
```

The decision to follow the community practice instead of the rational utility maximization in the "to choose-contract" procedure is randomly defined by a variable – pOfFollowingMyCommunity – that reflects the intractability of irrational choices.

The code interface is now changed to include additional sliders and switches, specifically: lookCommunity switch, communityNumber slider and pOfFollowingMyCommunity slider as presented in Figure 51.

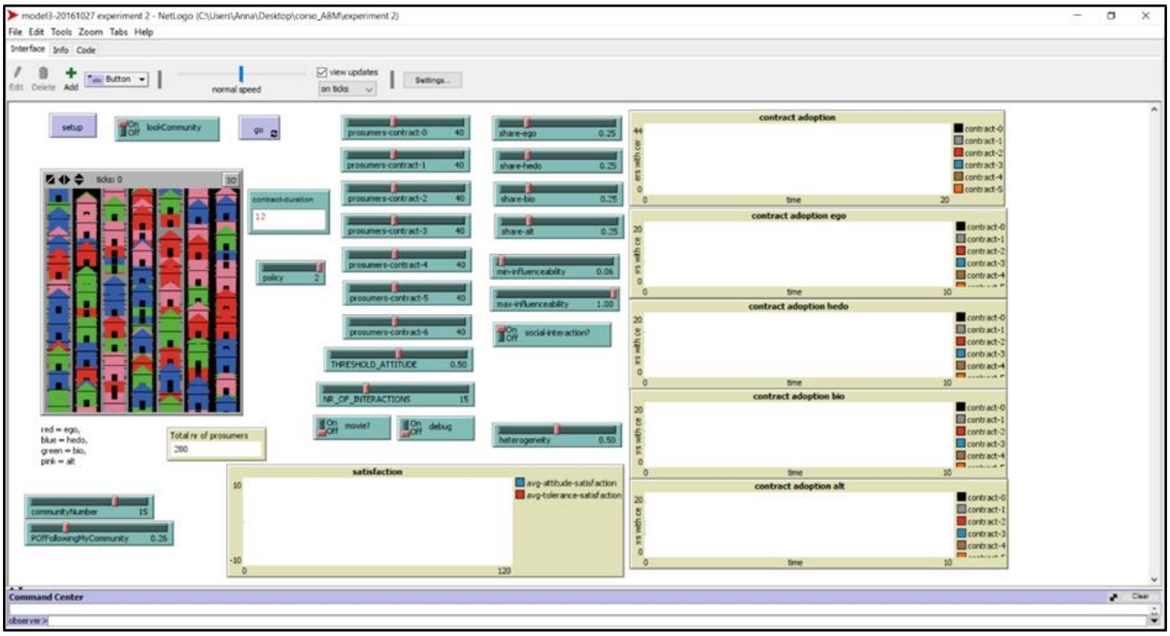

Figure 51. Screen shot of model GUI SIMP-N interface

5.2.2 Simulation

Data analysis is performed by building experimental set-up relative to the following variables: policy, community number, initial contract distribution and contract duration.

I replicate the experiments built in Chapter 4, relative to the initial contract distribution and contract duration (as presented in Table 14). The differences in the scenarios refer to different smart metering deployment contexts and contract durations. Concerning smart metering deployment, Scenario 1 and 3 are representative of the current situation in EU where smart metering are not yet fully rolled out and scenario 2 and 4 are representative of future market conditions where various contract offers will be available. Concerning contract duration the difference is between a fixed duration (t = 12) and unlimited duration (t = indefinite); in this case the interest is to explore possible "lock-in" periods, during which consumers would need to pay a penalty for leaving the contract or other switching barriers, in case of fixed contract duration

.

Scenario	Initial contract distribution	Contract duration
Scenario 1	All agents have the less technologically advanced contract	12 months
Scenario 2	Equal contract distribution	12 months
Scenario 3	All agents have the less technologically advanced contract	Indefinite
Scenario 4	Equal contract distribution	Indefinite

Table 14. Experimental set-up

The model is run in an experimental set up of 20 runs for each parameter combination. The parametrization of the simulation experiments for SIMP-N is presented in Table 15-18. The variable "communityNumber" defines the number of communities that exist and of which consumer can be member (consumer's membership). To assess the influence of the number of possible communities (and therefore possible social interactions) on contract adoption it is interesting to verify the effect of different "communityNumber" values on contract adoption levels. For this reason, a sensitivity analysis is performed considering different values, namely: 3, 5 and 15 (Table 15).

Variable name	Brief description	Value
w_e, w_h, w_b, w_a	Weight factors, as relative importance agent gives to certain criterion (egoistic, hedonic, biospheric, altruistic)	Chosen from uniform distribution [0,1]
w_{SN}	Susceptibility factor: measure of the importance agent gives to the opinion of her social network peers	0.5
techno-tolerance threshold	Acceptance level due to perceived risks associated with smart metering technology	[1,11]
communityNumber (n_c)	Number of communities (i.e.: social groups) to which the consumer belongs	3; 5; 15

Table 15. Agent-specific variables

Variable name	Brief description	Value
n	Number of peers each agent communicates with	7 (fixed)
policy	The policy determines what contracts are available, and whether an environmental campaign is introduced at t=40 months	voluntary, environmental
heterogeneity	Level of peers belonging to different archetype then agent's own	0.5
Initial contract distribution	Contract distribution among agents at the beginning of the simulation	Equal distribution or all consumers have contract A
threshold-attitude	Measure of agent satisfaction with the certain contract. If the overall attitude is lower than the threshold-attitude, agent decides to change contract.	0.5 (fixed)
contract-duration	Contract time duration	12 months or indefinite
pOfFollowingMyCommunity	Probability that consumer decides to choose the contract adopted by its social network ("myReference")	0.3

Table 16. Simulation parameters

Variable name	Brief description	Value
N	Number of household agents; depends on the policy	280
Available contracts	The contracts that are available to the consumers; depends on the policy	A, B, C, D, E, F, G
Environmental campaign	Determines whether or not an environmental campaign is introduced in month 40; depends on the policy	Yes or no

Table 17. Simulation variables (depending on the parametrization)

The contract specific variables are presented in Table 18.

Variable name	Brief description	Value	Source
$a_{emin,}a_{emax}$	communicated range for financial savings	See Table 4.1	Eurostat statistics explained (Eurostat, 2016)
$a_{hmin,}a_{hmax}$	communicated range for comfort change	See Table 4.1	B. Boardman et al. (Boardman *et al.*, 2005)
$a_{bmin,}a_{bmax}$	communicated range for CO_2 savings	See Table 4.1	Covenant of mayors, 2010
$a_{amin,}a_{amax}$	communicated range for social welfare	See Table 4.1	S. Darby et al., 2012 (Darby *et al.*, 2012)
Techno-risk	perceived technological risk	[1, 6]	-

Table 18. Contract specific variables

5.2.3 Data analysis

The aim of SIMP-N is to verify if the introduction of the social network will affect contract adoption and therefore system level performance. In this section I will present the contract adoption for the different scenarios under the new condition (i.e.: social network introduction through "communityNumber") and I will analyse if different degree of social membership ("communityNumber") affect contract adoption levels. I will also present how attitude satisfaction and techno tolerance satisfaction vary under the new simulation conditions.

5.2.3.1 Contract distribution

In this section I will present the contract distribution for each scenario. Considering that the focus of the present simulation is to verify the effect of social interactions on consumer's choice in terms of contract adoption, I have decided to focus the attention of this simulation only on two policies: voluntary policy and environmental policy. I will not consider the mandatory policy.

