Comparing the impact on energy security under different policy scenarios concerning decentralised renewable electricity generation in the State of New York

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This work can be found it the TU Delft Repository, visit: https://repository.tudelft.nl

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Preface

Perseverance pays off, is what I would like to start with. During this process, which yes has taken almost a year, I found time and time again when I felt like quitting, I stuck with it and am happy that I did. I am proud to present this work that lays in front of you. In hindsight this project for me was not so much ado about finding out the intricacies of the electricity network in New York, but more an exercise of keep on keeping on. And yes of course, the subject matter of this thesis, i.e., shifting away from fossil fuels toward decentralised renewable electricity production, is important and interesting, but this preface is about my experience. That is why I would like to thank a few people that have helped me during, not only with my thesis but throughout my years as a student as well.

I would first like to thank my graduation committee members. First off, Amineh, I would like to thank you for your patience, even when communication was not running smoothly at times. And for your kind words when I got stuck in my own head and bogged down. And then Thomas, although we have not had a meeting in person, I think your feedback during the meetings we had was constructive and direct. This helped me to make progress in the writing of the actual report, a message you have hammered home. Thank you for that.

Then to Arno en mama, although sometimes what I was doing in Delft might have seemed like a black box (“wat spookt die jongen uit?!), I want to thank you for your support. You have been kind and patient throughout my whole life, with only the best of intentions. I am proud to show you this report as a closing statement of my years as a student, and hope that you are proud in return.

Then pap, I want to thank you for helping me in figuring out what I want. I still do not know what I “really” want to do, but you have, from an early age I think, tried to help me in figuring it, whatever that may be, out. Thank you, for thinking critically about this report and for being a kind, gentle, and caring man.

Niek, Sophie, Rian, and Siena, I am glad to have you as brothers and sisters. Youse good people. To the rest of my family, I can say safely say that I have enjoyed being part of this one.

Then on to my friends, at the risk of sounding sentimental, I am really glad to have you. But then again, when something is true, it is not sentimental. De Ongekende Hoogte (nieuw en oud), TB-diner vrinden, Eetclub moaten, Barco lui, De Gekke foto’s, to name a few, all of you have helped me in one way or another, either by getting me to relativise during my thesis, discuss my work, or talk to in general or just hanging out. Bere gezellig gehad in de afgelopen jaren.

I am glad and satisfied when I look back on the last almost 10 years of my life and look forward to whatever I can look forward too. But for now, I hope you enjoy this work and will see you around.

All the best and a satisfied greeting,

Coen

Summary

The rising need for renewable electricity production, has made nations look towards forms of electricity generation other than the traditional centralised fossil fuel power plants and more towards decentralised systems. These new systems are promising in providing solutions towards problems that are associated with centralised networks, such as high transmission costs, efficiency losses, and high greenhouse gas emissions. With this shift towards decentralised renewable electricity generation, different actors are involved in the electricity generation, such as private households or communities, next to the conventional utilities.

The United States, one of the largest economies in the world, still relies heavily on centralised electricity systems. Some states, however, have shown their intent to make changes. The State of New York is currently one of the highest producers of renewable electricity, and in the top ten states when it comes to solar electricity generation. A large part of this generation capacity is installed by households and "community solar" projects. Community solar refers to commercially owned projects, owned and operated by developers who subscribe private households or entire municipalities, who can benefit from a reduction on their electricity bills. Community solar is thusly different than the community-owned projects that are present in Western Europe.

The State of New York has proposed, and partially implemented, several new policies that will affect these community solar projects (CSP), as well as residential photovoltaic systems (RPV). This research will analyse how these policies will affect the decision making of households who will want to install RPV systems or join a CSP. In order to evaluate the effect of these policies the concept of "Energy Security" will be used. This concept has traditionally been used to describe the security of supply of energy, or in this case electricity. However, in this research a broader definition is used, developed by the Asia Pacific Energy Research Centre (APERC), which has described Energy Security across four dimensions: Availability, Affordability, Accessibility, and Acceptability. The gaps addressed in this research are thus the following: how can the concept of Energy Security as defined by the APERC be used to analyse RPV and CSP (decentralised solar electricity) as it is defined in the State of New York. Secondly, previous research has shown how households make decisions concerning renewables, but it has not shown the effect of policy changes on this process. This leads to the main research question of this research:

What are the effects of selected policy instruments concerning ***decentralised solar electricity generation*** *on energy security in the State of New York?*

To answer this question, a design-science research approach is used, based on Hevner and Chatterjee (2010). In this approach firstly the knowledge base created, by gathering relevant theories. This was done by analysing relevant theories on decision-making of households. Three theories were used to describe the way households make decision concerning their electricity procurement, namely the theory of planned behaviour (TPB), developed by Ajzen (1991); the value-belief-norm theory (VBN), developed by Stern et al. (1999); and diffusion of innovations theory (DOI), by Rogers (2003). These three theories have been combined into one framework by Wolske et al. (2017), and it is this framework that will be used further in the research. Secondly the environment in which the decentralised solar electricity operates is analysed. This is the electricity system of the State of New York. This not only include electricity generators, but also system operators and policy makers. Thirdly, an artefact is designed, in the form of an Agent-based Model (ABM). This modelling approach allowed for the analyses of households' behaviour on the system level, i.e., the electricity system in the State of New York.

Several different key aspects were defined for household decision-making when it comes to their electricity procurement: i) households are influenced by peers, through either perceived social norms or through communication in their social network, ii) the level at which an individual is informed on decentralised renewable electricity generation is linked to certain demographic factors such as education and socio-economic status, iii) information will be processed based on the value set an individual has towards environmental behaviours, such as joining a CSP or installing RPVs, iv) the perceived control an individual has over successfully accomplishing the desired environmental behaviour determines whether an individual will engage in the decentralised renewable electricity generation.

After reviewing the literature and the analysing the environment, the four dimensions of energy Security were operationalised into 4 KPIs: Availability, Affordability, Accessibility, and Acceptability. Initially being just these four KPIs it was found that within the State of New York a more financial oriented approach was needed, resulting in 2 KPIs being added, Ability and Appeal. The introduction of three different policies was analysed, as proposed (and partially implemented) by the State of New York, were analysed, and evaluated based on these six KPIs. These policies were:

1. The Expanded Solar-for-all (E-SFA) program: an effort to provide cheaper electricity for low-to-middle income households. This comes at a cost for the CSP developers, resulting in less profits.
2. The Value of Distributed Energy Resources (VDER) structure. Currently net metering is in place, but this new VDER resembles a feed-in-tariff structure.
3. Customer Benefit Contribution (CBC). A monthly charge imposed on households with RPVs.

After implementing these three policies as interventions into the model, several interesting results were made evident:

- When the E-SFA program was only partially implemented, the amount of renewable electricity generated in the model was less than the implementation of the full program.
- When the VDER only reduces the benefits of households having RPV by 10 percent as compared to the net-metering structure, an increase can be seen in the amount of renewable electricity in the model.
- The introduction of the CBC-charge does not have significant effects on the model.
- When the E-SFA program and the VDER program are implemented simultaneously, the implementation of the full E-SFA program led to a less renewable electricity within the model than when the partial program was introduced. This is the opposite of what had happened when the E-SFA program was introduced in isolation.
- No significant changes in costs for households were found when implementing the policies, both in isolation and when combined.
- In terms of reaching their climate goals, the state will be one step closer, however across the scenarios the goals will not be reached in full. The GHG-emission reductions range from 14-16% in the year 2030, whilst the goal is set at 50% reductions. The production of electricity from renewables is set at 40% by the year 2030, but the model results show a range from 17-20% of electricity coming from decentralised solar. A large part of the goals should therefore be supplemented with other renewable electricity sources.

These results indicate that there is an interconnection between the proposed policy and their effect on household decision making. The effects differ between when policies are implemented in isolation and when they are combined. To answer the research question: the proposed policy instruments, if implemented simultaneously, will lead to a reduction in RE produced within the State of New York, however the effects on household finances has not shown to be significant. As an additional conclusion, this research has shown the how utilities use their market and political power to maintain at the centre of electricity generation in the state. Both the E-SFA and the CBC-charge are aiding in the strengthening of the positions of these investor-owned utilities, begging the question whether the State of New York is moving toward a more decentralised electricity market. Granted, the electricity will be generated at decentralised locations, but the market power still lies with the major utilities.

Table of Contents

1 Introduction

The access to energy can be seen as a basic human right. Sustainable Development Goal (SDG) 7, designed by the UN (2015), is created for the purpose of ensuring everyone can claim that right, and studies have tried to use a human rights approach to the access of energy (Wewerinke-Singh, 2022; Tully, 2006; Löfquist, 2020).

The world's energy consumption can be divided into three major parts: heating, transport, and electricity production. The interesting aspect of electricity is that it can be used as an energy source for the former two activities. For instance, electric cars and electric heating are gaining a lot of traction. Therefore, expansion and organisation of the electricity system in a sustainable manner, in all senses of the word, is generally thought of as a good and essential task.

Electricity can be produced using multiple sources, however most commonly it is generated by the burning of fossil fuels at a central plant, after which the electricity is distributed through a grid. This traditional form of central electricity production has several benefits such as: economies of scale (Van Helden & Muyskens, 1981; Christensen & Greene, 1976); the infrastructure, which has been developed over the last 200 years, is designed to reduce transaction costs (Williamson, 1979); and has a relatively high energy density, is convenient in its use, and is reliable (Gross, 2020). However, it has been made evident that the production of electricity in this manner is not sustainable. Predominantly because during combustion of these fuels, vast amounts of greenhouse-gasses (GHGs), such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are emitted into the atmosphere (EPA, 2022a). The emission of these gasses results in climate change which causes: "…changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes" (IPCC SPM, 2014, p.2.). Secondly the centralized network structure of traditional electricity generation has several drawbacks, mainly: high transmission costs, investment in networks, efficiency losses, and the lack of electrification of rural areas (Martin, 2009).

Therefore, new sustainable ways of electricity production have been introduced that limit the impacts on the climate, under the name of renewable electricity. The current share of renewable electricity generation capacity has reached almost 29% globally (IEA, 2021b). Renewables being: "…wind, solar, aerothermal, geothermal, hydro, ocean energy sources, biomass and the biodegradable fraction of waste." (EEA, 2018). The IEA expects that in the coming 5 years this capacity will grow with 60%, almost reaching he 50% mark (IEA, 2021a). Since these new technologies do not fully rely on an infrastructure that has been developed over the last 200 years, new ways of designing electricity systems are possible, in which production does not rely on one central facility, but on multiple sources, linked in a distributed network. These decentralised electricity production networks, in contrast to centralised networks, can overcome the hurdles mentioned in the previous paragraph and could be better at dealing with environmental constraints (Martin, 2009).

The United States, the biggest electricity consumer after China, can take major steps in decreasing their impact on the climate by increasing renewable electricity production (IEA, 2022). In the US currently only 10% of the total energy supply comes from renewable sources (excluding nuclear energy) (EIA, 2021a). States in the US hold relatively great autonomy over their electricity production, where the federal government sets guidelines and provides oversight when it comes to interstate commerce. Nevertheless, many states still opt for a traditional centralized electricity system. However, some states have seen a growth in installations of decentralised electricity systems over the past few years. For instance, the State of New York has witnessed an increase in the solar power capacity installed, with a rise of installations each year since over the last decade (SEIA & Wood

Mackenzie, 2022). New York can be seen as one of the frontrunners in the United States when it comes to decentralised renewable electricity generation. It is the 4th highest producer of renewable electricity, partly because of the large hydroelectric facilities close to the Canadian border (Shahan, 2022). Even more remarkable is that despite having one of the lowest peaks in sun-hours, it still ranks among the top solar electricity generators in the country (SEIA, 2022; Turbinegenerator, 2022).

It is of relevance to know how the State of New York implements certain policies to maintain this growth to reach its climate goals, and how these policies affect targeted actors in the electricity market. The latter aspect has not only to do with whether actors can meet their electricity requirements, but also in what manner. The analysis of energy systems has increasingly been measured not only in terms of abundance of resources and price (Asif & Muneer, 2007), but fairness and equity as well (Sovacool & Mukherjee, 2011; Sovacool, 2010). This research will focus on policies that have been issued and implemented in the year of 2022 by the governing bodies in New York, and their effect on the electricity system in the State.

1.1 Literature review

In the following section, a literature review will be conducted which will aid in understanding the background of policy implementation concerning solar PV in the State of New York by shedding light on: i) policy in sociotechnical systems, ii) community solar in the State of New York, and iii) the concept of energy security.

1.1.1 Policy in sociotechnical systems

Electricity markets can be seen as socio-technical systems (STS) (Van Dam et al., 2012). STSs are described as networks in which a social network of actors is connected with a system of technical artefacts (Geels, 2004). In the electricity market there are many technical artefacts: power plants, transmission lines, distribution networks, as well as many social actors who interact with this technical system: power generators, transmission and distribution operators, end-users, with regulatory authorities and policy makers providing oversight. Targeting one aspect of such systems therefore will not merely have effect on the aspect in question but will affect the entire system over time. Borrás and Edler (2020) have highlighted the difficulty of policy implementation within such systems, and the different roles a governmental body can have when implementing policy. A sound understanding of the relevant subsystems of the electricity market is therefore needed, to avoid unwanted outcomes caused by poor policy.

‘Bad policy’, a term coined by James A. Robinson (1998), which he describes as a factor for a stagnation within technology adoption. What this means is that during the policy implementation process, unwanted effects have not been sufficiently considered. This can lead to poor results, or even the exact opposite of what the policy was intended for. In order to avoid this path for energy policy, research has been conducted on what drives the transformation in energy and electricity networks. Most salient is the increase in electricity-efficiency of technologies, e.g., solar panels, electric cars, smart-meters, etc., but equally as important is people’s response towards these technologies. Or as Allcott and Mullainathan (2010) phrase it: “Energy efficiency, however, depends on both these technologies and the choices of the user.” The latter is important to consider, user choice, or more specifically understanding of the decision-making process that leads to the user’s choice. Up to recently, most studies addressing understanding of how households make decisions concerning their electricity supply and renewable electricity, have mainly focussed on willingness to pay (Dogan & Muhammad, 2019; Ma et al., 2015; Zhou et al., 2018). However, some research has focussed on a broader view towards understanding decision-making processes at the household level (Wolske et al. 2017, Jacksohn et al., 2019; Liobikienė et al., 2021).

1.1.2 Solar PV in New York

The changes put forward in the State of New York are mainly applicable to private residential photovoltaic (RPV) systems and community solar projects. RPV are systems that will be installed by a professional on a households' roof, which is in essence the same as in Europe. However, the term 'Community Solar' has a vastly different meaning than community energy projects in Europe. In research, community energy is usually interpreted as a cooperative structure through which residents take control over their energy supply. For instance, Punt et al. (2022) have given a clear definition of what characterises the ideal Renewable Energy Cooperatives, namely:

1. Collective ownership by private individuals, through the organizational and legal form of a cooperative.
2. Focus on activities in the renewable energy sector.
3. Broad in scope, including activities along the energy industry value chain, from generation to services.
4. Members of the cooperative share a common objective.
5. Democratic voting systems are in place, in the form of "one member, one vote".