Scenario 1

The conditions for Scenario 1 are presented in the following table:

Contract duration	12 months
Contract distribution	all A contracts
communityNumber (n_c)	3, 5 ,15

The results of the simulation for Scenario 1 are presented in Figure 52. The graph top left presents the contract distribution as presented in Chapter 4 where only peer influence is present (no social influence, therefore $n_c = 0$). The graph top right presents the contract distribution for $n_c = 3$ and shows a change in contract adoption. It emerges that, due to social interaction, more consumers shift to more technologically advanced contracts (contract F and contract G), thus increasing the system level performance. It appears that the effect of social network ("communityNumber") has a more powerful effect than the peer interaction presented in Chapter 4. It emerges that the interactions with different social circles produce a stronger effect that make consumers overcome technological concerns ("techno-tolerance risks"). Figure 52, bottom left, presents the contract adoption when the number of social networks increases from 3 to 5. It can be observed that the increase of "communityNumber " ($n_c = 5$, bottom left in Figure 52)) produces a small increase in contract adoption and this is mainly for the environmental policy. Further increasing the number of social interactions do not further impact contract adoption (bottom right, $n_c = 15$). It also stands out that the effect of the environmental campaign appears not particularly significant. It is argued that standard information-intensive campaigns are not the best way to engage and motivate the consumers (Frederiks *et al.*, 2015). Targeted campaigns may have a more effective impact on consumers' choices (Gangale *et al.*, 2013). Interestingly, the effect of the number of social networks seems to level out when the social network increases above a certain value of "communityNumber" ($n_c = 15$). This is an interesting finding that could be explained by the fact that consumers tend to be confused by too many opinions/point of views and therefore tend to keep as definitive the decisions taken when in discussion with a limited number of "members" (community number = 3). It is claimed that the strength of relations between individuals is more important to information diffusion than the number of connections individuals have (Du *et al.*, 2016).

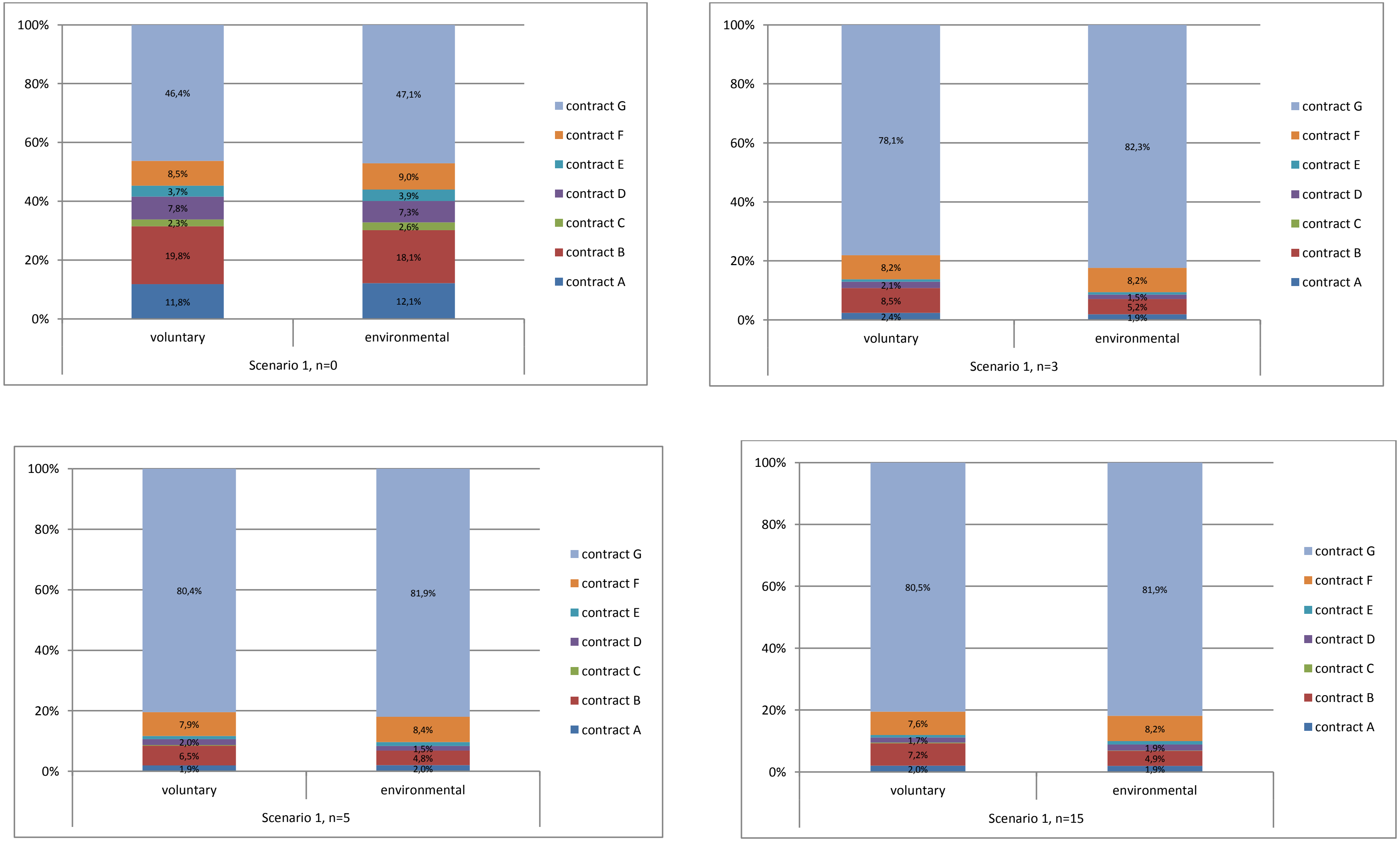

Figure 52. Average contract adoption Scenario 1 (n_c = 0, 3, 5, 15)

Scenario 2

Contract duration	12 months
Contract distribution	Equal distribution
communityNumber (n_c)	3, 5 ,15

The results of the simulation for Scenario 2 are presented in Figure 53. The graph top left presents the contract distribution as presented in Chapter 4 where only peer influence is present (no social influence, $n_c = 0$). The graph top right represents the contract distribution for $n_c = 3$ and shows a change in contract adoption. The pattern is similar to the one observed for Scenario 1, where there is an increase in the adoption level of the most technologically advanced contract (contract F and contract G). A similar pattern as in Scenario 1 is also observed for $n_c = 5$ (bottom left) where the increase of the number of "communityNumber" produces a small increase in contract adoption of contract G, mainly for the voluntary policy. The initial contract distribution - in this scenario all the contracts are presents in the market at the beginning of the simulation - produces similar results to those of Scenario 1 when $n_c = 3$ and $n_c = 5$. However, it emerges that the number of social networks may have an influence on contract distribution when $n_c = 15$ (bottom right). In this case there is still a high adoption of technologically advanced contracts (contract F and contract G), but the distribution is different with a decrease in the number of consumers that have adopted contract G. As argued for scenario 1, the strength of relations between individuals may play a more important role to information diffusion than the number of connections individuals have. This is an interesting finding that needs further exploration.