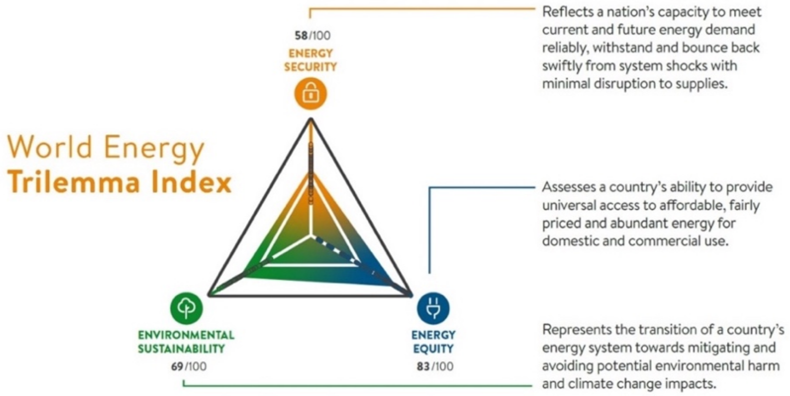
These characteristics can be seen as a basis for cooperative community solar projects. However, only one of these characteristics (no. 2) applies to community solar projects in the United States. Most of these projects are commercially owned and operated, where the households are merely a client of the solar project. In the State of New York too, community solar refers to commercially owned projects, who sell their energy to either individual households or entire municipalities. They are not community-owned or lead. To date, no cooperative community solar projects have been found in the State of New York and are therefore not included in this research. However, since the first installation of 'community solar projects' (CSP) in 2015, many commercially owned and operated solar projects have been established in the State of New York. As of March 2022, over 1 GW capacity of community solar has been installed, enough to provide electricity to 200.000 households (Governor NY, 2022).

1.1.3 Energy security

Several frameworks have been proposed to assess the State of a nation's energy system. For instance, the "World Energy Trilemma Index", developed by the World Energy Council, can be used (Figure **1.1**). This tool differentiates three main elements: Energy Security, Energy Equity, and Environmental Sustainability.

Figure 1.1

World Energy Trilemma Index



Reflects a nation's capacity to meet current and future energy demand reliably, withstand and bounce back swiftly from system shocks with minimal disruption to supplies.

Assesses a country's ability to provide universal access to affordable, fairly priced and abundant energy for domestic and commercial use.

Represents the transition of a country's energy system towards mitigating and avoiding potential environmental harm and climate change impacts.

Note. The scores shown in the figure do not resemble a real way of generating energy. From *"World Index Trilemma 2020"* (p.10) by Lowe, P. et al., 2021.

This framework serves as a metric for evaluating countries on their energy generation. It integrates the importance for an electricity network to be able to meet current and future energy demands sustainably, as well as ensuring access for all. Traditionally the focus always was on energy security and equity, with affordability, efficiency, and reliability as the key performance indicators (Scholten & Künneke, 2016). However, as mentioned previously, this has led to a centralized fossil fuelled system which has proven itself unable to perform properly on the sustainability aspect. The definitions given in the figure above are a good starting point, however it is too focussed on the national level. Especially the term 'energy security'. Traditionally, the term has focussed more on the security of supply, just like the definition by the World Energy Council (Figure **1.1**). However, in academic literature, the focus has shifted towards a broader approach, where security has several more dimensions. One of these definitions is given by the Asia Pacific Energy Research Centre (APERC): "…the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy." (APERC, 2007). In addition to this definition, APERC suggests using the 4A's concept to measure energy security, the 4A's being: availability, affordability, accessibility and acceptability. These concepts can be seen as a combination of the "energy security" and "energy equity" concepts defined by the World Energy Council (Figure **1.1**). The application of energy security has mostly focused on centralized energy systems (Sovacool, 2010), however recently it has also been used to analyse decentralised systems (Fouladvand et al., 2022).

1.2 Goal of research and research questions

The goal of this research is to examine the effects of the policies on the aspect of energy security, as proposed by the APERC (2007). This framework has already been used in a modelling setting by Fouladvand et al. (2022), who have shown how these aspects are interconnected and how they can be modelled. However, this framework has not been used to analyse RPV and CSP as it is defined in the State of New York. Moreover, previous research has shown how households make decisions concerning renewables, but it has not shown the effect of policy changes on this process. The goal of this research therefore is to answer the following main research question, along with several sub-research questions:

What are the effects of selected policy instruments concerning ***decentralised solar electricity generation*** *on energy security in the State of New York?*

Sub-research questions:

1. How do households make decisions concerning their electricity supply?
2. What does the current electricity market in which community solar and RPV-systems operate in the State of New York look like?
3. How can energy security be defined in the State of New York?
4. What are the proposed policy instruments, and how will they affect the decision-making process of households?
5. What is the impact of the chosen policy instruments?

1.3 Methodology

To answer these questions, this research follows the Design Science Research method developed by Hevner and Chatterjee (2010). Design science research stems from the desire to improve an environment by the introduction of new artefacts and processes (Simon, 1996). Design research is a paradigm in which the researcher tries to answer questions 'relevant to human problems via the creation of innovative artefacts, thereby contributing new knowledge to the body scientific evidence.' (Hevner & Chatterjee, 2010 p. 5). This is in line with the analyses and improvement of sociotechnical systems, i.e., the purpose of this research.

Their framework (Figure **1.2**) combines an application environment, theoretical background, and the design of an artefact. The environment represents the (socio-technical) context to which this research pertains, including its actors, processes, institutions, technologies, i.e., the electricity market of New York. Secondly the knowledge base describes the 'scientific foundations, experiences, and expertise' that informs the research. For this research these are theories on decision-making processes of household adoption of (sustainable) innovation. Lastly, is the design of the artefact, which lies at the heart of this research. The artefact in this research will be an agent-based model. An agent-based modelling (ABM) approach is chosen because it allows for analysing the impact of individual behaviour on the system level (Van Dam et al., 2012). Within the ABM-approach three anatomies are defined that make up a model (Van Dam et al., 2012):

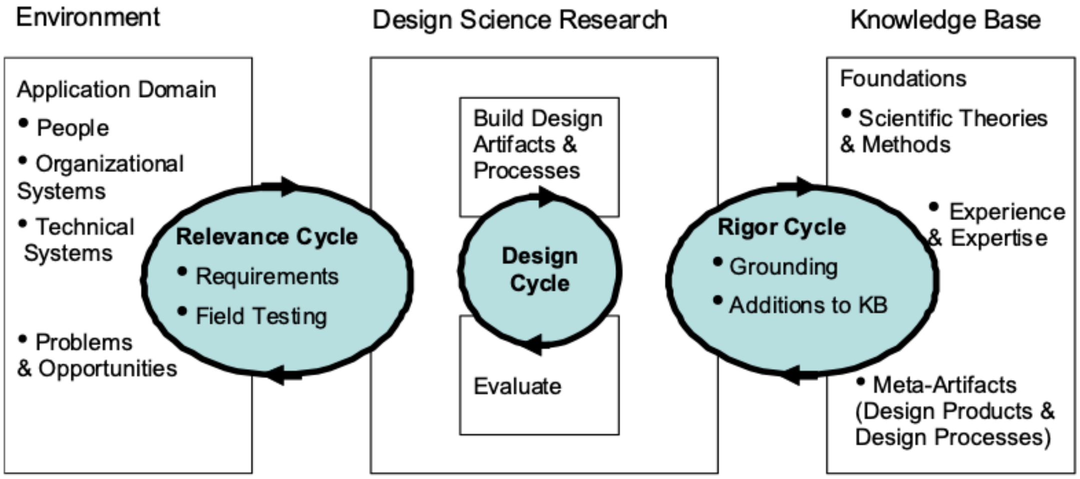
- Agents: Agents can be a representation of any entity, ranging from individuals to organizations and nations (Van Dam et al, 2012). Agents have a certain set of internal structures, and perform certain actions, leading to a certain goal-oriented behaviour (Jennings, 2000). In this research there are two types of agents, households with a goal of meeting their electricity requirements, and community solar developers, with the goal of making a profit.
- An environment: agents can interact with their environment, and vice versa. This environment includes both a representation of the physical environment of the real world, as well as information. The information can be obtained by agents, and in turn can change their internal structure or their actions. In this research the physical environment is a representation of New York households. The information available for agents are things like electricity prices, rebate structures, and installation costs.
- Time: ABM uses discrete time steps in which agents perform their assigned behaviours, triggering interactions with other agents or their environment. In this research the time is considered in weeks, meaning that agents review their electricity procurement every once a week. This allows for analysis of system behaviour over time (Gilbert, 2019).

As this research is focussed on the impacts of policy intervention over time on household (agent) behaviour, given the rules in the state of New York (environment), the use of ABM is of considered appropriate.

Within the Design Science Research framework three cycles are proposed for the analysis of a system: the Relevance, Rigor, and Design cycle. These cycles represent aspects that are necessary within proper design research of Information Systems (IS) (Hevner, 2007).

Figure 1.2

Design Science Research framework (Hevner and Chatterjee, 2010)



Within the Relevance cycle the contextual background is described. It is within this context the artefact operates. The problem is defined, the system is analysed, and the evaluation criteria for the results are determined. This last step ensures that the artefact not only aids in scientific understanding but is also useful in the improvement of the environment (Hevner, 2007).

Within in the Rigor cycle, appropriate theories and experiences are gathered for the construction and evaluation of the artefact, in order to ensure the innovativeness of the artefact. Grounding the research in past theories and experiences helps understanding of the current gap within them, while the results of the implementation of the artefact can benefit the scientific knowledge and bridge said gap (Hevner, 2007). In chapter **2**, the theories used in this research will be analysed.

Within the Design cycle, an iterative process of constructing, evaluating, and giving feedback of the artefact is performed. This is where the main portion of the work is focused on. In this research, as mentioned previous, the artefact is an agent-based model. For the construction of this model the steps proposed by Van Dam et al. (2012) are used, they aid in the constructing and subsequent use of an agent-based model.

Step 1: Problem formulation and actor identification
Step 2: System identification and decomposition
Step 3: Concept formalization
Step 4: Model formalization
Step 5: Software implementation
Step 6: Model verification
Step 7: Experimentation
Step 8: Data analysis
Step 9: Model validation
Step 10: Model use

The first two steps are in coherence with the Relevance and Rigor cycle prosed by Hevner and Chatterjee (2010). These steps performed by analysing official governmental literature of the State of New York, using internet keyword searches, as well as reviewing articles by proclaimed experts in the field. This is mainly done in chapter **3**, where the history and context of the decentralised electricity market of New York is described.

Part of the system identification is defining the decision-making process of actors within the system. This decision-making process will be based on theories (in coherence with the Rigor cycle) concerned with psychological and social determinants for decision-making concerning electricity use of households. This is done by using relevant key words in Google Scholar and Scopus. Words used were “decision-making”, “renewable energy/electricity”, “determinants household choice”, or a combination of these words. After some initial relevant papers were found, citations within those papers were used in further researching the theories.

From these steps multiple conceptual models will be built, that will serve as the basis of the model formalization and subsequent implementation of the computational model. These conceptual models will be models of the environment, i.e., a representation of the decentralised renewable electricity market in New York, and of the decision-making process of the relevant actors. For the software implementation, the software Netlogo will be used (Wilensky, 1999). Netlogo is “…a multi-agent programming language and modeling environment for simulating complex phenomena.” (Tissue & Wilensky, 2004, p. 1). This tool is described as well suited for describing the agent paradigm (Van Dam et al., 2012), i.e., the modelling approach in which agents are autonomous, capable of learning and communicate with others (Bouquet et al., 2015). These activities are described in chapter **4**.

In step 6 the model will be verified, by checking whether the model implementation into Netlogo was successful. This step has the goal of checking if the relationships and entities from the conceptual model are properly translated. This will be done in chapter **5**. Next the model experiments will be run, which is the implementation of different policies into the model. The effects of these policies will be differentiated across multiple experiments, described in an experimental design.

The results of these experiments will be described and analysed in chapter **6**. This will be done using Python, with visualization tools installed such as the Matplotlib (Hunter, 2007) and Seaborn (Waskom et al.,2017) libraries, as well as statistical analyses libraries Scipy (Virtanen et al., 2020) and Statsmodels (Seabold & Perktold, 2010). Before interpreting the results, a model validation will take place. This will be done by performing a Global Sensitivity Analysis (GSA) using R, with the help of the nlrx-package (Salecker et al., 2019). The effects of the GSA on the model will be compared to real world observations.

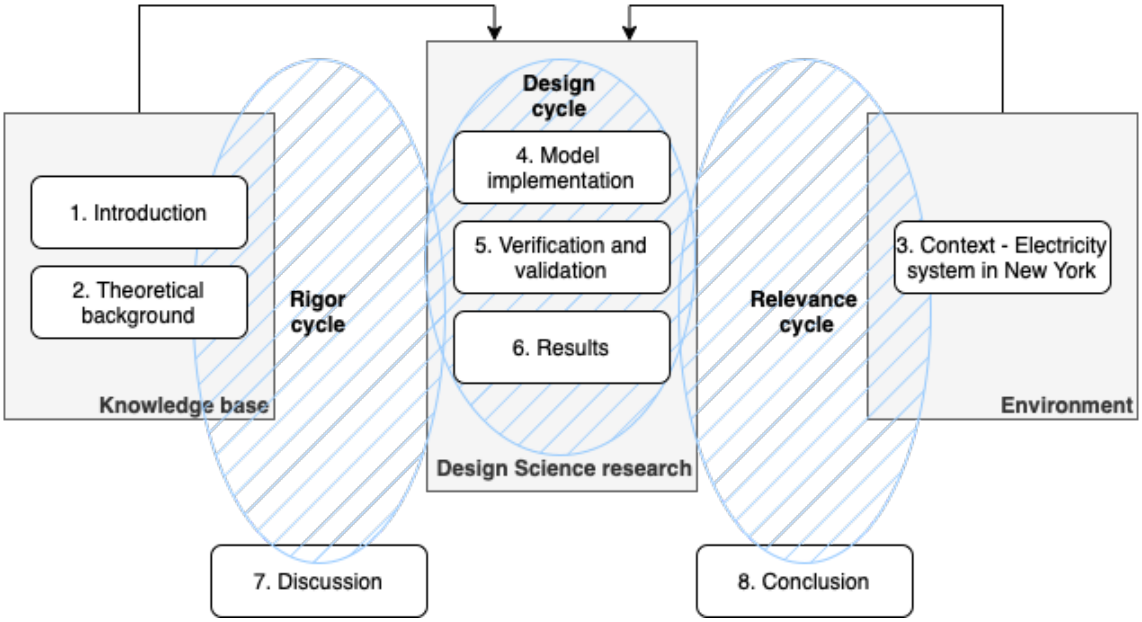
Finally, the model results will be assessed, in order to answer the main and sub-research questions. During this process, elaboration on the limitations of the research will be kept in mind. To complete the Relevance cycle, the results of the model will be used to provide relevant policy recommendations. This will be done in chapters **7** and **8.**

1.4 Thesis outline

This research is structured in 8 chapters. Chapter **2**, in combination with chapter **1**, provides the knowledge base for this research and helps answering sub-research question one. With the description of the electricity market in the State of New York in chapter **3** and the subsequent operationalisation in chapter **4**, sub-research question two, three, and four can be answered. After validation and verification in chapter **5**, the model results (chapter **6**) will be used to answer sub-research question 5. Based on the discussion of these result (chapter **7**), the research will be concluded by answering the main research question, with additional recommendations being made in chapter **8**. The relation between these chapters and the Design Science Research framework (Hevner and Chatterjee, 2010), can be found in Figure **1.3**.

Figure 1.3

Thesis outline



2 Theoretical background

This chapter can be divided into two parts: the first part describes the different theories that will be used for the conceptualisation of the decision-making process of households concerning their electricity procurement (section **2.1** and **2.2**). This will answer sub-research question 1. The second part will give the basis for the conceptualisation of the energy security concept (section **2.3**) and will help answer sub-research question 3.