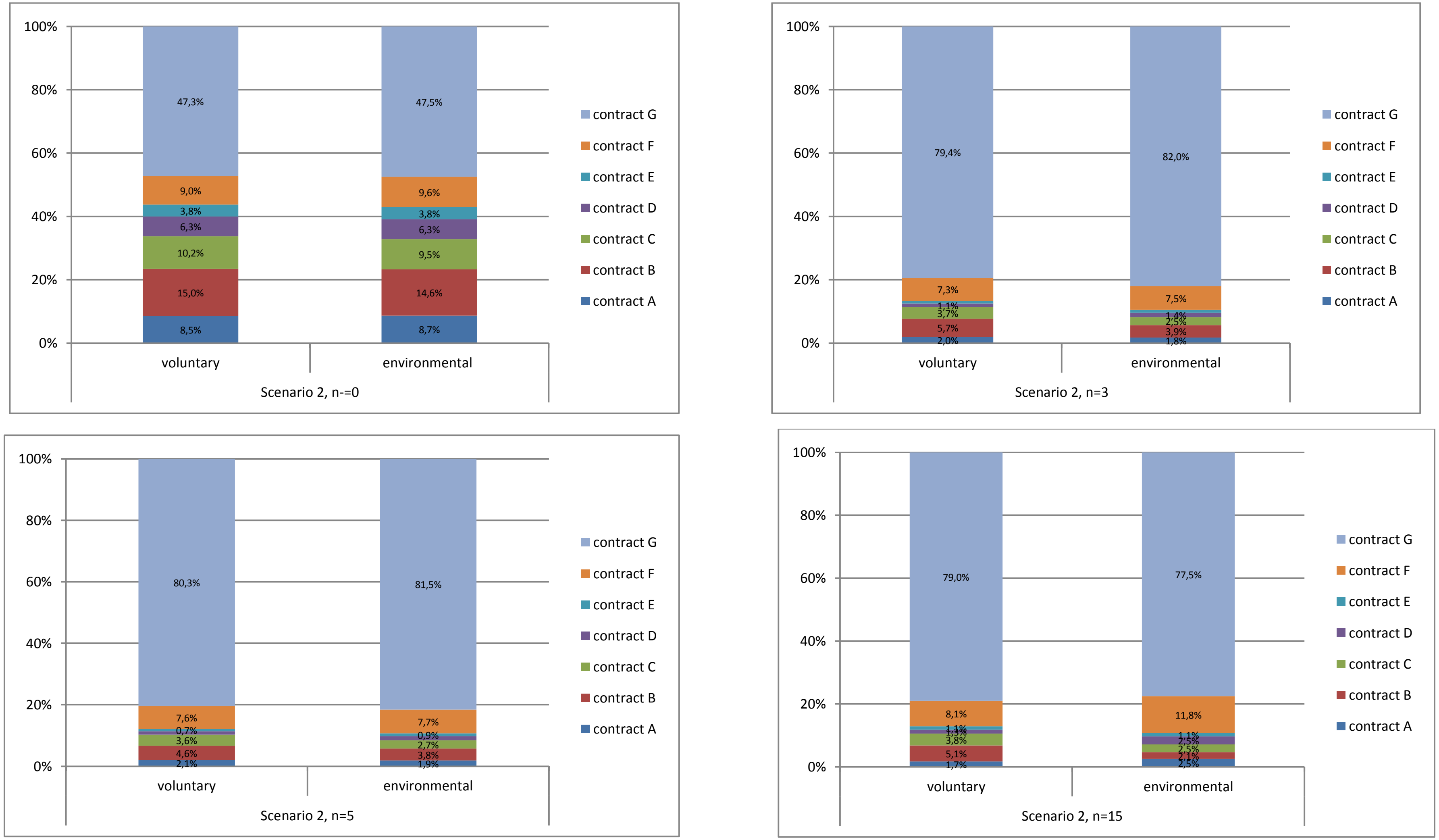

Figure 53. Average contract adoption Scenario 2 ($n_c = 0, 3, 5, 15$)

Scenario 3

Contract duration	indefinite
Contract distribution	All A contract
communityNumber (n_c)	3, 5 ,15

The results of the simulation for Scenario 3 are presented in Figure 54. The graph top left presents the contract distribution as presented in Chapter 3 where only peer influence is present (no social influence, $n_c = 0$). The graph top right presents the contract distribution for $n_c = 3$ and shows a change in contract adoption. As for Scenario 1 and 2, it emerges that more consumers, because of the social interactions, shift to more technologically advanced contracts (contract F and contract G). The effect for this scenario appears to be stronger that what observed for Scenario 1 and 2. Consumers appear to move to the more technologically advanced contract (contract G) with few consumers staying with contract F, differently from the previous scenarios. Almost 97% of consumers move to contract G for environmental policy and 92% for voluntary policy. This pattern doesn't seem to change when "communityNumber" increases from $n_c = 3$ to $n_c = 15$. Two observations can be made on this emerging trend: 1.contract duration may have an influence on contract adoption and in case of indefinite duration it seems that consumers, though not forced to change due to contract conditions, do consider and value the choices of their community, 2.environmental policy seems to have an effect on those consumers that do not have yet switched to more technologically advanced contracts in case of unlimited contract duration. These are observations that need further exploration.

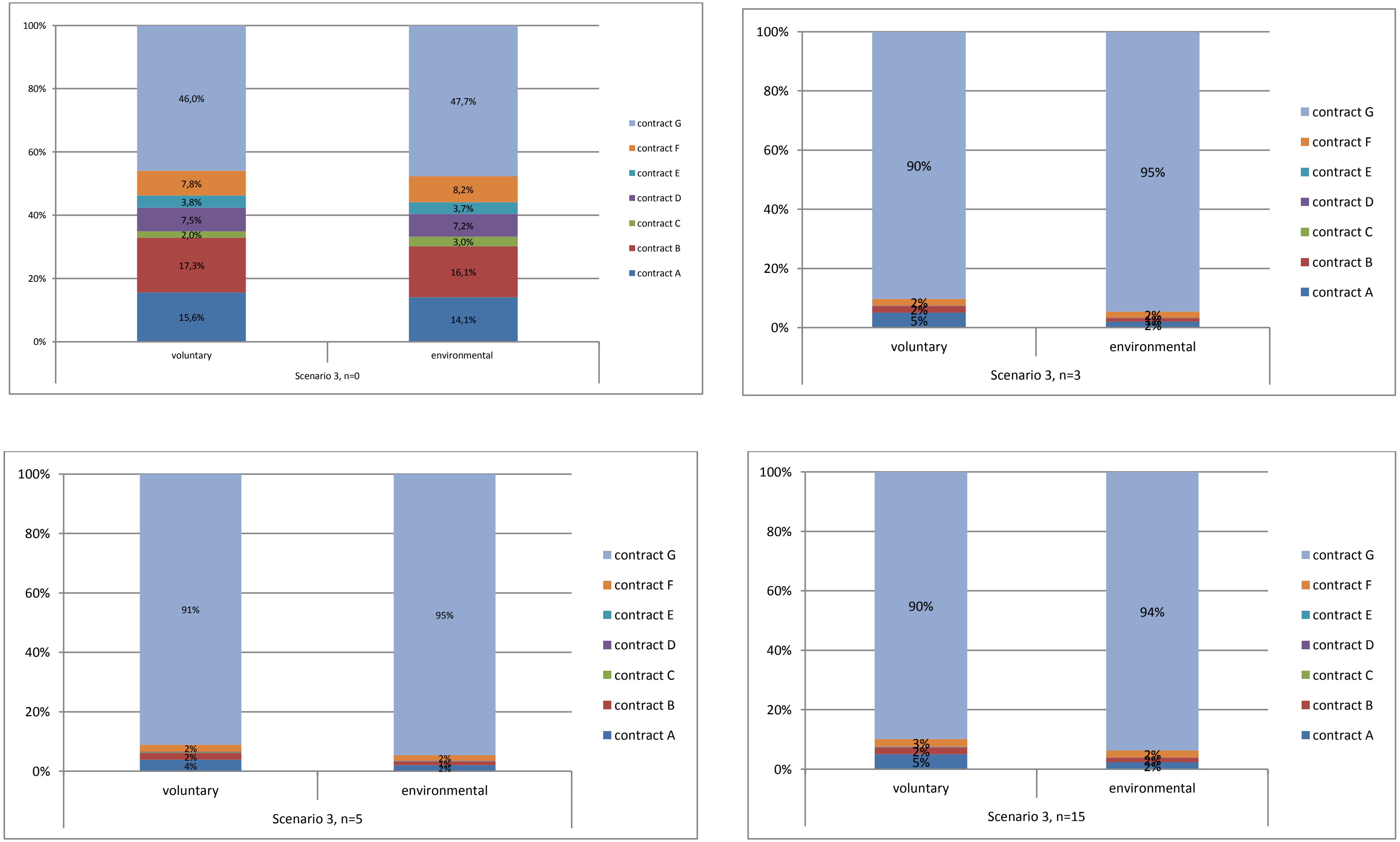

Figure 54. Average contract adoption Scenario 3 (n_c =0, 3, 5, 15)

Scenario 4

Contract duration	indefinite
Contract distribution	Equal distribution
communityNumber (n_c)	3, 5 ,15

The results of the simulation for Scenario 4 are presented in Figure 55. The graph top left presents the contract distribution as presented in Chapter 3 where only peer influence is present (no social influence, $n_c = 0$). The graph top right presents the contract distribution for $n_c = 3$ and shows a change in contract adoption. As for Scenario 1 and 2, it emerges that more consumers, because of the social interactions, shift to more technologically advanced contract (contract F and contract G). The effect for this scenario appears to be stronger that what observed for Scenario 1 and 2. Consumers appear to move to the more technologically advanced contract (contract G) with few consumers staying with contract F, differently from Scenario 1 and 2. The same observations made for Scenario 3 are also valid for this scenario.

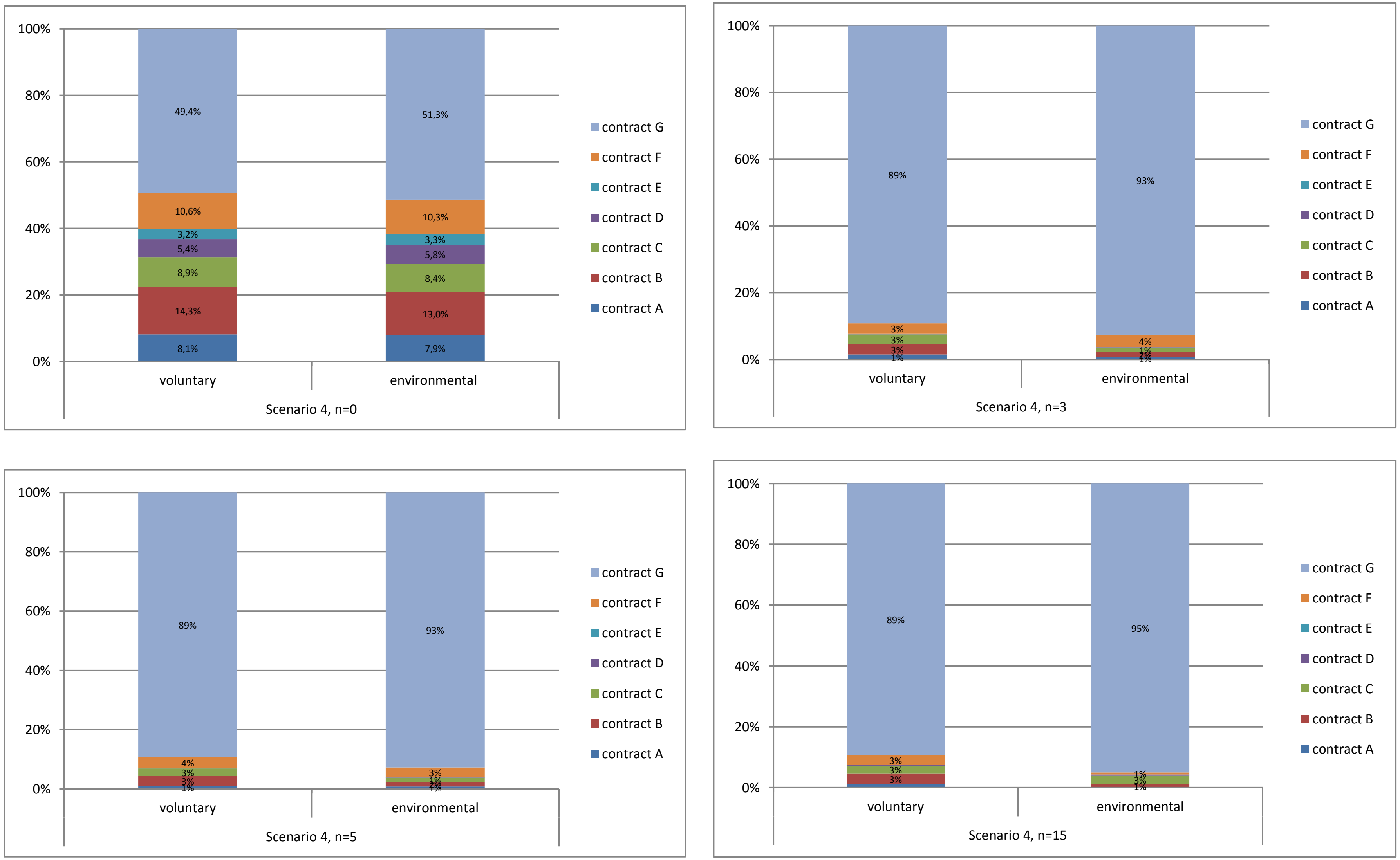

Figure 55. Contract adoption distribution Scenario 4: n_c = 0, 3, 5, 15

Figure 56 provides an exemplification of the variation of final contract distribution (t = 120) when n_c = 0 (left) and n_c = 5 (right) for voluntary policy (policy 1). It is clearly visible how the introduction of the social network impacts the contract distribution.

a) b)

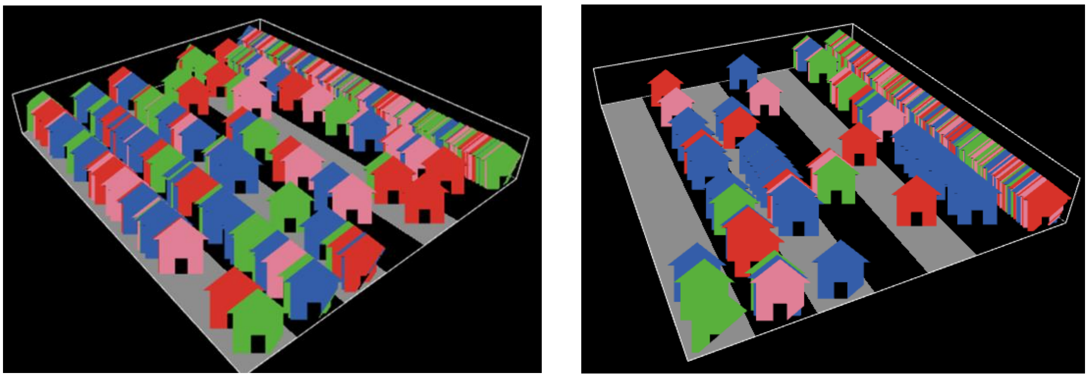

Figure 56. Contracts' distribution among household: a) t=120, n_c=0, policy 1, b) t=120, n_c=5, policy 1

Figures 57-60 present an example of contract adoption evolution for different values of "communityNumber " at t = 24 for the environmental policy (policy 2).

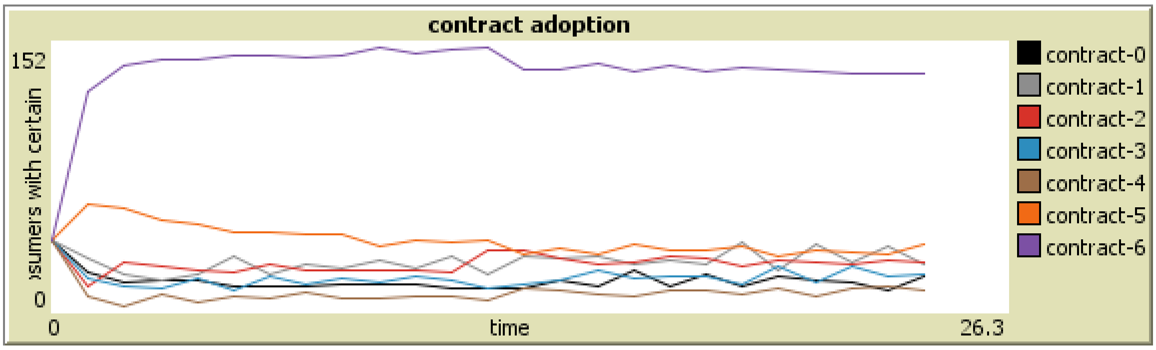

Figure 57. Contract adoption (t=24, n_c =0, policy 2)

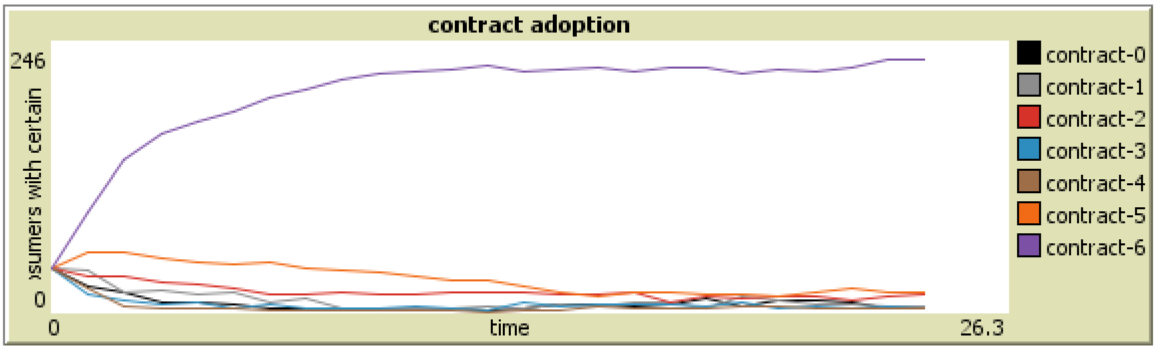

Figure 58. Contract adoption (t=24, n_c =3, policy 2)

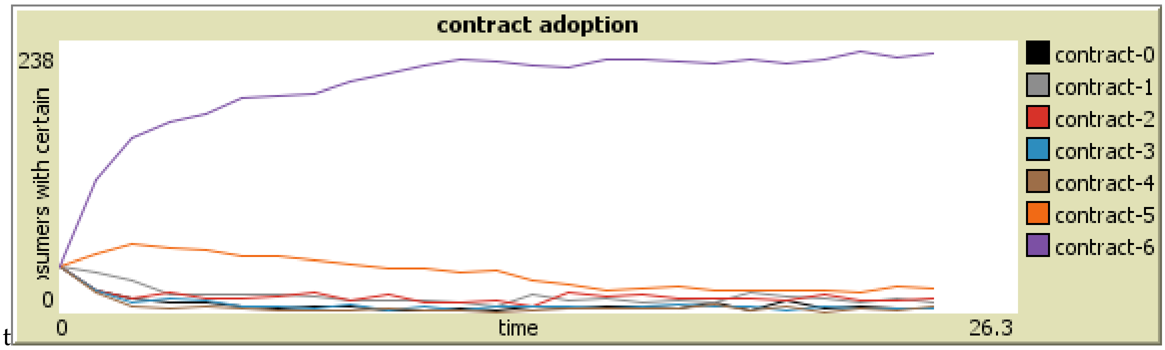

Figure 59. Contract adoption (t=24, n_c =5, policy 2)

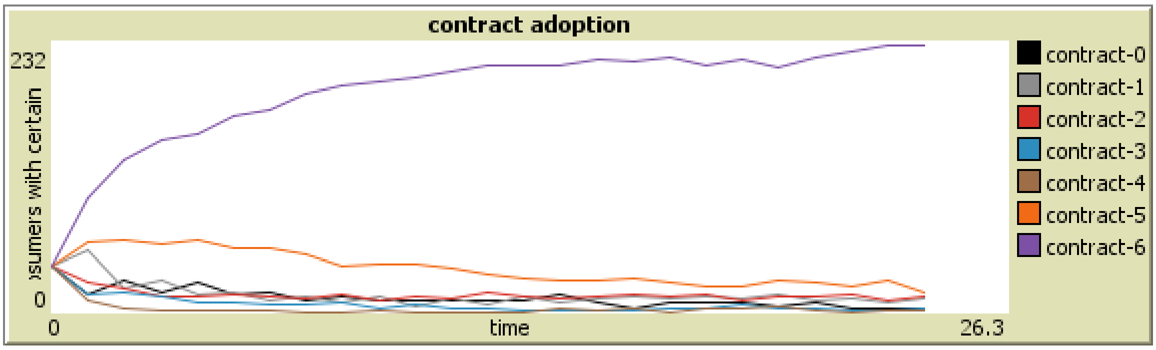

Figure 60. Contract adoption (t=24, n_c =15, policy 2)

5.2.3.2 Average attitude and techno-tolerance satisfaction

In this section I will look into attitude and techno tolerance satisfaction and explore how these vary once the social network is introduced. I will present for each scenario the variation of attitude and techno tolerance satisfaction, considering different values of the "communityNumber" variable, namely $n_c = 3$, $n_c = 5$, $n_c = 15$.

Scenario 1

Contract duration	12
Contract distribution	all A contracts
communityNumber (n_c)	3, 5 ,15

Figure 61 presents the variation of attitude and techno tolerance satisfaction for Scenario 1, in the case of voluntary policy (p1) and environmental policy (p2) for different values of the variable "communityNumber" specifically *n_c =3, 5, 15.