2.1 Household decision-making process

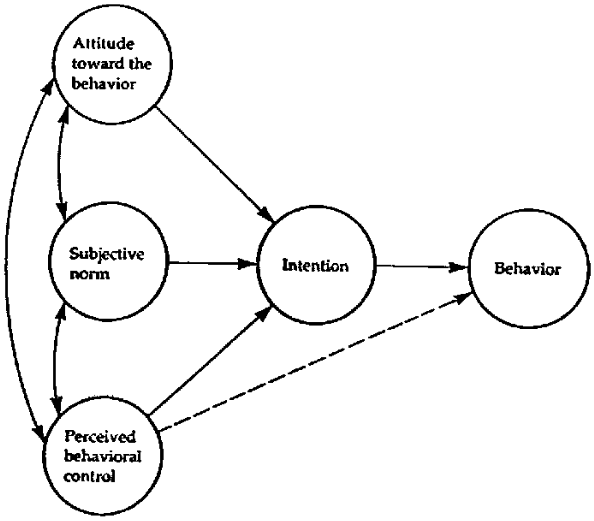
Understanding the decision-making processes of individuals is important for the implementation of effective policies. In this research effectiveness is defined as how well policies positively impact the concept of energy security, as described in the previous paragraph. Several theories from the academic disciplines in psychology and social sciences have been used to explain behaviours of individuals and the adoption of innovations. In this chapter, three relevant theories are described, including their place in the field of energy and environmental behaviour. The theories are the theory of planned behaviour (TPB), developed by Ajzen (1991); the value-belief-norm theory (VBN), developed by Stern et al. (1999); and diffusion of innovations theory (DOI), by Rogers (2003).

2.1.1 Theory of Planned Behaviour

TPB argues that not only a person's intention to perform a certain behaviour determines the actual behaviour, but the perceived control over the behaviour in question as well. Perceived behavioural control differs from actual control in that it can be that a person perceives to be able to reach a certain behaviour, when in fact they cannot or vice-versa. E.g., "I will become president *(intent)*, because of my political skills *(perceived control)*" However, the person might not have the needed time, money, resources to do so (actual control). According to Ajzen (1991), perceived control is in line with the concept of self-efficacy (Bandura, 1982) which "is concerned with judgments of how well one can execute courses of action required to deal with prospective situations" (Bandura, 1982, p. 122).

Figure 2.1

Theory of Planned Behaviour (Ajzen, 1991)



Moreover, intent is not merely based on the will to perform a certain behaviour, but it is made up out of three aspects: the attitude towards the behaviour, subjective norms, and again the perceived behavioural control (Figure **2.1**).

Firstly, the attitude of a person is based on a person's behavioural beliefs, which are formed by associating certain attributes to an object. For behaviour this means that belief makes a link between behaviour and outcome, e.g., "if I do A it will lead to B". People will act in accordance with the beliefs they have about certain behaviour, because they expect a certain outcome, also called the expectancy-value (Fishbein & Ajzen, 1975). An important aspect is belief salience. Belief salience acknowledges the fact that not all of a person's beliefs towards a certain behaviour will be active at any given moment. Beliefs towards a singular behaviour can differ between contexts.

Secondly, subjective norms are formed through normative beliefs. Normative beliefs refer to the influence of important peers, albeit individuals or groups, on an actor's behaviour. They can be both descriptive, i.e., "what will others do in this situation?", or injunctive, i.e., "what do others think is the right thing to do?". Or as Göckeritz et al. (2010) describe it: "*descriptive normative beliefs can be understood as norms of* ***is*** *and injunctive normative beliefs as norms of* ***ought****.*" (p. 515) The strength of each normative belief is multiplied by the individual's motivation to comply with the specific peer, and consequently the summation of all the products of all relevant peers' results in the subjective norm (Ajzen, 1991). Basically, it is an amalgamation of the opinions of one's peers.

Thirdly, besides perceived behavioural control being a direct determinant for behaviour in combination with intent, it is also a determinant for intent. As a direct determinant, Ajzen (1991) gives two reasons:

1. Holding intent constant, successfully concluding a certain behaviour will likely increase by perceived behavioural control.
2. Perceived behavioural control can often be used a substitute for actual control, depending of course on the individual's knowledge of the behaviour.

As a determinant for intention, perceived behavioural control is formed by control beliefs. This set of beliefs is formed through past experiences or communication with others about the behaviour. This is interpreted as follows, the more an individual believes he has resources and possibilities, and the fewer obstacles they see, the more perceived control they will have over the behaviour, increasing the intent to act.

2.1.2 Value-Belief-Norm theory

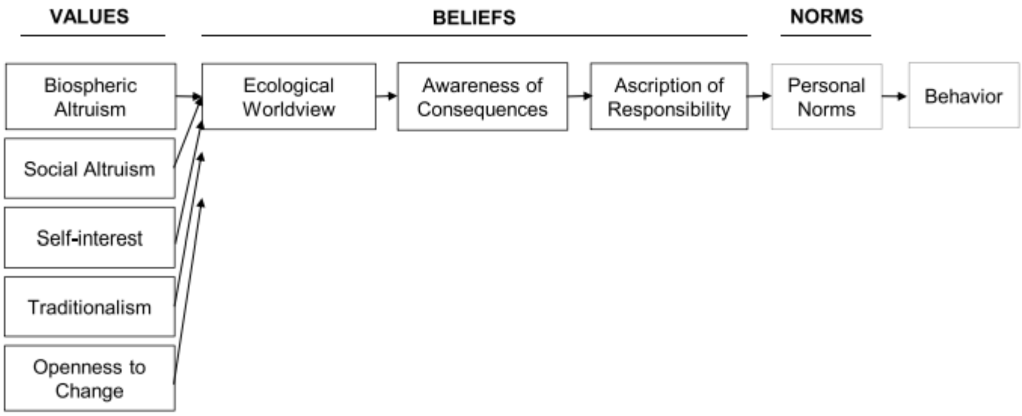
To add to the TPB, Ajzen (1991; 2012) notes that values can complement the theory. One of the theories proposed is the value-belief-norm theory (VBN), introduced by Stern et al. (1999), which hypothesises values as drivers behind social movement support. The theory focuses on a social psychological explanation of environmental movement. Stern et al. (1999) understand movement as all discourses and organizations that promote the social movement. There might be opposing views on why people act harmful towards the environment or on the remedies that will help resolve the problem, but the general idea is the same. For instance, scientists agree unanimously that climate change is real and caused by human activities, but how to resolve the situation is a subject of debate. The term "support" differs from activism in that it is more passive. With activism, promotion of a movement becomes an integral part of an individual's life whereas support can be reached by minor, non-activist changes. Stern et al. (1999) define three types of non-activist behaviour:

1. Engaging in low-commitment citizenship, e.g., non-public political activities such as reading movement literature or contributing funds to the movement.
2. Acceptance of public policies that are implemented to reach the goals of the movement
3. Changes in behaviour in the private sphere, e.g., for the environmental movement this means changing energy consumption and purchasing renewable energy technologies.

Especially the 2nd and 3rd point are of relevance, since this research is concerned with policy changes that are aimed at increasing the number of private RPV-systems and community solar projects. Interestingly the paper highlights that like TPB, an individuals' perceived capabilities and constraints will determine the level of support. Determinants for the emergence of this behaviour is shown in Figure **2.2**.

Figure 2.2

Value-Belief-Norm theory (Stern et al., 1999)



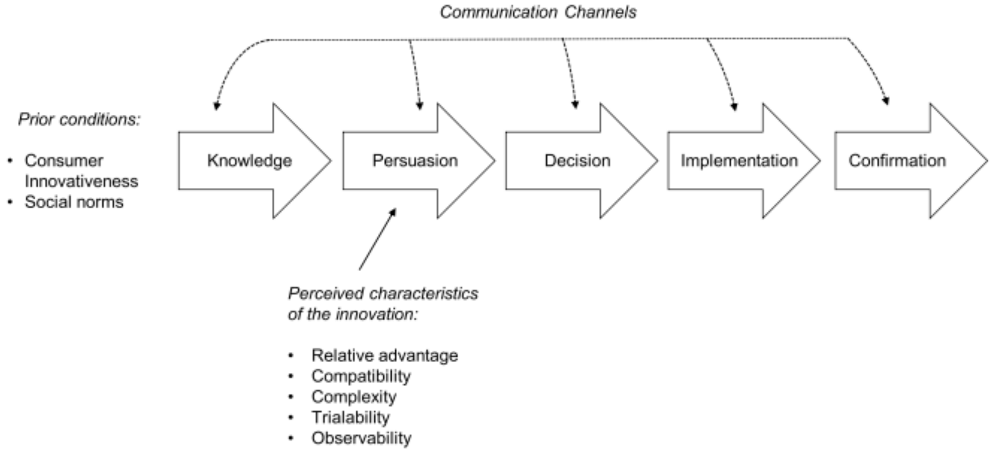
VBN hypothesises that at the root of behaviour lie different types of values. These values determine an individuals' beliefs, which can be seen as the mediating variables. This is based on Schwartz's Norm Activation model (NAM) (1977), which has been adapted by Stern et al. (1993). VBN emphasizes the importance of altruism in the shaping of one's beliefs, both towards other humans (social) and to other species and the biosphere (biospheric) (Wolske et al., 2017). In the context of environmentalism, altruism can be seen as having pro-environmental attitudes and behaviours. Next to the altruistic values, self-interest, traditionalism, and openness to change are values that need consideration.

2.1.3 Diffusion of Innovation theory

To understand not only why an individual makes decisions, explained by TPB and VBN, understanding of how adoption of new technologies or practices on a higher scale is needed for this research. The instalment of PV systems or subscription to a community solar project does not happen in a vacuum, not solely within the household. TPB already highlights the importance of peers, through the determinant 'subjective norms' (Ajzen, 1991), but in what manner an individual responds to new technologies or practices are not considered. The diffusion of innovations (DOI) theory explains the steps technology/practice adopters go through (Wolske et al., 2017). The theory, developed by Everett Rogers, who defines diffusion as "…the process in which an innovation is communicated through certain channels over time among the members of a social system." (Rogers, 2003, p. 41).

Figure 2.3

Diffusion of Innovations (Rogers, 2003)



Firstly, individuals become aware of the innovation and gather information (knowledge), they will shape their attitudes towards the innovation (persuasion), make a decision on whether to adopt it, implement the innovation, and afterwards seek conformation. During the knowledge stage individuals will gather information differently. It is hypothesised that mass media communication is the most effective in order to diffuse the innovation at this stage. In this stage *earlier knowers*, the ones who acquire the information first, are likely to be more educated, and have a higher socio-economic status. This does not mean they will also be easily persuaded to implement the innovation, since other factors come into play such as personal beliefs. Where the knowledge stage is a cognitive/active exercise, the persuasion stage follows a more subconscious path. In this stage an individual will form an attitude towards the innovation, which is influenced by different aspects such as:

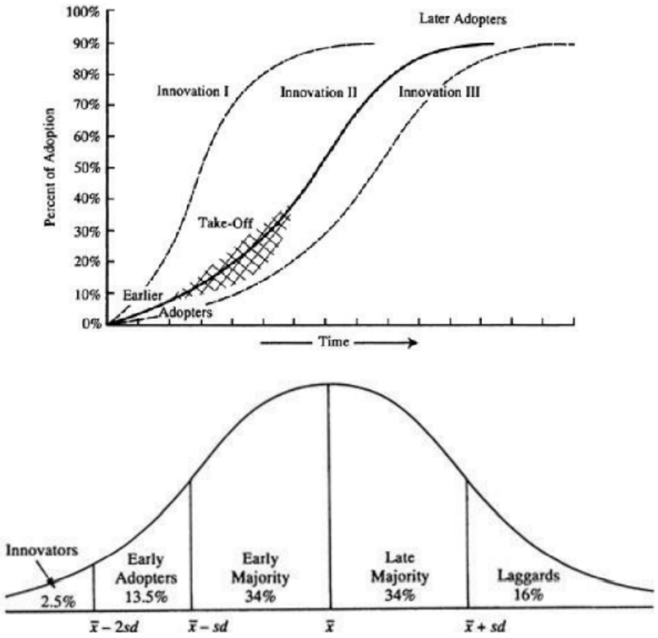
- Complexity: how difficult is it to use and understand the innovation?
- Relative advantage: how much better is the innovation compared to my current situation?
- Compatibility: does the innovation align with my own needs and values?
- Observability: will others see my innovation?
- Trialability: how much can I experiment with the innovation?

These factors are shaped by past experiences, existing values, and much like in TPB, communication with peers. Wolske et al. (2017) note that especially when the effectiveness of an innovation is uncertain, peer communication is significant. This deliberation process will lead to the individual deciding to either implement or reject the innovation. The last step considers the fact that innovation adopters will seek out information after they have implemented it, in order to evaluate their decision, and maybe even reverse their decision (Rogers, 2003) (Figure **2.3**).

The speed at which an individual goes through these steps determines what type of adopter the individual is, resulting in a S-curve of the diffusion process. Rogers (2003) defined five types of adopters: (1) innovators, (2) early adopters, (3) early majority, (4) late majority, and (5) laggards (Figure **2.4**).

Figure 2.4

Diffusion process (Rogers, 2003)



To summarize these theories, several aspects of an individuals' decision-making process have become apparent. Firstly, the influence of peers is of significance in the formation of a person's attitude towards a certain behaviour. This can be through the perception of social norms (TPB) or through personal communication (DOI). Secondly, the level at which an individual is informed of a specific innovation is linked to certain demographic factors such as education and socio-economic status (DOI). Thirdly, this information will be processed on the basis of the value set an individual has towards the specific behaviour that is associated with the innovation (TPB, VBN, and DOI). Lastly, the perceived control an individual has over successfully accomplishing the desired behaviour determines whether or not an individual will engage in the behaviour in question (TPB).

2.2 TPB, VBN, and DOI in renewable energy practices

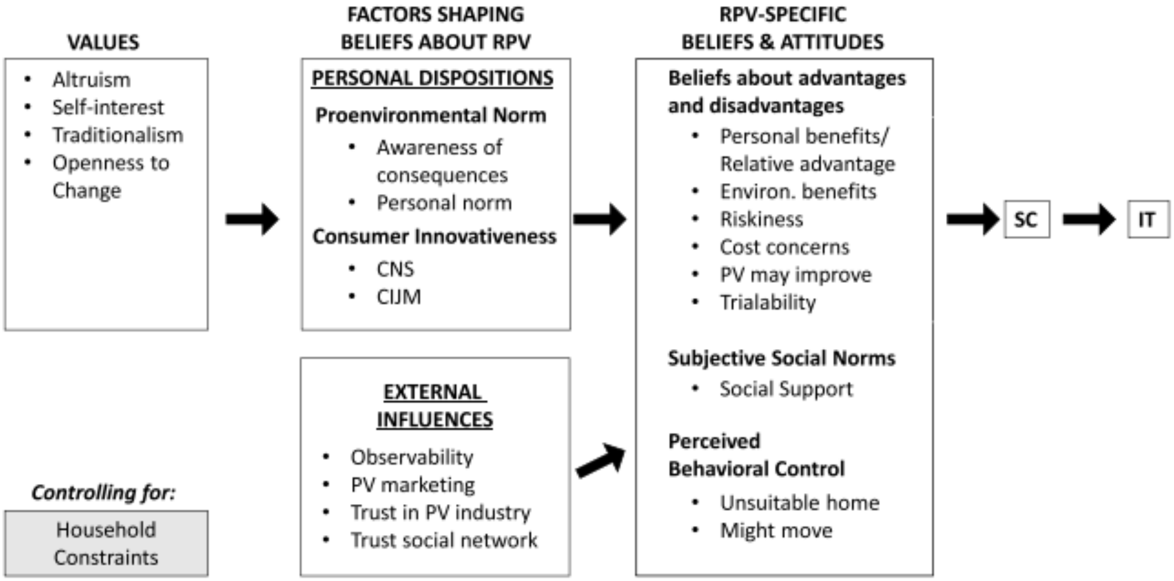
In this section the application of the previously mentioned theories (TPB, VBN, and DOI) within the fields of renewable energy will be discussed.