* The figure shows a clear drop in techno-tolerance satisfaction. This is not surprising since the consumers move to more technologically advanced - thus more technologically risky - contracts. However, it can be argued that the fact of belonging to a social group ("membership") help consumers overcome their technological concerns in the sense that they feel reassured by the "community adoption". There is no major change in attitude satisfaction which consistently remains close to zero.

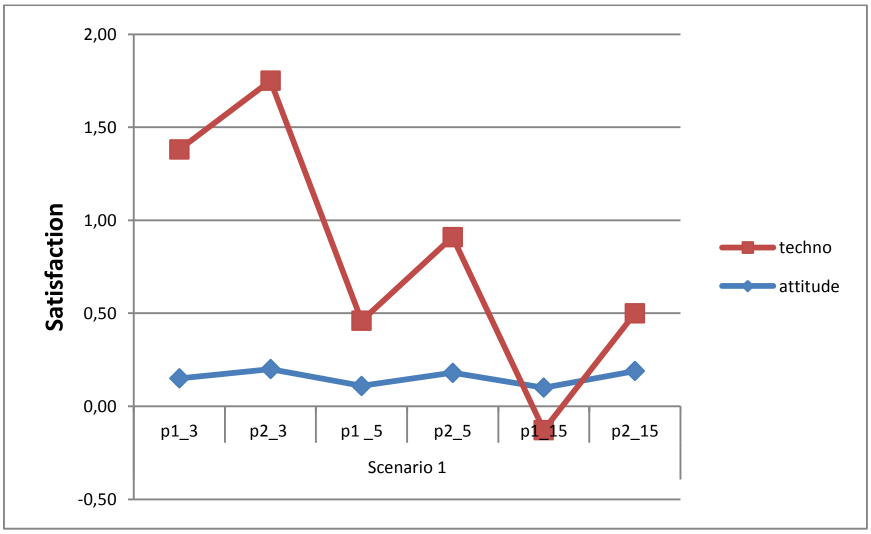

Figure 61. Attitude and techno-tolerance satisfaction for Scenario 1- voluntary (p1) and environmental (p2), for n_c =3, n_c =5, n_c =15

Scenario 2

Contract duration	12
Contract distribution	Equal distribution
communityNumber (n_c)	3, 5 ,15

Figure 62 presents the variation of attitude and techno tolerance satisfaction for Scenario 2 in the case of voluntary policy (p1) and environmental policy (p2) for different values of the variable "communityNumber" specifically n_c =3, 5, 15. Differently from the previous scenario, here some irregularities emerge. In particular unexpected behaviours concerning techno-tolerance satisfaction emerges for the environmental scenario when n_c = 3. Irregularities also emerge for the attitude satisfaction. Though it is difficult to provide explanations for these unexpected behaviours, this kind of behaviours should be taken into account in the policy making process and not disregarded.

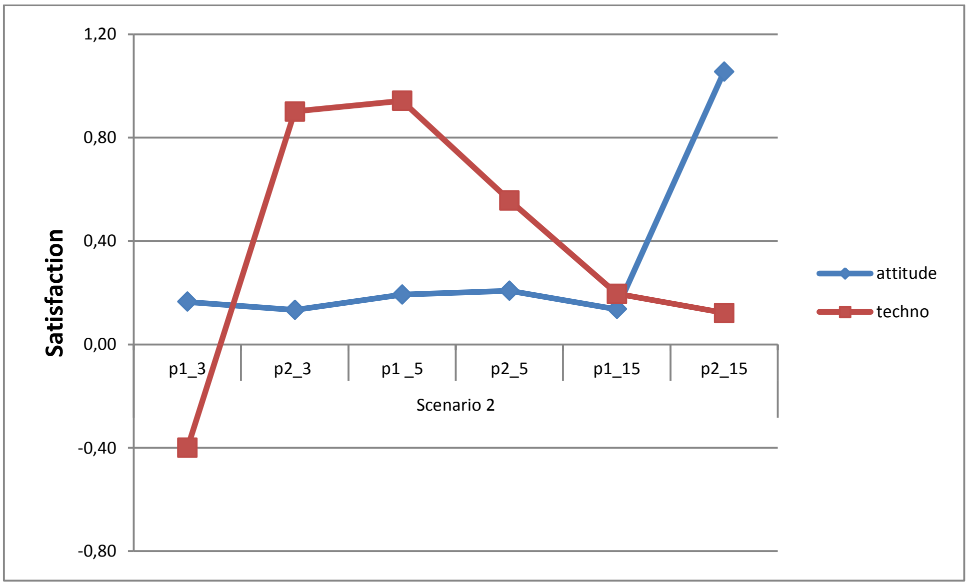

Figure 62. Attitude and techno-tolerance satisfaction for Scenario 2- voluntary (p1) and environmental (p2), for n_c =3, n_c =5, n_c =15

Scenario 3

Contract duration	indefinite
Contract distribution	All A contract
communityNumber (n_c)	3, 5 ,15

Figure 63 presents the variation of attitude and techno tolerance satisfaction for Scenario 3, in the case of voluntary policy (p1) and environmental policy (p2) for different values of the variable "communityNumber" specifically n_c *=3, 5, 15.* As in Scenario 2, also in this scenario unexpected behaviours emerge with irregularities for the value of techno tolerance satisfaction for policy 2, $n_c = 3$ and policy 1, $n_c = 15$.