TPB can be used to describe all types of behaviour, making it suitable to be used for analysing renewable energy practices. Liobikienė et al. (2021) noted that TPB encompasses both internal aspects (environmental concern, attitudes towards innovation) and external aspects (availability, energy price), which are both very important for the promotion of renewable energy. For the adoption of RPV-systems TPB has successfully been used to predict household behaviour in Germany (Korcaj et al., 2015). VBN has not explicitly been used to describe the uptake of RPV-systems, but it has been used to describe behaviours of residents concerning renewable energy (Fornara et al, 2016). DOI has been used to describe the adoption process of solar technologies over the past decades. Labay & Kinnear (1981) found that *early adopters* and *innovators* found solar thermal systems less risky and more in line with their personal values. In the UK, research has shown that the *early majority* was convinced of the environmental benefits of RPV-systems, but the perceived uncertainty of the financial, aesthetic, and economic characteristics was limiting adoption (Faiers & Neame, 2006).

Integrating these theories into one framework has been proven to be a fruitful exercise. Wolske et al. (2017) have used an integrated model to find determinants for RPV-adoption in the US. They have successfully shown that their integrated model is able to predict solar energy adoption using values, beliefs, attitudes, household characteristics, and external influences. (Figure **2.5**). Similarly, Van den Broek et al. (2019) have used a similar model to find determinants for household energy saving behaviours. They used the Comprehensive Action Determination Model, proposed by Klöckner & Blöbaum (2010). This model integrates TPB, with the Norm Activation Model (NAM) (Schwartz, 1977) and Ipsative Theory (Tanner, 1999). Since VBN draws heavily on Schwartz's theory, and Ipsative theory uses self-efficacy, opportunities, and objective constraints to determine behaviour (like TPB), the CADM framework can be seen as akin to integrating the TBP, VBN, and DOI theories into one framework.

Figure 2.5

Integrated framework TPB, VBN, and DOI (Wolske et al. 2017).



Note: Abbreviations: Social Curiosity (SC) and Interest in Talking to a RPV installer (IT).

Since this research is focused on analysing the impact of the implementation of policy instruments, understanding the effect of policies not only in a pragmatic sense, e.g., changes in finances of households, but also understanding how certain policy instruments affect decision making is of relevance. Since effects of climate change make the future uncertain, creating consistent policy has been proven difficult (Aaheim, 2001). This inconsistency can lead to an increase in public uncertainty which affects people's decision-making (White et al., 2013). Decision-making under uncertainty, and in particular sustainable behaviour under uncertainty, has been a subject of research over the last years (van der Wal et al., 2018; Gifford, 2013). What is found in this body of research is that temporal discounting will increase when individuals perceive a situation as uncertain, i.e., people will focus on the short-term instead of the long term. Since the installation of RPV-systems is a decision that needs to be considered on the long-term (break-even periods lie on average around eight years in the United States (Hurst, 2022)), this is an aspect to consider in the adoption of said systems. Next to decision-making under uncertainty, is the issue of public trust. Public trust is an important factor in the acceptance of renewable energy generation (Upreti & van der Horst, 2004). Trust not only in the government, but in institutions as well, such as utilities and the policies that govern them.

2.3 Energy security

Seemingly, energy security can in its more traditional form be seen as a supply issue, “do we have enough” and “for what price”, which some researchers focus on (Spanjer, 2007). But in a literature study performed by Ang et al. (2015), it was found that most literature had expanded this definition to include seven aspects: energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency. Similarly, Sovacool (2011) in interviewing experts, was able to identify a set of 20 dimensions that describe energy security, even including land-use and water-use of energy generation. In this research not all these aspects will be considered but a selected few, summarized in the 4A’s principle designed by APERC (2007). These include:

I. Availability
II. Affordability
III. Accessibility
IV. Acceptability

Ang et al. (2015), note that in their study, energy availability was found to be the most important, appearing in almost all the analysed literature. In this research the definitions will be based on the work of Fouladvand et al. (2022), who have used the 4A’s concept in an ABM-modelling context.

- **Availability** is defined as the existence of an energy resource that is going to be used for the energy system. One indicator for this concept is the amount of domestic energy production capacity per capita. Another indicator is the shortage percentage, which represents a negative supply.
- **Affordability** refers to the costs related with the energy system. An indicator that has been most often used is the energy-price.
- **Accessibility** is defined as the manner in which individuals have access to commercial energy. One indicator is the diversification of energy resource, which can help increase accessibility. Diversification can also lead the reduction of supply risk.
- **Acceptability** considers the public opinion and support of energy resources. It is in this concept issues like social-welfare, environmentalism, and fairness are embedded.

Another important aspect of energy security is the consideration of scale. Pasqualetti & Sovacool (2012) distinguish four different scales on which energy security can be considered: household, workplace, national, and global. Each scale holds its own set of energy securities. For the household scale these pertain towards equity and public health. For the workplace, energy security relates to the occupational hazards at the workplace and the energy that is embodied into the products the company produces. On the national scale the more traditional forms of energy security are defined, such as national defence and infrastructure and the environmental costs of both. On a global scale energy security pertains to geopolitics and war, transboundary externalities, and global investment boundaries. In this research the focus lies on the scale of the State of New York, which corresponds to the national approach as described by Pasqualetti & Sovacool (2012).

2.4 Summary chapter 2

This chapter has elaborated on relevant theories that could be used to describe how household make decisions concerning their electricity procurement. Several important determinants were found after analysing three theories (TPB, VBN, and DOI); 1) the influence of peers is of significance in the formation of a person's attitude towards a certain behaviour, 2) the level at which an individual is informed of a specific innovation is linked to certain demographic factors such as education and socio-economic status, 3) information will be processed on the basis of the value set a person has towards the specific behaviour, 4) the perception of control a person has of achieving a certain behaviour influences a person's engagement in that behaviour. These theories have been combined into a framework by Wolske et al. (2017) and will be used as a basis for the conceptualisations made further on in this research.

Since the term energy security is an ambiguous term, a definition has been given based on the interpretation of the term by the APERC (2007). They describe 4 different dimensions: 1) availability, 2) affordability, 3) accessibility, and 4) acceptability. These terms will be the basis for further analysis of the electricity system in the State of New York.

3 Context – Electricity system in New York

Like most modern energy markets, the electricity market in the State of New York is a complex system in which different stakeholders try to meet their individual and collective goals. In this chapter I will explain the motivations of each relevant actor, meaning the actors that have a stake in the community electricity market in New York. I will first give a short history of the electricity market across the US, to aid in the understanding of the context in which RPV and community electricity projects operate.

3.1 The origins of the market

After the invention of the practical lightbulb by Thomas Edison in 1879, Edison decided that for this invention to add value for people, it needed to be incorporated into an entire electricity network. The bulb alone was not enough. It was then that he founded the first central generating plant in New York City, on Pearl Street in 1882; the world's first permanent central electric generating station (Sulzberger, 2013). Edison used a direct current (DC) to power electronics, which at the time came with a lot of losses during transmission. This meant that the production and consumption of electricity needed to be relatively close to each other to remain efficient. Within two decades Edison's direct current was replaced by the alternating current (AC) which was introduced by Westinghouse Electric, aided by Nikola Tesla. AC allowed for an easier transformation between high and low voltages, making transmission more efficient over longer distances (University Calgary, 2020). This meant that power plants could be placed further away from the end-consumer, i.e., outside the city (Tuttle et al., 2016). This allowed for power stations to grow in capacity, making it possible for both producers and consumers to benefit from economies of scale. This led to a traditional utility model of electricity production: large scale centralised electricity generation, send to consumers through high voltage transmission lines, and low voltage distribution networks, all vertically integrated into one company. Financing these networks and power generation plants was not cheap. So, new ways of financing were introduced in the form of holding companies. This allowed for bonds from existing power plants and networks to be blended with new investments, leading to a reduction in risk for the investor.

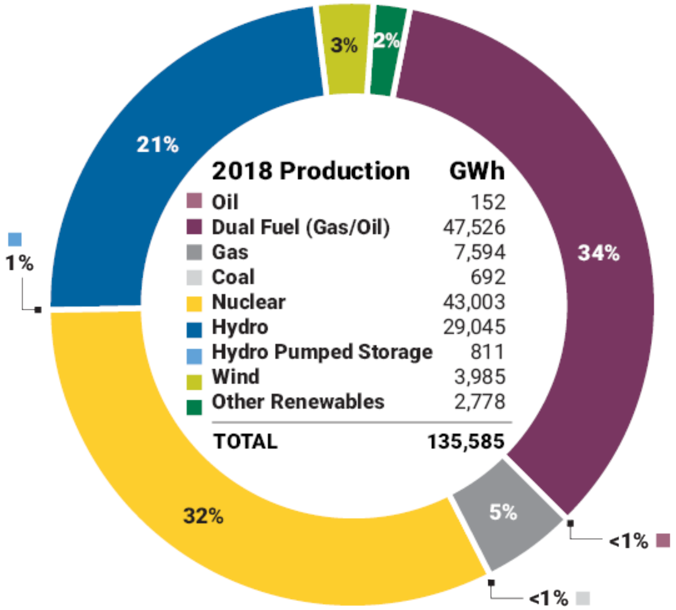
Governments understood the benefits of electrification at a cheap price. So, they allowed these monopolistic utilities to form, initially leaving the market unregulated. However, they quickly realised that regulation was needed to avoid monopolistic prices. Moreover, as there were no profits to be made in rural areas, utilities lacked incentive to provide their services to large parts of the US. Lastly, governments realised that after the pyramid structures of layered holding companies had led to the Great Depression that these needed to be more strongly regulated. This culminated into the Public Utility Holding Company Act of 1935 (PUHCA), which would govern the monopolistic utilities unchanged until the 1970s (Tuttle et al., 2016).

In the 1970s, the oil crisis caused by the Arab Oil Embargo in 1973, other players entered the market. Mainly companies which helped consumers reduce their consumption and save costs. These companies were named "Energy Service Companies" (ESCO's). These companies are mainly involved in "…identifying, developing, designing, constructing, owning, financing, maintaining, and monitoring energy efficiency projects." (Bullock & Caraghiaur, 2001). Still, utilities held monopolies when it came to energy production, transmission, and distribution. This changed during the 1990s. In 1992, with the passing of the Energy Policy Act, non-utility generation facilities were authorized to sell their electricity at market prices. In 1996, the Federal Energy Regulatory Commission (FERC) ordered state governments to increase market access by: i) requiring transmission owners to offer non-discriminatory services to others outside of their own facilities, ii) ensure potential suppliers of electricity having equal access to the market, and iii) encourage the creation of a price exchange to reveal market clearing prices (Tuttle et al., 2016).

These developments over the last 150 years have led to the State of New York resourcing their energy needed for electricity production mainly from fossil fuels, nuclear, and hydro (Figure **3.1**). Although being one of the nations' leaders in terms of producing solar energy, it can be noted that looking at the figure below, the State of New York still has very little electricity generated by solar in their electricity mix.

Figure 3.1

Electric Energy Production in New York State by Fuel Source: 2018



Note. Solar falls under the "Other Renewables". Source: NYISO (2019)

3.2 Actors

3.2.1 Policymakers

The State government in New York is divided up under the classical "Trias Politica"-principle of Montesquieu, in which the power of government is divided in three parts: legislative, executive, and judiciary (Montesquieu, 1750). Designed in such a way that there is no hierarchy among the three bodies with the goal of preventing concentration of power through checks and balances mechanisms.

In New York it is the Legislature, consisting of two houses, the Senate, and the Assembly, which holds the legislative power. The Senate can consist of a varying number of members and is chosen every two years (New York Constitution art. III § 1.). The President of this house is the Lieutenant Governor, the person second in charge to the Governor. Within their role, which is mostly of ceremonial nature, they are responsible for guiding and directing the senate, naming committees and naming Senate employees. The Temporary President, usually the majority leader, takes over these tasks in absence of the Lieutenant Governor (The New York State Senate, 2022a). The second house is the Assembly, consisting of 150 members also chosen every 2 years, chosen from single-member districts (New York Constitution art. III § 5.). This house is presided over by the Speaker, which is elected from and by the Assembly (The New York State Senate, 2022a). The Speaker holds similar duties as the President of the Senate does.

It is these houses that make the laws for the State of New York. The steps from idea to law are shown below (The New York State Senate, 2022b):

1. An idea is formed in either the Senate or the Assembly. It must be stated that these ideas do not have to come from Senators or Assembly members but can also come from the constituency or organisations.
2. A bill is drafted, which states how the laws of NY State need to be altered. Assembly Bills (AB) and Senate Bills (SB) are drawn up by the respective houses.
3. The bill undergoes the committee process. The committees decide whether to "report" the bill to the senate or assembly floor where the bill will be put up to vote by the entire Senate or Assembly.
4. After the bill is passed by the respective house, it goes to a vote in the other house. If the bill is passed by the other house without amendment, the bill is sent to the Governor. Otherwise, the bill, including the amendments, will go back to the initial house who drafted the bill, and another vote will take place.
5. If both houses have passed the bill, the Governor has ten days to sign or veto a bill. If the Governor fails to do either within ten days, the bill automatically becomes law. A veto by the Governor can be overturned if in both houses two-thirds of the members vote to override the Governors decision.

Secondly, the Judicial Branch of the state is responsible for the enforcement of the laws that have been signed by the Governor. It is the duty of the court to check the practical application and constitutionality of the laws that are in place (The New York State Senate, 2022a). This part of the government is not involved in the policy-making process, thus is not elaborated on as part of this research.

Lastly, executive power lies with the Executive Branch, headed by the Governor, who is elected every four years. Next to the right to veto or sign a bill proposed by either house, the Governor can amongst others appoint and remove non-elected state officers, grant pardons, and summon the Legislature for certain sessions. In addition to the Governor, two other elected officials are serving within the Executive Branch, the State Comptroller and the Attorney General. The former being the chief fiscal officer and the latter being the State's chief legal officer. These three offices, the Governor, Comptroller, and Attorney General, each head their own department. Other departments, responsible for coordinating policy for a certain topic, within the State's government are headed by people appointed by the Governor (The New York State Senate, 2022a).

It is at both houses of the Legislature and the Governors' office where lobbying is allowed to take place. In accordance with the Lobbying Act (2014), lobbyists are allowed to express their opinions on legislation and governmental operations, and petition for the redressing of grievances caused by governmental activities. The activities, expenditures, and identity of people or organizations designated to influence the process of any legislation-forming need to be publicly available (Lobbying Act art. I §1-a, 2014). As energy sectors are characterised by their capital intensity and asset specificity, players within the market have a high incentive to influence policy outcomes (Alt et al., 1999). This is made evident when looking at the US-wide data on lobbying expenditures: the Oil and Gas industry spent around US$119 million and Electric Utilities US$112 million in 2021, ranking 5th and 9th respectively among all industries (OpenSecrets, 2022). Through these efforts, the energy industry is able to exert substantial influence on energy and environmental policies (Kim et al., 2021).

Not only the size of the lobbying activity, monetary or otherwise, determines whether lobbying is effective. The type of influence is also important. Aisbett & MacAusland (2013) define two types of influence: intrinsic and exerted. Intrinsic influence arises when a firm has influence through perceived positive spill overs, government shareholdings, and personal connections, whereas exerted influence is defined as monetary donations to the specific campaign.