There is not major change in attitude satisfaction which consistently remains close to zero and do not present irregularities.

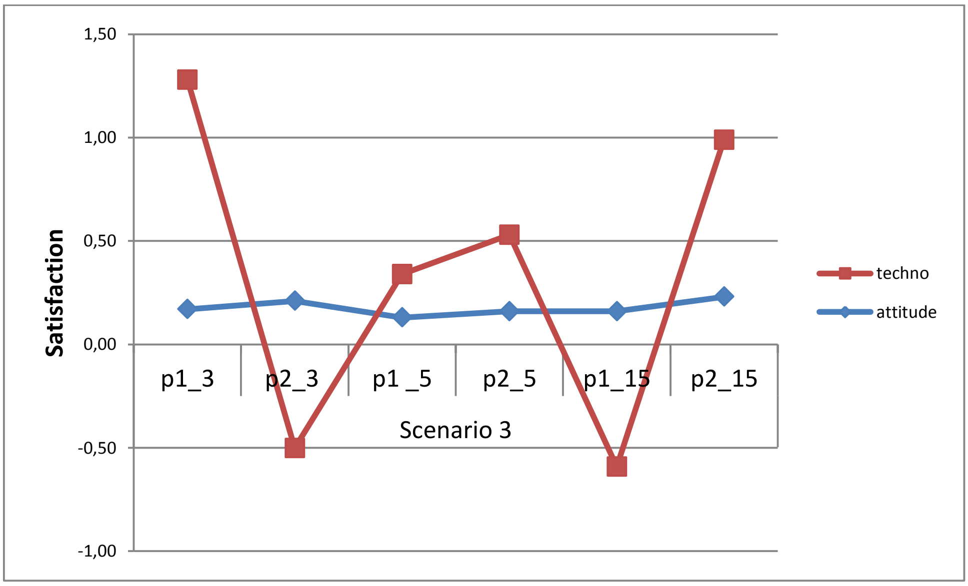

Figure 63. Attitude and techno-tolerance satisfaction for Scenario 3- voluntary (p1) and environmental (p2), for n=3, n=5, n=15

Scenario 4

Contract duration	indefinite
Contract distribution	Equal distribution
communityNumber (n_c)	3, 5 ,15

Figure 64 presents the variation of attitude and techno tolerance satisfaction for Scenario 4, in the case of voluntary policy (p1) and environmental policy (p2) for different values of the variable "communityNumber" specifically n_c *=3, 5, 15.* As in Scenario 2 and 3, also in this scenario unexpected behaviours emerge with irregularities for the value of techno tolerance satisfaction.

There is not major change in attitude satisfaction which consistently remains close to zero.

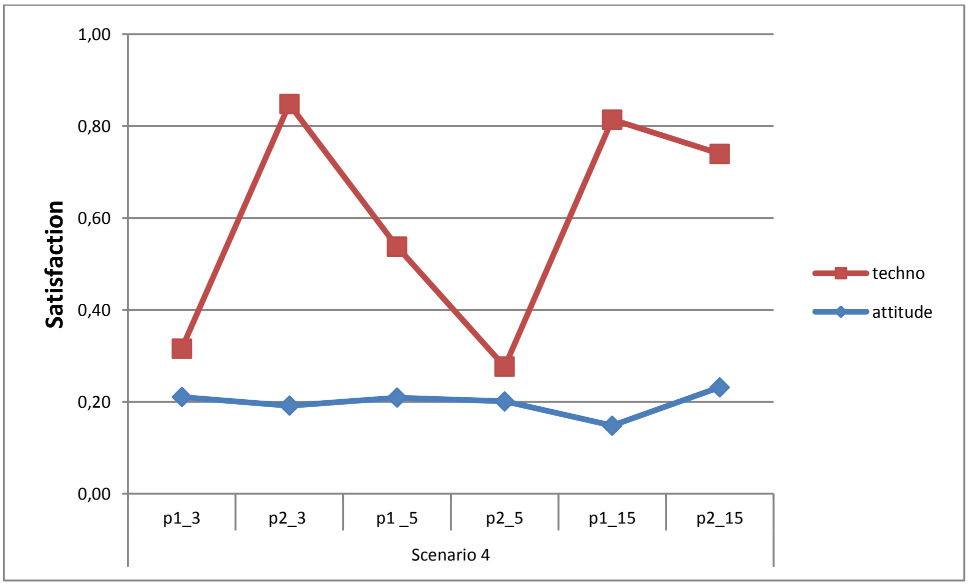

Figure 64. Attitude and techno-tolerance satisfaction for Scenario 4 - voluntary (p1) and environmental (p2), for n_c =3, n_c =5, n_c =15

5.3 SIMP-N: Discussion and conclusions

The results of the introduction of the social network in the model have produced interesting findings that can be summarized as follows:

- The introduction of the social network ("communityNumber") has a strong influence on the decision making process and on consumer's contract choices and final contract distribution;

- The value of "communityNumber " that represents the communities or social networks to which consumer belongs, seems to influence the consumer's choice when this number is relatively low (n_c = 3); however the effect levels out when the number increases (n_c = 5 or n_c = 15). This can be justified by fact that belonging to many communities may create confusion ("information overload") and consumers tend to stick to the choice of a limited number of communities that they trust. This is supported by studies that argue that strength of relations between individuals is more important to information diffusion than the number of connections individuals have;

- Consumers' membership seems to reassure consumers about techno risks and encourage them to move towards more technologically advanced contracts;

- The results can be linked to social theory of practice that emphasis endogenous and emergent dynamics were people are carriers of practices (Shove, 2010) that they share within a community as opposed to the theory of behaviour that focus on causal factors and external drivers (or barriers) (Ajzen, 1991);

- Irregularities emerge for what concerns patterns of consumer satisfaction (attitude and techno tolerance). These irregularities can be ascribed to the non-linearity of the underlying processes that are at the core of the model. These are unexpected behaviours that emerge from the present analysis; they should be taken with caution since they may be linked to the simplified way in which consumer interactions have been modelled. However they shouldn't be neglected and should be considered in the policy decision making processes;

- The results provide interesting insight in the importance of social networks and community approaches to energy choices and deserve further analysis and exploration of the mechanisms at play.

The social interaction introduced in SIMP-N presents similarities with comparable research in consumer modelling. In the model proposed by Izquierdo an Izquierdo (Izquierdo *et al.*, 2007) the social network is created by connecting pairs of agents at random, with a parameter used to adjust the number of connections ("communityNumber" in SIMP-N) from completely connected to completely unconnected. The research concludes that without a social network consumer confidence falls to the point where the market is not anymore viable, while with a social network the aggregation of agent's own experience and the more positive collective experience of others help to maintain market's stability.

In conclusion, SIMP-N shows how social information can aggregate group experience to a more accurate level and so reduce the importance of a single individual's bad experience (Gilbert, 2008).

The famous quote by P.E. Box states that "*all models are wrong, but some are useful*". While there are clear useful insights to be drawn from SIMP and SIMP-N models, limitations emerge that should be addressed in future research.

6 Roadmap for ABM of Emerging Electricity Systems: an integrated chain of models

6.1 Introduction

The scope of this chapter is to present a framework for an integrated approach to the simulation of emerging energy systems and markets. As discussed in Chapter 2, the electricity system can be considered as a multilayer complex system where technological, social and environmental layers interact. Common approaches tend to focus on one dimension at a time using analytical and simulation tools specific for each discipline addressed. The insights obtained by matching different results coming from the different modelling perspectives are not likely to provide satisfactory support for the development of sound policy decisions. The limitations are that the interactions among the different dimensions of the problem are not explicitly addressed and that the scenarios and assumptions may not be consistent among the different layers.

Implementing an integrated approach to the simulation of retail electricity markets and distribution systems requires considering the heterogeneity of the dimensions, factors and interactions that characterize the problem at stake. As argued in Chapter 2, the energy systems should be considered as a system-of-systems, that is to say a collection of dedicated systems that pool their resources and capabilities together to obtain a new, more complex system that offer more functionalities than the sum of the distinct systems.

The scope of the present thesis has been mainly focused on the interaction of the electricity consumer, as an individual and social agent, with smart metering technologies. Future developments should be in the direction of integrating SIMP model within a broader context. In particular it would be of interest in the current EU energy policy development to integrate the consumer model (SIMP) with the retail electricity market, the distribution system operator (DSO) and the electricity network. Studying the interactions between consumer/prosumer, electricity network and the market is at the core of the legislative proposals included in the Clean Energy Package.

6.2 Integrated approach to consumer, market and electricity network - REMS

In this section I will introduce an integrated modelling framework that will include the consumer, the electricity network and the retail energy market. The aim is to build a tool that can simulate the economic and technological aspects of the electricity market: Retail Energy Market Simulation (REMS) tool. Differently from SIMP where the agent-consumer was assumed to be representative of a household (for what concerns decision making processes), here consumers and households are separated. By "household" here is meant the collection of smart home appliances that determines the household load profile. The model is composed by three modules:

- **The market**: it includes 3 entities, namely the *consumer*, the *electricity supplier* (retailer) and the *Distribution System Operator* (DSO). DSO operates as an interface between economic transactions and the physical network playing the role of a neutral market facilitator. Here, DSO communicates with the retailer sending information about network costs (i.e.: congestion costs, network losses and wheeling costs).

Box 6.1: Distribution System Operator

With growing penetration of renewable and dispersed power resources, electric vehicles and active demand side participation, DSOs play an increasingly important role in facilitating effective and well-functioning retail markets. DSO's traditional role is swiftly evolving towards a role of neutral market facilitator or information hub provider, granting the energy end-users with the possibility to opt for better energy contracts and allowing retail companies to offer options and services best tailored to the customer needs. In the future, it will be expected that DSO will be increasingly required to perform more active grid development, management and operation as these changes place new requirements on the network in terms of operational security, while offering the DSO more options to manage the grids in a more flexible and efficient way (van den Oosterkmap *et al.*, 2014). Recent studies on smart grid development shows that DSOs are proactively researching and testing new solutions, as well as new roles and business models to prepare for the new tasks and opportunities that are emerging in the evolving electricity system (Vasiljevska *et al.*, 2016).

- **The network:** it simulates the electricity network at the distribution level. It receives consumption load from the households, computes congestion costs and losses and wheeling costs that are sent to DSO agent.
- **The household:** it includes several heterogeneous "houses". Heterogeneity is given by the differences in household's load profiles. These profiles depend on the contracts the consumer has agreed with the retailer and on socio-demographic parameters (age, income, number of occupants, etc.); these parameters have an influence on the way household appliances (e.g.: air conditioning, boiler, fridge, freezer, etc.) are used. Each household sends its load profile to the electricity network (for load computation) and to the retailer (for billing and demand response). The household can be modelled as a system of electric appliances used by the house residents. The model has the capabilities of determining in detail the electricity load of the set of electric appliances within a house under different conditions of usage. The simulation of household load profiles is performed by resLoadSIM (Residential Load Simulator) (Wilkening, 2015).

The schematic representation of REMS is presented in Figure 65.

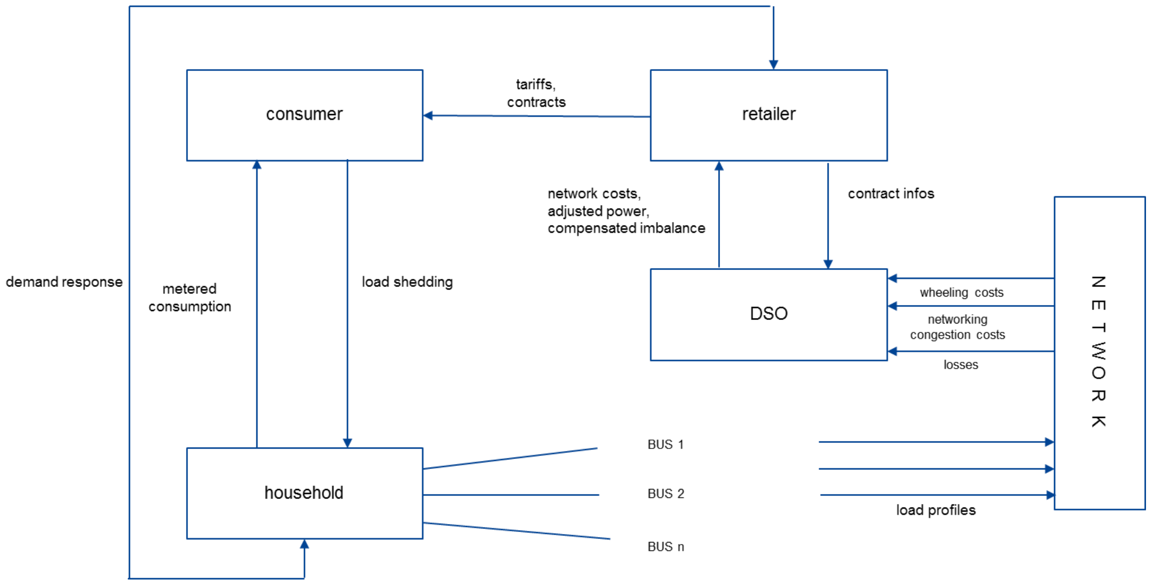

Figure 65. Retail Energy Market Simulator (REMS) proposed framework

6.2.1 Objectives of REMS model

REMS model can serve several purposes. Different initial conditions may produce different model results and model dynamics. Some of the possible objectives are briefly presented below:

6.2.1.1 Consumer

Differently from SIMP, REMS would foresee a fully operational energy retail market, where different retailers with different contract portfolio are active in the market. Consumers are free to choose from the different energy contracts available on the market. From the consumer's point of view, the model would be capable of providing the switching rate among the different contracts offered by the retailers and the switching rate between different retailers. The first outputs consider switching among contracts offered by the same retailer, while the switching rates between different retailers refer to contracts provided by different retailers. These outputs can be considered as a proxy for competition and consumer awareness. Another interesting output of the model could be the market share of different contracts. The composition of demand could be observed considering different behavioural rules for the consumers. Finally the yearly amount of bills and the yearly energy consumption are tracked, considering both their average values and their evolutions.

6.2.1.2 Retailers

The market in REMS, differently from SIMP, is a mature market where different retailers are offering different contracts and services to the consumer. Of interest from the retailers perspective would be first: to evaluate the market share of retailers, particularly in respect to some salient features such as innovative services and offers, green energy, etc.; second: to follow the evolution of the share of contracts including demand response. Flexibility is present both in term of variable tariffs and of contracts that allows for load shedding.

6.2.1.3 Network and DSO

From the point of view of network operation, it is interesting to investigate the minimum share of contracts with demand response option that is necessary to balance the network. Moreover, the model could be able to provide the yearly values of network congestion costs, losses and wheeling costs. These outputs express the feasibility of the transition to a more dynamic energy distribution system. In addition, it could be possible to include local generation at medium voltage level, exploring how prosumers and local energy community could enter the market. REMS would also allow the simulation of different operational regimes that could be explored using specific national regulatory frameworks. REMS would also allow the exploration of possible new roles for DSO (see Box 6.1).

6.2.1.4 Households

The household module deals with the home infrastructure and control mechanisms for load management at household and appliance level. The set of rules defining the load control mechanisms are linked with the behavioural patterns of the agents, as characterized in the consumer module. The output of the household module is mainly the evolution of consumption profiles in several situations (week-end, working days and different seasons) and under different consumer preferences.

REMS could be a valuable tool for testing different policy scenarios.

6.2.2 Entities and variables

A first proposal for variables to be included in each module of REMS is presented in Tables 19-22. These tables summarize the results brainstorming and discussions among a group of researchers with different academic background (engineers, economists, social scientists). These tables need further elaboration and adjustments, however they define and summarize the main model variables and the developments required for a more advanced simulation tool of emerging electricity systems.