For instance, back in 2016 while the State of New York was in the process of implementing the Climate Leadership and Community Protection Act (CLPCA), a proposal stating that New York will be using 100% renewable energy and supporting low-to-middle income and climate-vulnerable communities using state funds, found major opposition from a lobbying group called the "Business Council of New York State". This group represents 19 fossil fuel companies and trade groups, but also banks, real estate developers, the healthcare industry, and major utilities such as Con Edison and National Grid. In this lobbying group an example of the intrinsic influence they can exert, is evident by the fact that the chief lobbyist of the group has direct ties to the Senate, being the former director of environmental and economic development of the State of New York (Connor, 2016). In spite of the opposition, the bill was passed in 2019. But as plans were being drawn up in 2022 to meet the goals stated in said bill, a similar lobbying group is providing resistance. This time by the "New Yorkers for Affordable Energy" group, which includes the "Business Council of New York State" and many more fossil fuel companies, utilities, lobbying groups, and corporate fronts (Galbraith & Seidman, 2022). The opposition in both instances have tried to hinder the establishment of a policy structure which allows the State of New York to become less reliable on fossil fuels, despite the majority of the public being worried about climate change and think that policy changes are needed (Howe et al., 2015).

Salient is the fact that in both groups the major utilities of the State of New York are represented. It shows a discrepancy between the goals the state has set for the utilities and the intentions of the utilities themselves. This is also evident when looking at certain laws which seem contradictory. Gundlach & Stein (2020) provided a case study of tensions between the New York Public Service Law and the CLPCA. This study focussed mainly on legislation pertaining to the use of gas but is still relevant for the illustration of the conflicts between certain policies.

One of the departments appointed by the Governor is the New York Department of Public Service (NYDPS). This department is responsible for ensuring "access to safe, reliable utility service at just and reasonable rates." (NYDPS, 2022a). The department is headed by a group of up to seven commissioners (NYPSC), selected by the governor and approved by the Senate, for a term of six years. It is this department, in combination with the Federal Energy Regulatory Commission (FERC), who provide mechanisms that improve transparency into utility rate design, wholesale market regulations, and distributed energy regulations (Nyangon & Byrne, 2018). The FERC is tasked with similar responsibilities at the federal level as the NYDPS at the state level (FERC, 2022). Their relationship is not purely hierarchical, as can be seen in the attempts to collectively improve state policies in the last years on topics as: wholesale markets, energy infrastructure, and the reconciliation between conflicting state and federal policies on these subjects (Sullivan, 2015).

Another regulatory body of which the board members are nominated by the Governor is the New York State Energy Research and Development Authority (NYSERDA). This organization is tasked with providing expertise, information, and resource to help New Yorkers make informed decisions about their energy usage (NYSERDA, 2022a). NYSERDA aims to reduce New York's reliability on fossil fuels whilst accelerating economic growth and reduction of the customer's energy bill. More on programs developed by NYSERDA in section **3.3**.

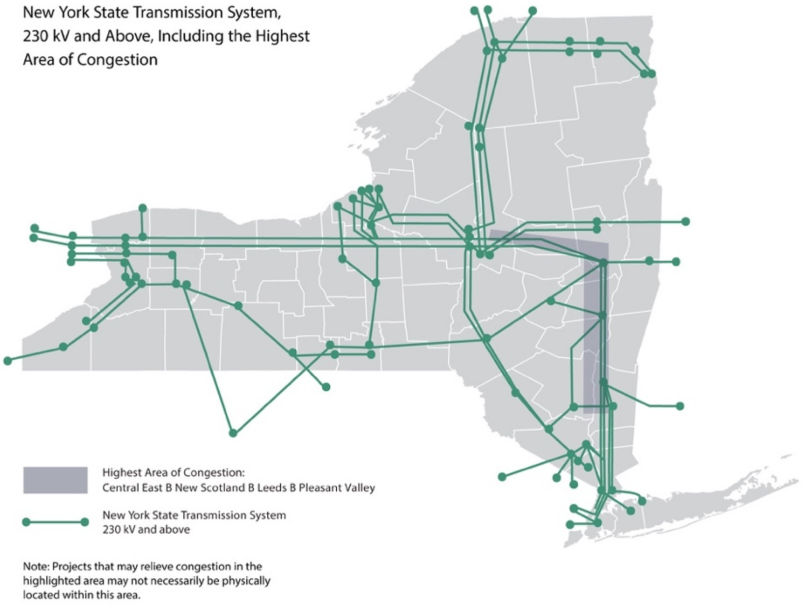
3.2.2 Reliability oversight

Besides legislation created by the FERC and NYDPS, there are three bodies overseeing reliability of energy provision, the North American Electric Reliability Corporation (NERC), the Northeast Power Coordinating Council, Inc. (NPCC), and the New York State Reliability Council (NYSRC). The NERC and NPPC are connected through the Electric Reliability Organisation Enterprise (ERO Enterprise). The NERC provides industry-wide oversight across Northern America. Whereas the NPCC is one of six regional organizations of North America, which carry out the vision of the ERO Enterprise on the regional level. Again, the relationship between the NERC and NPCC is not purely hierarchical but more collaborative in nature. The NERC develops and enforces reliability standards (NERC, 2022), which are applicable to all relevant entities in the United States once approved by the FERC (NYSRC, 2008), and the NPCC has been delegated more regional tasks (NPCC, 2022). It is the New York State Reliability Council (NYSRC) that has been tasked with the setting and monitoring the compliance of the rules of the bulk power system in the State of New York (NYSRC, 2010).

Essentially, with each step down in geographical scope (NERC -> NPCC -> NYSRC) the reliability rules become more stringent, but still in line with the rules set by the entity above it. The rules at a lower level are established more efficiently and usually are envisioned to be of shorter duration (NYSRC, 2010). One of the more regional issues in NYS for instance is the difference in population density between Upstate and Downstate New York. The region around New York City accounts for more than half of the population of the state, demanding great amounts of electricity. However, it is Upstate New York that is producing great amounts of renewable energy, mostly coming from hydropower, such as the Robert Moses Niagara Hydroelectric Power Station and the Lewiston Pump Generating Plant (NYISO, 2021; NYPA,2022). This leads to certain congestion in sensitive areas, mainly located in the Mohawk Valley and Hudson Valley (Figure **3.2**). Increasing the installed decentralised electricity generation capacity can, in combination with decentralised flexibility options such as demand side flexibility (changing of load over time) and increased storage capacity, help reduce congestion on the transmission grid (Bauknecht et al., 2022).

Figure 3.2

Transmission network and congestion area of the State of New York



Note. Source : https://www.lspgridnewyork.com

3.2.3 The market players

The rules set out by the policy makers described in the section **3.2.1** affect the electricity market in New York. The high-voltage transmission system depicted in Figure **3.3** is divided into eleven different load zones and is operated by the New York Independent System Operator (NYISO). This not-for-profit corporation was established in 1999, opening the wholesale market for utility and non-utility consumers and suppliers (FERC, 2010). The NYISO has three overriding responsibilities: i) maintaining safe and reliable operation of New York's bulk power system; ii) operating wholesale electric markets; and iii) planning for the reliability and economic needs of New York State's bulk power system (New York State Energy Planning Board, 2012). The NYISO charges the participants of the wholesale market with a surcharge, which in turn is a small fraction of the consumer's electricity bill (NYISO, 2022).

Figure 3.3

New York Control Area Load Zones

Note. Source : https://www.nyiso.com/documents/20142/2924447/rpp_mnl.pdf

The transmission network is connected to more local distribution networks, mostly operated by the investor-owned utilities (New York State Energy Planning Board, 2012). Historically utilities owned power generation units, but, through the market liberalization process, power generation is now dispersed among a wide range of companies. Next to profiting from power generation, utilities make money by charging its customers for two things: operating expenses and capital expenses. Operating expenses are the costs for operation of the day-to-day business: rent, salaries, inventory, and recovered by charging the customer. The utility does not make a profit. However, it can make profit with their capital expenses, i.e., physical infrastructure. This is done by adding a profit margin on top of their capital expenses. For instance, laying new power lines for US$100 million, might lead to customers being charged a total of US$110 million. This creates an incentive for the utility to increase the amount of capital spending (Kibbey, 2021). Moreover, it creates the incentive to prohibit other parties to introduce (renewable) energy solutions that do not include the utility spending money on physical infrastructure. Next to the role of system operator, the utility has the role of energy and service provider to the customers of New York. Electricity can be bought from the wholesale market, via bilateral contracts, or from their own power generation plants. In the state there are six major investor-owned utilities regulated by the NYPSC (Figure **3.4**):

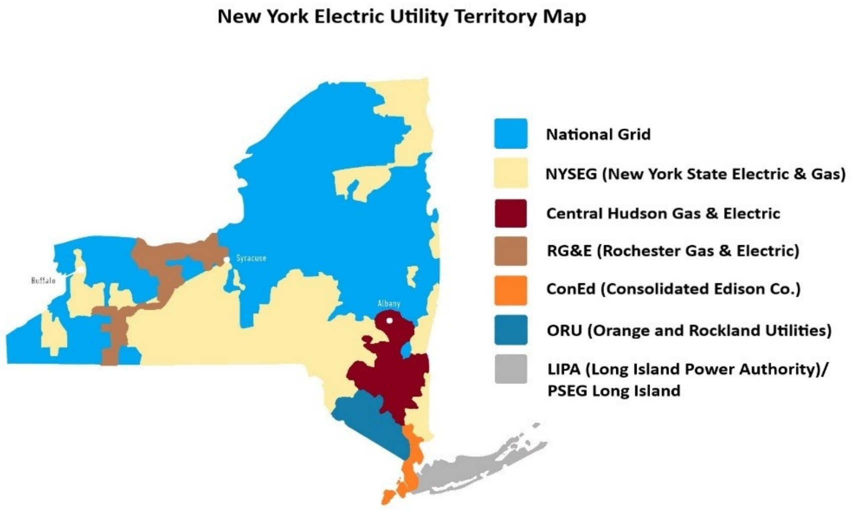
1. Consolidated Edison, Inc.
2. National Grid, Inc. (British owned utility company, not to be confused with the concept of a national grid)
3. Central Hudson Gas & Electric, Inc.
4. New York State Electric and Gas Corporation
5. Orange and Rockland Utilities, Inc.
6. Rochester Gas & Electric Company

These six major players formed a coalition in the form of the "Joint Utilities of New York".

Next to these investor-owned utilities there is the Long Island Power Authority (LIPA), providing utility services to Long Island as well as being responsible for the transmission lines. There are number of municipal utilities in the state, forty-nine in 2012. Lastly there is the New York Power Authority (NYPA), which generates and delivers power to public entities, municipalities, industry, business customers, and to the wholesale market, as well as maintaining transmission lines throughout the state (New York State Energy Planning Board, 2012).

Figure 3.4

Utilities in the State of New York

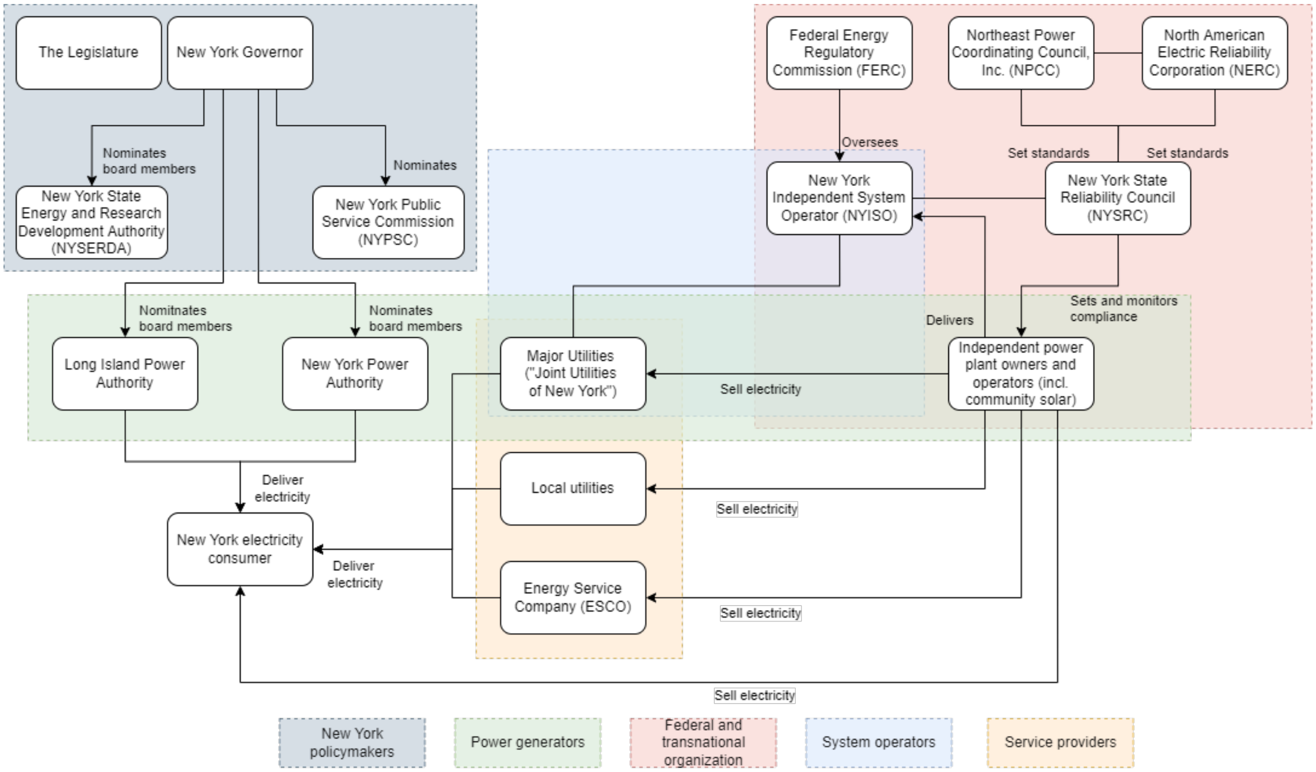


Note. New York's service area for the major utilities. Source : https://www.energytoolbase.com/newsroom/blog/new-yorks-solar-storage-market-key-acronyms-entities-and-online-resources

As you can see in Figure **3.5**, the utilities in the State New York are responsible for multiple tasks as service providers, power generators, and system operators. See Appendix **A** for the original overview by Nyangon & Barne (2018). This high form of vertical integration, from generation to distribution and delivery, stems from the nature of the electricity system. Power cannot be stored, therefore making transmission and distribution lines essential. These lines need to be physically in place for the system to function and generation needs to be coordinated to avoid blackouts (Michaels, 2006). Michaels (2006) suggests that either contract or vertical integration as the industrial organisation of the market. However, under contracts, however stringent they may be, opportunistic behaviour might still occur between generators and utilities. The negotiating process also brings transaction costs, increasing costs for the end-consumer. So, vertical integration makes for a more efficient organisational choice. However, this integration into one company can lead to high vulnerability to disruptions in the supply chain (Bouffard & Kirschen, 2008). Moreover, it has been shown that these integrated companies have tried to leverage their market power into political power (Farrell, 2019), and actively have hindered the effort of sustainable energy policy in the State of New York (section **3.2.1**).