Consumer			
Variable	*Definition*	*SIMP*	*Development*
Susceptibility	Sensitivity to peer pressure (each consumer receives opinions by the neighbors about contract satisfaction)	Static	To be defined
Number of agents	Number of electricity prosumers included in the simulation	Currently 200 and 280	Larger set of population
Archetypes	Linked to weights (values) and the highest determines the archetype	Static	Dynamic
Weights	Egoistic, Hedonic, Biospheric, Altruistic	Static Scale 0-1. They sum up to 1	Dynamic (endogenous)
Size of household	Socio-demographic characterization of the household	Absent	Number of members
Techno-tolerance threshold	Concerns about the privacy	Static	Dynamic
Memory	Consumers have memory of their contract experience= average of the past experience and the new experience	Agent look at the experience one step back	To be defined
Satisfaction threshold	Limit under which the consumer decides to look for a new contract/retailer	Static	Dynamic
Choice set	The number of contracts available for the choice task of each consumer	Complete choice set	Complete/incomplete Transaction costs Sensing (only a of options)
Social networks	Number of neighbors linked to the consumer	Sampled over the space of values (weights)	?
Metered Consumption			kWh (from resLoadSIM)
Expected consumption	Expected consumption for the next 15 min		kWh (from resLoadSIM)

Table 19. Consumer module characterization

Retailer			
Variable	*Definition*	*SIMP*	*Development*
Number	Retailers active in the market	1	Several
Contracts	See contract table		
Retailer network	Actions determined by observing other retailers	N.A	To be defined
Ancillary selling price	15 min price	N.A.	From real data
D/R compensation	Compensation to consumer for participating in DR	N.A.	To simulate
Ancillary buying price	15 min price	N.A.	From real data
Total power to sell	Total power to sell on the ancillary selling market.	N.A.	It is computed every 15 min.
Total power to buy	Total power to buy on the ancillary selling market.	N.A.	It is computed every 15 min
Expected consumption	Forecast from past consumption data	N.A.	

Table 20. Retailer module characterization

Contracts			
Variable	*Definition*	*Actual setting*	*Development*
Duration	Contract duration	12 months	To be defined
Contract condition	Price	Range of values	To be defined
Types of energy pricing	Tariff	N.A.	Fixed, variables,
Payment and billing possibilities	Direct debit, paper and e-billing	N.A.	It could be included in "Additional services"
Energy source	Fossil vs. renewable	N.A.	Percentage of renewable sources
Additional services	e.g.: meter reading, e-billing, maintenance, supermarket points, gifts, feedback…	N.A.	High/Low
Demand side response for load shedding	Possibility given to consumer to participate to DR	N.A.	On/Off
Components of the tariff	Detailed information of elements of the electricity bill	N.A.	To be defined
Maximum load per contract		N.A.	To be defined

Table 21. Contract module characterization

Network			
Variable	*Definition*	*Actual setting*	*Development*
Wheeling cost	Cent/kWh. cost for using the network to transport electricity from one point to another one	N.A.	Fixed. Real data (possibly)
Congestion cost	€/(15 min). Cost for resolve congestion problems. Info to DSO	N.A.	Calculation
Losses	€/(15 min). Dispersion of energy. Info to DSO	N.A.	Calculation
Adjusted power	Adjustments of the load/consumption for the household/consumer	N.A.	Calculation
Compensated imbalance from transmission	1/kW. It would be send to retailers and DSO	N.A.	Calculation

Table 22. Network module characterization

6.3 The way forward

The framework presented in this chapter is a proposal for a further development of SIMP model in line with the multilayer approach presented in Chapter 2.The REMS framework includes a chain of models representing the social, economic and technical layers of the emerging electricity systems. Therefore it could be employed for generating explorative scenarios assessing various possible policy options.

7 Conclusion

7.1 Answering the research questions

This section explains how the research questions have been answered through the analysis of the empirical evidence from ongoing smart electricity system activities in EU and through agent based modelling simulation.

The first question asked which role the European consumer is envisaged to play in the future electricity systems. It emerges that the increasing integration of renewable energy resources and the transition to a sustainable energy system requires an active role of the consumer. This is recognized by the EU energy policy developments where the role and active participation of the energy consumer is considered as "*a prerequisite for managing the energy transition successfully and in a cost-effective way*". This active role should not only be seen in terms of consumers or users, but also in terms of active contribution to the shaping of policies in the area of energy (energy citizenship).

The second question asked how complexity science can contribute to the understanding of the emergent socio-technical interface of the future electricity systems. The complexity of the smart electricity system rests on the multiplicity of interacting players that operate as independent decision makers with behaviours that are driven by individual as well as socially driven goals and attitudes. Specifically, the social layer has been identified as the main source of complexity that lead to the unpredictable performance of the overall system. The agents in the social layer interact through physical and social networks by sharing information and learning from one another through social interactions. These interactions determines self-organization and emergent behaviours in energy consumption patterns and practices that evolve in time according to contextual factors. Conventional modelling tools do not cope well with this complexity and agent based modelling is considered as better suited to represent the complexities of consumer behaviours and to study emergence in consumer systems, in particular how values and beliefs at consumer level lead to macro behaviours such as adoption over time and space.

The third question asked which values, goals and norms drive the electricity consumer towards the adoption of smart grid technologies. It emerges that a rich literature on sustainable consumption and behavioural change exists, shifting from an individual to a collective approach to behavioural change and different theories and models are proposed. For the purpose on this thesis, after having reviewed the main theories, I have chosen to use elements from the goal framing theory and the social practices theory.

I have reviewed the relevant social psychology theories and explored consumers attitudes, concerns and beliefs through the analysis of EU energy consumer surveys and demand side management pilot projects. Moreover I have performed focus group discussions to further substantiate the individual as well collective dimension of energy use and the different lenses and perspectives of analysis. It has emerged that energy consumption is an individual as well as collective process that need to be understood and tackled in its complex dimension and may benefit of community-based local approaches.

The fourth question asked which drivers and barriers may encourage or hinder consumers' adoption of smart grid technologies and their participation in demand response and energy community schemes. From the analysis of European surveys, pilot projects and focus groups it emerges that well-designed information strategies can contribute to consumer engagement and may induce behavioural change and technology adoption. However, attention should be paid to tailoring the feedback information to different consumers' segments. Drivers other than economic/monetary (e.g.: environmental, social welfare) can help to engage different consumer segments and to maintain consumers engaged over time. The analysis has also highlighted that consumers have concerns mainly linked to data privacy and security issues, loss of control and change in comfort level.

The fifth question asked which impacts interacting electricity prosumers exposed to different polices may have on sustainability, market competitiveness and energy savings. I have addressed this question developing an agent based model (SIMP and SIMP-N) to explore the emergence in consumer systems and how values and beliefs at consumer level (as defined by social psychology and behavioural theories and informed by empirical evidence) and social dynamics lead to macro behaviours. More specifically, I have explored the diffusion of smart grid technologies enabled services among a population of interacting prosumers and evaluate the impact of such diffusion on individual and societal performance indicators under different policy scenarios and contextual factors. It emerges that different psychological characteristics, social dynamics and technological elements can strongly influence consumers' choices (in terms of energy contract choices) and overall system performance.

7.2 Contribution of this dissertation

This dissertation contributes to a better understanding of the interface between technology and society in the emerging electricity systems. It contributes to the ongoing discussion on the central role of the energy consumer/prosumer in the EU energy transition.

7.3 Limitations

While the work presented in this dissertation provides interesting and useful insight into the complexity of consumer behaviours in emerging electricity systems, it also has some limitations. There are limitations linked to the choice of the general factors that drive consumer behaviours and choices. Alternative theories of human behaviour could provide different results. Limitations are also linked to some variables being modelled as exogenous without taking into consideration consumers learning processes through the implementation of adaptive variables. Moreover, the model should consider more reflexive and reactive institutions, as well as explore institutions emerging from agents' behaviour. Finally, the possible availability of empirical data constitutes a major route for further development of the model.

7.4 Future developments

Future developments should be in the direction of integrating SIMP model within a broader context. In particular it would be of interest in the current EU energy policy development to integrate the consumer model (SIMP) with the retail electricity market, the distribution system operator (DSO) and the electricity network. Studying the interactions between consumer/prosumer, electricity network and the market is at the core of the legislative proposals included in the Clean Energy Package.

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