Figure 3.5

Actor overview



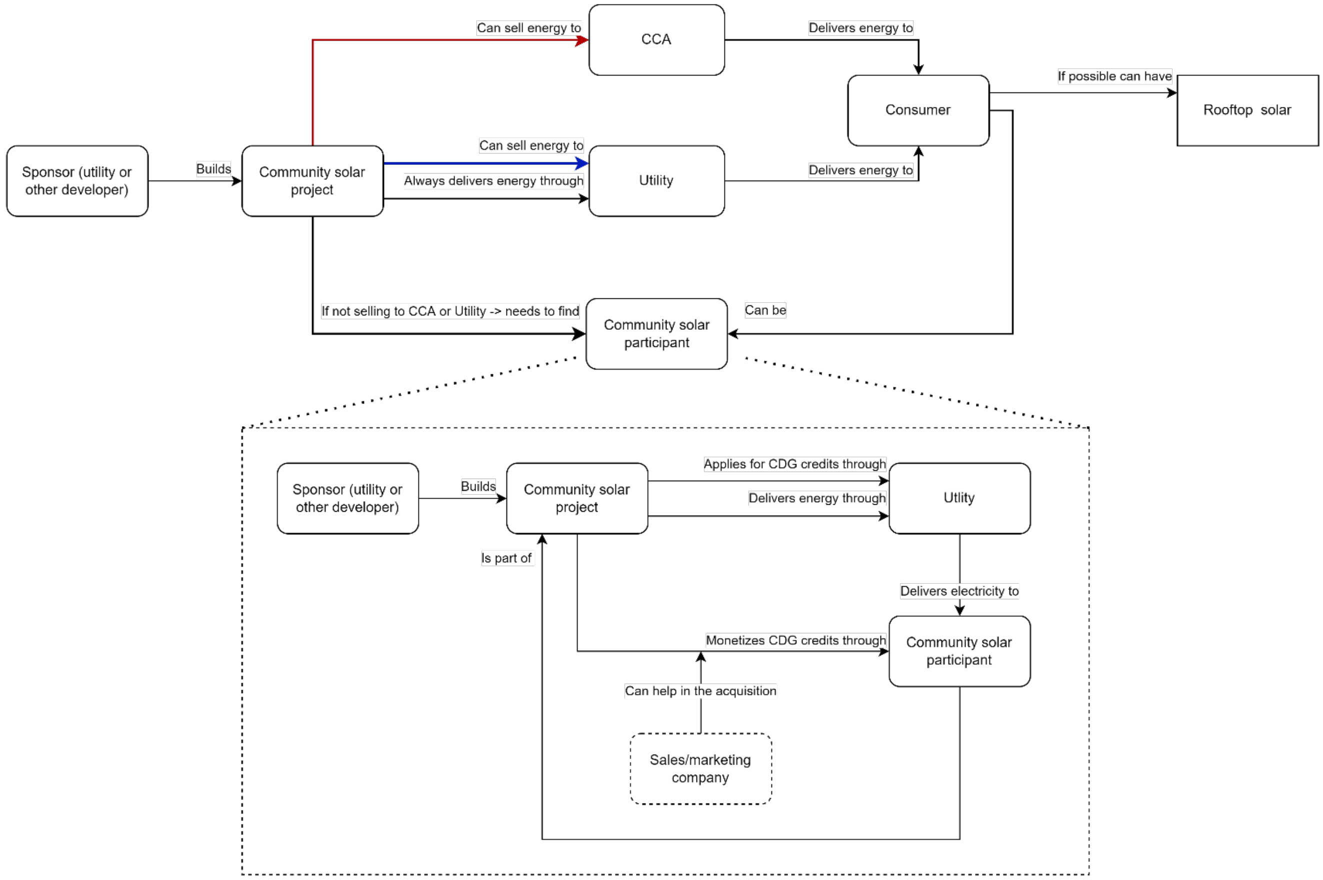
Note. Adapted from Nyangon & Byrne (2018)

3.2.4 Community solar developers

As mentioned before, community solar in the State of New York are commercially owned and operated projects, in which the developers look for customers who want to participate in renewable electricity generation. These developers are most commonly large companies who own several sites (Energy Sage, 2022a). In Figure **3.6** a visual representation is shown of how community solar works in the state.

Figure 3.6

Community solar mechanism



The developer of the project has three options for selling their electricity:

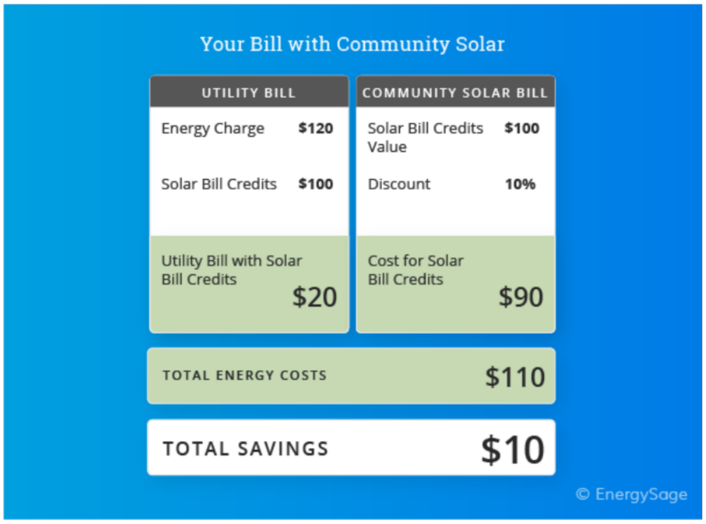
1) It can receive Community Distributed Generation (CDG) credits from the utility and monetize these credits by signing up participants who will receive a reduction on their utility bill. This comes at no costs for the participant. In this option the utility is responsible for the accounting for the right amount of CDG credits per signed up customer of the community solar project. Some requirements apply in this structure (Farrell, 2021). Each project must have:
    - At least 10 participants
    - Individual participants cannot own more than 40% of the total capacity or more than 25kW
    - Participants get billing credits (reduction on energy bill)
    - Pay subscription or 1 off. In New York the subscription model is applied more.
2) The utility buys the electricity directly and distributes energy to customers within their load zone.

3) A Community Choice Aggregation (CCA), or municipal aggregation, buys the electricity directly and distributes energy to customers within their load zone. Allowing the CCA to make use of the CDG credit, making it possible to reduce the energy bill of customers within the area of where the CCA is incorporated, usually a municipality. A CCA is a structure which allows local governments to take control over their electricity procurement. A CCA can aggregate the demand of residents who want to partake, gaining leverage in the negotiation process with utilities, for instance improving rates or demanding higher percentages of green power (EPA, 2022b).

In the first option, participants will receive a reduction on their utility bill. See the example below (Figure **3.7**). This structure does not mean that the consumer can claim they are using solar energy, i.e., they do not hold the Renewable Energy Certificates (RECs), it is just a billing crediting system. The utility gets the right to claim the RECs to meet their Clean Energy Standards (CES), as they incorporate the electricity of the CSP into their energy mix.

Figure 3.7

Example of a bill reduction for a household



Your Bill with Community Solar

UTILITY BILL		COMMUNITY SOLAR BILL	
Energy Charge	**$120**	Solar Bill Credits Value	**$100**
Solar Bill Credits	**$100**	Discount	**10%**
Utility Bill with Solar Bill Credits	$20	Cost for Solar Bill Credits	$90

TOTAL ENERGY COSTS $110

TOTAL SAVINGS $10

© EnergySage

Note. Source : https://news.energysage.com/community-solar-savings/

3.3 Energy policy in the State of New York

Some goals the separate entities in New York have already been described. In the following paragraphs, a short overview of the governments energy goals and relevant policy instruments will be described. Only policy instruments that effect residential solar are examined.

3.3.1 New York's "Reforming the Energy Vision" (REV)

In 2014 Governor Cuomo alongside the NYPSC introduced the plan "Reforming the Energy Vision (REV)" of New York. The goal of this plan is to align markets and regulations with the overarching goals of the state government of giving customers opportunities for energy savings, local generation, and enhanced reliability visa-vis safe, affordable, and clean energy service (NYDPS, 2022b). In this plan the energy goals for 2030 are laid out (NY Gov, 2016):

- 40% reduction in GHG-emissions;
- 50% of New York's energy comes from renewables;
- 23% decrease in energy consumption of buildings as compared to the 2012 levels.

Through three pillar activities: Regulatory Reform; Market Activation; and Leading by Example, New York strives to achieve these goals. Most interestingly is the Market Activation pillar, which is focussed on financing energy programs through the Clean Energy Fund (CEF), committing US$5 billion over a period of 10 years (NY Gov, 2016). The relevant programs for solar energy in the state will be discussed in the following paragraphs.

3.3.2 Solar Program (NY-Sun)

Before the REV was drawn up, New York already had already committed funds towards increasing the solar generation capacity in the state with the introduction of the NY-Sun Solar Initiative in 2012. Most of the funds set aside for this initiative are embedded in the MW-Block Incentive Structure, in which New York is divided into three regions (ConEdison, Upstate, and LIPA). Each region is allocated a certain solar capacity target, which is divided up in blocks. Each block is assigned a specific incentive, once one block is fully subscribed the block is closed, and subsequently the specific incentive cannot be applied for (see Figure **3.8** for an example). NYSERDA keeps track of the blocks and evaluates whether future expansion to the MW-Block is needed (NYSERDA, 2022d). Currently, the already committed, planned uncommitted, and additionally requested funds amount to US$3.3 billion, aimed at installing 10 GW of solar in 2030.

The MW-Block is different across the three regions but within each region a similar division is made between project into residential, small non-residential and large non-residential PV-systems. Per project type an incentive is defined. The rebates are collected by the contractor who has the contract with the customer (end-user). For instance, a household within the ConEdison region would like to install 20 kW of rooftop solar, and the current base-incentive for residential is US$0,20/W, the rebate will be US$4000 for the entire PV-system.

Figure 3.8

MW-Blocks for the three regions in NY

ConEd: **Block 9** | $0.2/W   Long Island: **Fully subscribed**   Upstate: **Block 9** | $0,5/W

Note. Source: https://www.nyserda.ny.gov/All-Programs/NY-Sun/Contractors/Dashboards-and-incentives

In addition to the standard MW-Block structure, certain adders were introduced. These adders are designed to promote the uptake of solar capacity in more specific demographics, by adding an incentive atop of the base-incentive. For instance, the 'Community Adder' let's contractors receive a higher rebate when their project is intended for community solar projects. The 'Inclusive Community Solar Adder' has a similar purpose only more specifically targeting solar projects serving low-to-moderate-income (LMI) subscribers, affordable housing, and other facilities serving disadvantaged communities.

An important aspect for the residential consumers is tax credits. There are two main credits: the federal and state tax credits. Only when implementing rooftop solar does a household have the right to apply for tax credits. The tax credits currently allow for a reduction up to 26% and 25% respectively.

3.4 Challenges for decentralised solar electricity generation in New York

Decentralised solar electricity generation has seen some positive developments over the last view years in the United States. The price for both residential and commercial solar panels in the US has dropped significantly over the last decade, around 75 percent and the market has had an average annual growth rate of 33 percent (OEE & RE, 2021; SEIA, 2022). This had led towards a shift from a centralized generation system towards a more distributed generation (DG) system. DG has several benefits such as promoting energy efficiency, reduction of greenhouse gas (GHG) emissions and air pollutants such as NO_x and SO_2, and subsequently benefits on human and ecological health (Akorede et al., 2010). Next to these physical benefits there are positive behavioural changes in energy use of households as well (Keirstead, 2007; Wiersma & Devine-Wright, 2014). However, this new structure raises governance challenges (Goldthau, 2014; Cherp et al., 2011).

In the US one of these governance issues, is that under the current rate structure in New York the fixed costs of utilities for maintaining and updating the grid cannot be fully recovered (Funkhouser et al. 2015). The structure in New York works on a volumetric charge, a per kWh charge in which variable costs, surcharges, late fees, credit rebates, and finally, fixed costs are included (NYSERDA, 2022c). Especially in a kWh-for-kWh compensation scheme, i.e., net-energy-metering (NEM), this becomes an issue (APPA, 2013; Blackburn et al., 2014). Initially, solar electricity generation had mostly been available for household who could afford RPV-system, i.e., people with higher income (Rai & McAndrews, 2012). These households generally also consume more energy, making NEM even more profitable, in turn making the NEM structure slightly regressive in nature (Blackburn et al., 2014). Moreover, solar electricity has the issue of being weather- and time-dependent, resulting in the need for back-up generation or demand resources to maintain reliability requirements (Blackburn et al., 2014). This means that the value of solar energy differs throughout the day, e.g., when the sun shines across the US, supply of electricity is high, making the value low. To adjust the value of energy for these other variables, research has been conducted towards understanding the actual value of solar electricity. However, calculating the Value of Solar (VOS) has been noted to be an ambiguous effort (Funkhouser, 2015), since it is up for debate which factors to include in the renumeration. Policymakers could include the standard fixed and variable costs, line losses, maintenance costs, but expand it with environmental costs, locational factors, demand reduction factors. The inclusion of these factors is, in part, up for debate.

3.5 Proposed policies

To battle these challenges, the State of New York has implemented a set of policy instruments over the course of 2022. In the following section these will be shortly described.

3.5.1 Expanded Solar-for-all program

As part of their NY-Sun program, the state aims to aid low-to-moderate income (LMI) households through the Expanded Solar-for-all program. This program will reduce the electricity bill of these households, with an expected US$5 per month. Currently, as shown in Figure **3.7**, developers (section **3.2.4**) hand down 5-10 percent of their value stream to their customers. However, one drawback of the E-SFA, is that this will increase to 15-20 percent, in order to accommodate the desired reductions for LMI-household (Gordon, 2021). This will lead to a less appealing business-case for potential developers, with the potential result of less CSP's in the state.

3.5.2 Value of Distributed Energy Resources

From 2022 onward the State of New York will be implementing a new structure to calculate compensation for residents with PV-systems, using the Value of Distributed Energy Resources (VDER). However, households who plan on installing RPV can still opt for NEM until 2023 (Lane, 2022). This policy uses a feed-in-tariff like structure where the value of each delivered kWh back to the grid is calculated under the Value Stack, comprised of (NYSERDA, 2022b):

- Energy value: day-ahead value
- Capacity value: based on peak hour of last year
- Environmental value: based on clean energy standards and social costs of carbon
- Demand reduction value: if a household overproduces during the peak hours, they will receive a higher credit than in off-peak hours
- Locational System relief value: Much like the temporal scale, the geographical scale is included. So, if a household feeds electricity back into the grid within in a high demand area, i.e., a city, they will receive more credits than in a low demand area, i.e., the rural Upstate New York.

It is expected that through this new scheme, households will receive less compensation for their generated electricity. The size of the impact of this policy on households' electricity bill is still uncertain. However, a study in California found that a similar feed-in-tariff scheme could lead to a reduction of bill savings as large as 54 percent (Darghouth et al., 2011).

3.5.3 Customer Benefit Contribution

Lastly, to retrieve some of the missed fixed costs, the State of New York also will introduce a Customer Benefit Contribution (CBC) (NYSERDA, 2022b). This will be applicable to all RPV systems that are installed after the first of January 2022 (Lane, 2022). This is a monthly charge based on the size of a households' RPV system, i.e., the number of kW's installed. A household pays this as part of their electricity bill. This charge is meant to alleviate some of the missed fixed costs recovery, caused by NEM, or in to a lesser extend in the VDER structure, as explained in section **3.4.** To reiterate, currently under NEM and VDER utilities miss income, as people who have a RPV system will consume less energy from the grid, therefore paying less of the fixed costs that are needed to maintain the grid. This charge is relatively low, approximately within the range of US$0,3-1,1/kW installed, depending on the region, but nevertheless will have an impact on the finances of households. A full overview of the pricing can be found in Appendix **B**.

3.6 Summary chapter 3

The chapter elaborated on the context in which decentralised solar electricity operates within the State of New York. The key takeaways will be shortly summarised in this section. Firstly, a short history was given to portray a narrative that would help in the understanding the current context. Secondly, the policymakers, organisations concerned with oversight, and major market players were described. It was found that due to the market power utilities hold, as a result of their monopolistic nature, they are actively leveraging this market power into political power. They have been shown to hinder the development of sustainable energy. Reasons as to why this has been happening has not been further analysed, however within section **3.4** it was described how utilities are trying to limit fixed-costs losses caused by the implementation of more decentralised electricity generation. This is indicative of the problem for the utilities as decentralisation increases since the use for utilities in the role as energy supplier diminishes as the decentralised market grows. However, this line of reasoning might be getting too close to speculation or political thinking.

In addition, the relevant policies applicable to the decentralised solar market were laid out, which the state of New York carries out under the REV. The main incentives are the MW-block structures, which can be supplemented by adders aimed at targeting specific groups or types of solar generation practices. Tax credits were also found to be an important incentive.

Lastly, the challenges the current decentralised solar market faces have been elaborated on. To battle these challenges, the State of New York has proposed three policies: 1) the Expanded Solar-for-All program, 2) the Value of Distributed Energy Resources, and 3) a Customer Benefit Contribution charge.

4 Model conceptualisation and implementation

In this chapter the model will be built. Firstly, a short description of the data that has been used will be provided. Secondly, the global variables within the model will be described. These are the variables that represent the context of New York's decentralised solar market. Thirdly, the conceptualisation and formalisation of both the households and CSP's will be explained. Lastly, the implementation of the three policy interventions, as described in section **3.5**, will be elaborated on, with the addition of some expectations on how the model will react to these interventions.

4.1 Data

Wolske et al. (2017) have based their research on a questionnaire interviewing residents who did not yet have RPV-systems from four different US states: Arizona, California, New Jersey, and New York. They used these states since they are at the forefront of RPV adoption in the nation. The aim of their research was to determine drivers behind the interest of talking to a PV company, in order to explain adoption of RPV by households within these states. It must be stated that the dependent variable, talking to a PV company, differs from the dependent variable in this research, adoption of PV and adoption of CS. However, within this research the work of Wolske et al. (2017) is used within the model as design for the intent mechanism of households to install PV or to join a community solar project. All their results have been standardized, i.e., represented as a normal distribution with a mean of 0 and standard deviation of 1 (N (μ= 0, σ^2=1)), and the calculated effects are represented as standardized coefficients. All other data has been retrieved from internet sources, most often from government institutions of the State of New York. A full overview can be found in Appendix **C**.

4.2 Global variables

4.2.1 Initialisation

The environment is set up such that it represents the RPV and CS market in the State of New York. This includes the tax incentives, MW-block structure, and pricing. The MW-blocks that are available are implemented as one-thousandth of the actual value within the State of New York, meaning that the MWs that are available in the real world will be divided by a thousand, i.e., 1MW/1000 = 1kW. Additionally, the effects of the proposed interventions are determined. Technical aspects of the electricity production are determined, namely how many kWh can be generated per kW PV installed and emissions per kWh generated for each electricity source. One important aspect of the model is the density, which determines the number of rooftops there are within the model. The state can be divided in two regions: ConEd, which is the metropolitan area of New York City, and "Upstate", representing the rest of the state. The percentage of houses with rooftops are 30 and 70 percent respectively. A full list of the initial settings for the global variables can be found in Appendix **C**. Every tick represents one week, and the model is setup to run for 520 ticks i.e., 10 years. The values at initialisation within the model are assumed to be data from 2022.

4.2.2 Dynamic updates

There is one variable that is updated with every step of the model, being the price of installation of solar panels for both RPV and CS projects. These are expected to be reduced by half by the year 2030 (OEE & RE, 2021). As the model is assuming a start in 2022, the halving of the panel price is assumed to take place over the period 2022 to 2032 and is represented as:

$$Installation\ cost_t = installation\ cost_{t-1} * \ 0.5^{\left(\frac{1}{520}\right)}$$

(Equation 4.1)

If the initial MW-block has been fully subscripted, a secondary MW-block will be activated (NYSERDA, 2022b). The height of this second block is 150kW for the ConEd region and 800kW for the Upstate region (Kinross, 2022).

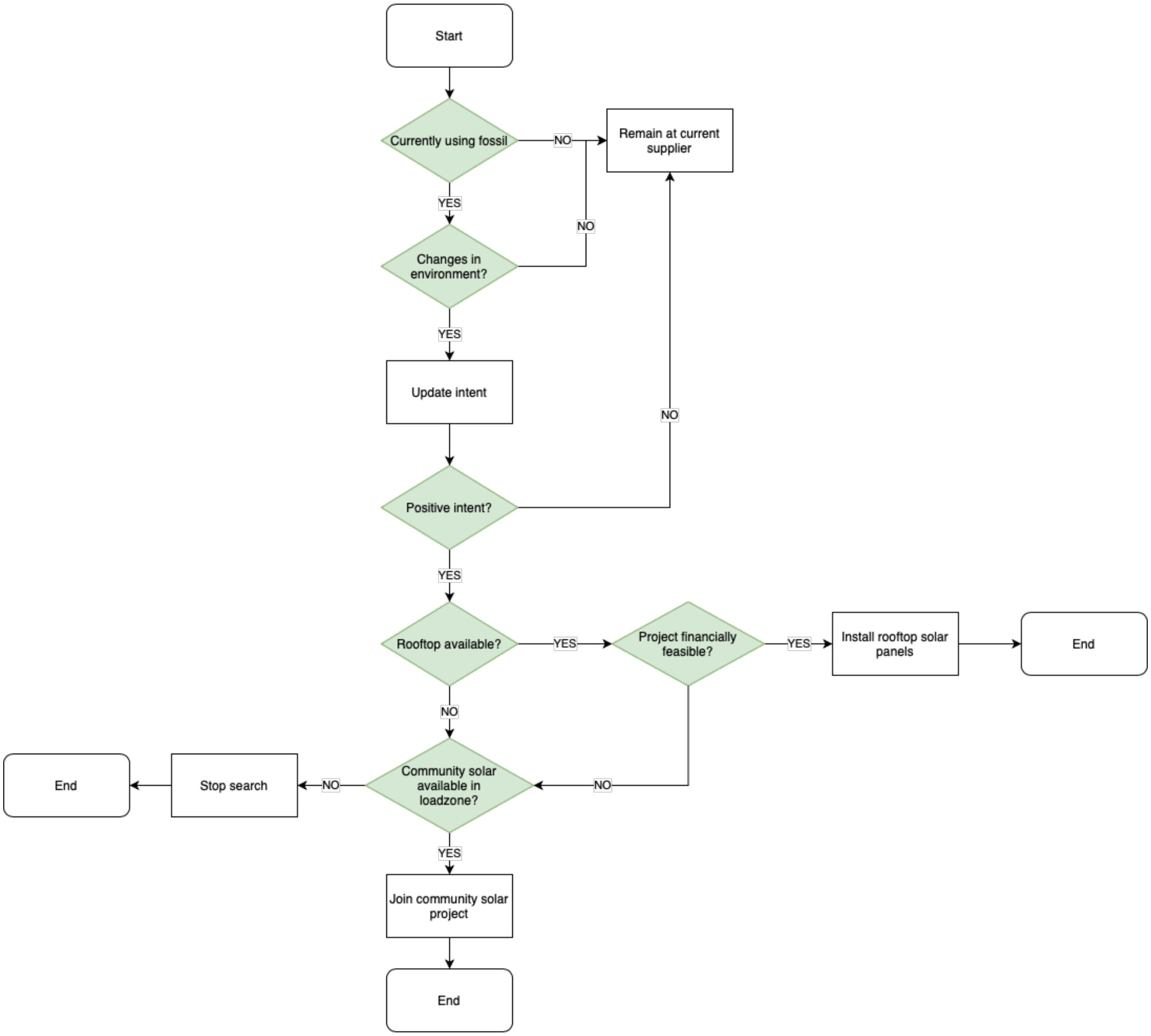
4.3 Household variables

4.3.1 Initialisation

The number of households within the model is set at 2000. This is approximately one-thousandth of the expected market potential of around 1,7 million households in 2035 who can be serviced by solar electricity in 2035 (Penrod, 2021). Moreover, the number provides a reasonably sized region, and makes for an easier number to work with as the MW-block structure as implemented in the model also represents one-thousandth of the actual MWs available (section **4.2**). Households within the model have one objective: acquiring electricity. The amount is based on their own electricity usage, which is assigned based on a normal distribution (*N* (973, 200)), representative for the State of New York (Energy Sage, 2022b). Initially all households are using electricity from the traditional electricity-production-mix of the State of New York (EIA, 2021a). All households are assigned their initial values for the determinants for attitudes towards RE as described in Figure **2.5**: external influences, and factors for shaping beliefs about RPV, as well as the attitudes themselves and household constraints. These will influence the intent of installing RPV or joining a CS project (see Figure **4.1**). Next to these factors, households are given financial characteristics, such savings and an electricity bill based on weekly electricity use. Households will be assigned a social network, created by links with other households ranging from 1 to 3 links. Households will review their electricity situation every couple of weeks, the intervals determined by the education level of each household (Rogers, 2003). The higher the education the more likely a household is to acquire the information necessary to get an overview of their electricity needs. A full list of the initial settings for households can be found in Appendix **C**.

Figure 4.1

Conceptual model household-decision making process



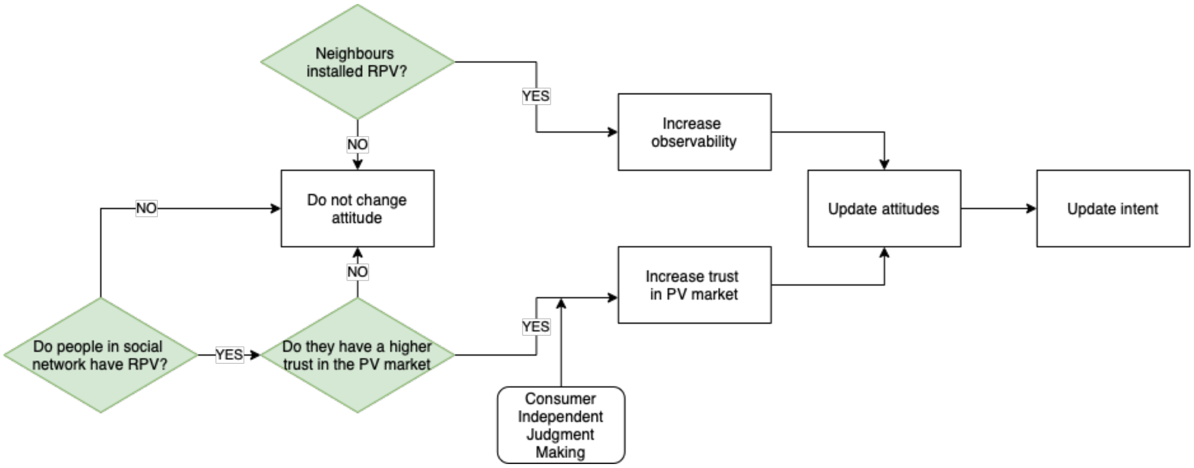
4.3.2 Dynamic updates

Determinants for attitudes, and as a result for intent, are generally static, however two determinants are dynamic (Figure **4.2**). These are the external influences observability and trust in the PV market. Observability can increase when the amount of RPV systems installed, by households within a certain range, has increased as compared to the last time the household has reviewed their electricity situation. Trust in the PV industry increases if households within the social network of the household in question, have a higher trust in the PV industry. This effect is mediated by the "Consumer Independent Judgement Making" (CIJM) level of the household. CIJM measures the extent to which a household turns to his peers for opinions on products before making a decision (Wolske, 2017). As a result, the attitude of the household will change, and consequently their intent. If the intent passes a certain threshold, they will look for a new electricity supplier. If a household has a roof, they will initially check their financials whether RPV is a viable investment. If this is not the case, they will look for a CS-project. For households without a roof the latter is their only option.

Apart from a households' changing intent of installing a RPV system or joining a CSP, their finances are weekly updated. Their savings increase follows the growth of household income in the State of New York (FRED, 2022).

Figure 4.2

Conceptual model updating intent



4.4 Community solar project

4.4.1 Initialisation

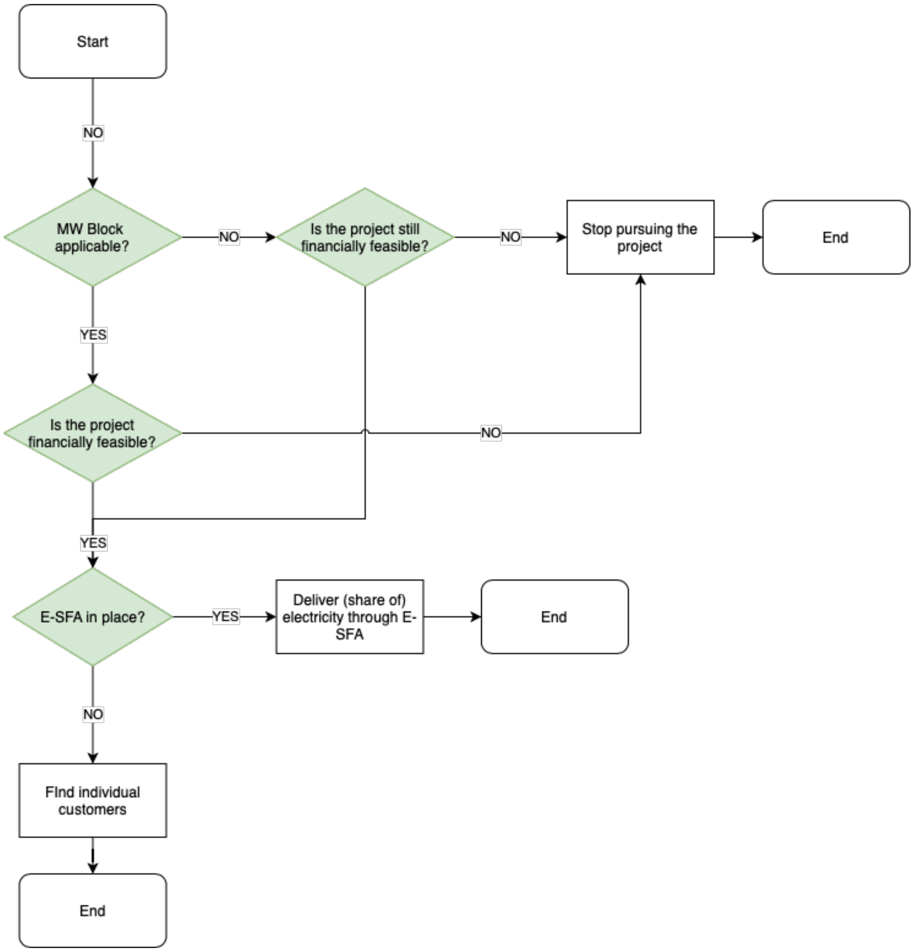
During initialisation, zero CS projects are generated. As explained previously, it is assumed that all household get their electricity from the traditional electricity-production-mix. Depending on the region in which the CS project is located, the average size of the project is set. For the ConEd region this is 115kW and for Upstate 2,300kW (2.3MW). Similar to a RPV system, the costs per kW installed is determined, however these prices are lower for a CS project, due to economies of scale.

4.4.2 Dynamic updates

During the runs of the model a developer will look within the region if there are enough potential participants. If the expected profits for a project are positive, a solar farm will be built (Figure **4.3**). The size of the potential CSP is assigned based on a normal distribution with a mean of the average project size in the region and the standard deviation one-eight of the average, e.g., in ConEd that will be: N (115, (115/8). In the model, for CS developers the decision of starting a project is purely a cost-benefit analysis, whereas this decision for households is based on their finances and their intent to join a CSP or install RPV, which in turn is determined by several other factors (section **4.3**).

Figure 4.3

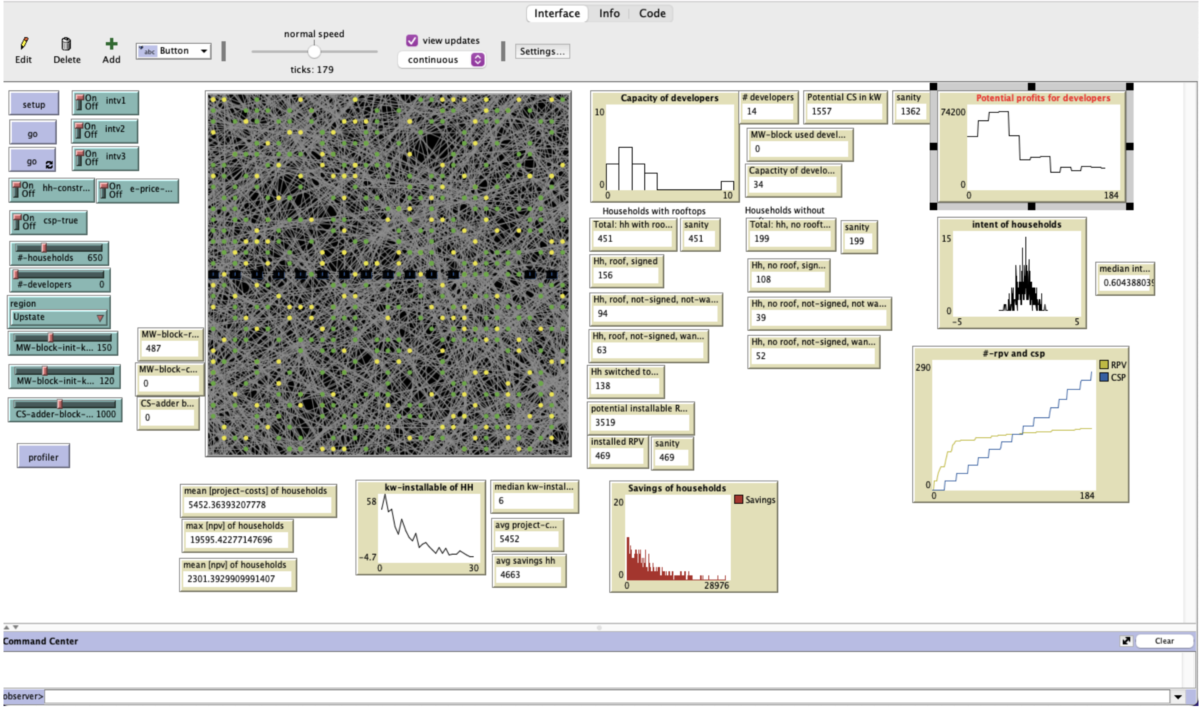
Conceptual model developer decision-making



The interface of the model is shown in Figure **4.4**. In the middle the environment is visually displayed, with each dot representing a household. On the lefthand side input parameters can be altered, whereas on the righthand side several parameters are plotted and monitored.

Figure 4.4

Interface Netlogo



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On Off intv2
On Off intv3
On Off hh-constr...
On Off e-price-...
On Off csp-true
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#-developers 0
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MW-block-init-k... 120
CS-adder-block-... 1000
MW-block-r... 487
MW-block-c... 0
CS-adder b... 0
developers 14
Potential CS in kW 1557
sanity 1362
MW-block used devel... 0
Capacity of develo... 34
Total: hh with roo... 451
sanity 451
Hh, roof, signed 156
Hh, roof, not-signed, not-wa... 94
Hh, roof, not-signed, wan... 63
Hh switched to... 138
potential installable R... 3519
installed RPV 469
sanity 469
Total: hh, no rooft... 199
sanity 199
Hh, no roof, sign... 108
Hh, no roof, not-signed, not wa... 39
Hh, no roof, not-signed, wan... 52
median int... 0.604388039
mean [project-costs] of households 5452.36393207778
max [npv] of households 19595.42277147696
mean [npv] of households 2301.3929909991407
median kw-instal... 6
avg project-c... 5452
avg savings hh 4663

Note. Model visualisation

4.5 KPI operationalisation

Fouladvand et al. (2022) have operationalised the 4A's principles for the analysis of community led energy initiatives. Their goal was to analyse under which conditions community led initiatives could be deemed successful in terms of 'Energy Security'. In this research the agents of interest are CSP participants and RPV system owners, i.e., the concept at the centre of the studies differs. Moreover, as mentioned in section **2.3**, it is important to consider the scale at which the analysis takes place. For their paper Fouladvand et al. (2022), analysed a community's ability to successfully produce their own energy, and the effects it has for the individual household. However, in this research the scale is on a higher level, namely the State of New York as a whole. In order to accommodate these two facts (the different focus of the study and the difference in scale), some alterations and additions were made. What follows are the definitions given by Fouladvand et al. (2022), the alterations that were made on them, and the additional KPIs. All the KPIs are reported per week, i.e., one tick in the model, and concern the entire population.

4.5.1 Availability

For their operationalisation, Fouladvand et al. (2022) use a measure that indicates the extent to which the energy is available to meet the demand of each individual agent, and is translated to the following equation:

$$Availability = (100\ \% - average\ voluntary\ shortage\ percentage\ (AVSP))$$

(Equation 4.2)

In which:

$$AVSP = (100\ \% - total\ RE\ \% - baseline\ energy\ \% - \ average\ willingness\ to\ compensate\ \%)$$

(Equation 4.3)

This pertains to the used the response of households to potential blackouts, caused by shortages of energy production by a community owned solar project. Fouladvand et al. (2022), modelled the households who have joined a project in such a way that they had an option of using the grid or install personal energy source in the form of a heat pump or solar PV, for when the project is unable to meet the demands of the households in the community project. For example: in households with strong environmental concerns but not enough financial resources to choose discomfort (AVSP) overusing the national grid, thereby having no energy supply. In this context the use of the AVSP is a valid way of representing availability. However, in this research the assumption is made that households will always want to have electricity, and that the grid will always be able to provide electricity when a household is need thereof. So, a change is made to the operationalisation above, altering the definition to:

Availability is the percentage of renewable solar electricity consumption within the system.

This is more in line with the definition given by Kruyt et al. (2009) and Tongsopit et al. (2016) who describe availability as the physical existence of a resource. RE is the summation of electricity generated by CSPs and RPVs. An important fact is that no electricity leaves the system, therefore making the RE production equal to the RE consumption. This definition is translated into the following equation:

$$Availability = \frac{Total\ RE\ production}{Total\ electricity\ demand} * 100$$

(Equation 4.4)

4.5.2 Affordability

In most definitions of security of supply an economical element considered (Kruyt et al., 2009). Fouladvand et al. (2022) have defined it as the total system costs per agent, which translated in their research to the following equation:

$$Average\ costs\ (€) = \frac{investment\ costs + costs\ energy\ import + investment\ new\ community\ members}{households}$$

(Equation 4.5)

In this research, the total system costs per agent are still considered, in line with Ranjan and Hughes (2014). However, as mentioned in section **3.2.4**, the community aspect is different. Joining a CSP comes at no costs for the customers, making the "investment new community members" obsolete. Therefore, only investment costs for RPV-systems are considered. Moreover, the costs of buying electricity for households depends on the amount of electricity bought from the grid and via CSP's, corresponding with the "costs energy import" in(Equation **4.5**). Affordability is therefore defined in this research as follows:

The total costs that are made for electricity procurement

This results in the following equation:

$$Average\ costs\ (€) = investment\ costs\ RPV + (electricity\ price\ grid * kWh\ grid) + (electricity\ price\ CSP * kWh\ CSP)$$

(Equation 4.6)

4.5.3 Accessibility

As a proxy for accessibility often the term diversity is used. Diversity indexes provide a way to quantify the diversity of the energy supply, which in turn can reduce the supply risk. The definition, and the accompanying equation (Equation **4.9**), are directly used from Fouladvand et al. (2022). Their definition is based on the Shannon Index, which mostly is used for the calculation of diversity within ecosystems. This calculation is based on the number of species and their abundance, or in this research the number of electricity sources, and the number of kWh generated per source (Ranjan & Hughes, 2014). The definition of accessibility is as follows:

The diversity of electricity produced within the system.

This results in the following equation:

$$\begin{aligned} Diversityindex &= -1 \\ &* \big((choosen.collectiveRE\ * \ ln\ choosen.collectiveRE) \\ &+ (choosen.individual\ RE\ * \ln choosen.individual\ RE) \\ &+ (choosen.nationalgrid\ * \ln choosen.nationalgrid)\big) \end{aligned}$$

(Equation 4.7)

4.5.4 Acceptability

Acceptability is usually linked to social elements such as households' welfare, fairness, and environmental issues (Ang et al., 2015). APERC uses an economy's effort to move away from using carbon intensive fuels as an indicator to evaluate acceptability. However, in literature just the emissions (CO_2 eq) of an energy system have been used as an indicator for acceptability (Kruyt et al., 2009). Therefore, Fouladvand et al (2022) have defined acceptability as the reduction in emissions that could be achieved associated with the production of electricity. Resulting in the following equation:

$$\boldsymbol{Carbon\ reduction\ (kg\ CO_2)} = \frac{\boldsymbol{carbon\ emission\ of\ the\ traditional\ system\ (kg\ CO_2) - carbon\ emission\ of\ the\ community\ energy\ system\ (kg\ CO_2)}}{\boldsymbol{households}}$$

(Equation 4.8)

However, in this research the difference between policy instruments is analysed, therefore a reduction is not deemed necessary. The addition of emissions within the system suffices. Acceptability is therefore defined as:

The total number of kilos CO_2 equivalent emitted associated with electricity production across the entire lifecycle, or supply chain.

The caveat "across the entire lifecycle" is added to consider other factors such as production of RPV panels or transportation of resources needed for fossil fuel burning. The IPCC (2014) has provided an overview of how much CO_2 equivalent is emitted for the generation of one kWh, for multiple electricity sources. The definition given above is translated into the following equitation:

$$Total\ emissions\ (CO_2eq) = Carbon\ emission\ of\ the\ energy\ system\ (kg\ CO2)$$

(Equation 4.9)

4.5.5 Additions

Wolske et al. (2017) found that environmental concerns are not proper determinants for the behaviour of households concerning their electricity needs for the population of New York. Therefore, two additions are made. The 'Acceptability' KPI is corresponds to the emissions that are generated by the electricity production (Fouladvand et al, 2022). But since the households in New York have limited environmental concerns, a more financial KPI is needed. This will be the KPI 'Appeal' and can be seen as the number of households who are able to make a return on investment on their project. For households wanting to install RPV this will be a positive net present value (NPV). Since joining a CSP is free of any costs, with a guaranteed reduction on one's electricity bill, a positive NPV is always present. So, the addition of the 'Appeal' KPI is defined as:

The number of households who can make a profit on a RPV system or who joined a CSP

$$Appeal = \#hh\ positive\ NPV + \#\ hh\ CSP$$

(Equation 4.10)

Secondly, to indicate how many households can participate in RE generation, an additional 'Ability' KPI is created. This can be described as the households being able to make the initial investment needed to install an RPV system, i.e., are their savings sufficient. Just as with the addition of the 'Appeal' KPI, households wanting to join a CSP do not need to make an initial investment, so as a proxy the amount of households who have joined a CSP will be used to calculate the second 'Ability' indicator, and is thusly defined as:

The number of households who have sufficient savings to install a RPV system or who joined a CSP

$$Ability = \#hh\ positive\ savings + \#\ hh\ CSP$$

(Equation 4.11)

For both factors it does not mean that the households will install an RPV system, it is merely the ability to make a profit or to make the initial investment that determines the KPI.

In the table Table **4.1**, an overview is shown of the KPIs used for further analysis.

Table 4.1

KPI description overview

KPI	**Description**
Availability	Availability is the percentage of renewable solar electricity production within the system.
Affordability	The costs that are made for electricity procurement per household
Accessibility	The diversity of electricity produced within the system.
Acceptability	The total kilos of CO_2 associated with electricity production across the entire lifecycle, or supply chain, per household
Ability	Number of households capable of installing a RPV system or join a CSP
Appeal	Number of households who are able make a positive return on their RPV investment, i.e., have a positive NPV, or join a CSP

4.6 Intervention implementation

The proposed interventions described in section **3.5**, will influence both the households' and CSP's finances. The following section will shortly hypothesise on how these policies are expected to influence model and consequently the KPIs.

The E-SFA is expected to make the business case for CSP developers less appealing. Since the E-SFA causes the developers to hand over more of their profit margin to the utilities, who want to use this part of the value stream to aid Low-to-Middle income households, it will be harder for developers to turn a profit. This is expected to reduce the number of CSPs being initiated within the model. When looking at the KPIs, it is expected that the availability will score lower in this scenario, just as accessibility, and appeal. The number of CSPs will affect the production of RE in the model, and if there is a reduction in CSPs, a reduction in availability will also take place. However, this could be counteracted by households initially wanting to join a CSP, but with lack thereof, opt for a RPV system.

For accessibility a similar reasoning could be followed. For the ability and appeal KPIs, as they are partially defined by the number of people able to join a CSP, are expected to score lower as well in this scenario. Since the reduction in CSPs within the model likely causes less households being able to join a CSP. For all other KPIs no hypotheses are made.

The VDER policy is aimed at the finances of households who want to install an RPV system. Therefore, it is expected that the affordability KPI will score lower in this scenario. However, the size of the impact is unknown, making the prediction for the ability KPI uncertain as households still might be able to install RPV, albeit with less profits in the net-metering scenario. For hypothesising the effects of the CBC-charge the same reasoning as for the VDER is used. For all other KPIs no hypotheses will be made.

In Table **4.2** an overview can be found of the hypothesised impact the policies will have on the model.

Table 4.2

Expectations of the impacts of policies on the KPIs

KPI \ ***Policy***	**E-SFA**	**VDER**	**CBC-charge**
Availability	🟥		
Affordability		🟥	🟥
Accessibility	🟥		
Acceptability	🟥		
Ability	🟥		
Appeal	🟥		

Note: Red indicates a negative impact. White cells indicate no hypothesis was made.

4.7 Summary chapter 4

The conceptualisation and operationalisation of the model were central in this chapter. Firstly, the global variables were set up. These represent the current context within the State of New York, as depicted in the third chapter, including the policies that are relevant for the decentralised solar market. Secondly, the way households make decisions was translated into a conceptual model. This included the theories and frameworks that were described in the second chapter. The same was done for the CSPs. The decision-making process for CSP developers was conceptualised in a relatively simple cost-benefit approach. Lastly, the KPIs that were introduced in the second chapter was expanded on and were operationalised.

5 Verification and validation

This chapter the model will be verified and validated. The verification will entail some model testing that is aimed assessing whether the right translation from theory and conceptualisation to the model is achieved. Secondly, other literature will be used to see if the model behaves in a manner which is representative of the New York decentralised solar electricity production system, as well as other literature associated with RE generation. Lastly, a sensitivity analysis will be performed to assess which variables are significant in determining artefact behaviour within the model.

5.1 Model verification

The goal of this section is to ascertain whether the model implementation was properly executed. The steps that were followed are given by Van Dam et al. (2012). They propose four phases of verification: i) recording and tracking agent behaviour, ii) single-agent testing, iii) interaction testing, and iv) multi-agent testing. This is verification is done for both the decision-making process of the households as well as for the developers.

As the building of the model was an iterative process, after the implementation of each new piece of code, the code was tested using a code walk through. This was done to verify if the other model properties were still behaving as expected. Simultaneously, agents were recorded and tracked during the run of the model.

Single agent testing was performed to analyse the chronological steps that a household or developer will go through in their decision-making process, in order to test if the conceptualisation of this process chapter **4**, was present in the model. Interaction testing was performed with a minimal amount of household agents in the model, this was found to be 20 households. With this initial number of households, the interaction between households themselves and between households and developers was considered working as desired. For examples of the steps performed see Appendix **C**.

In the final part of the verification, namely multi-agent testing, the model variability is tested by running the model with high repetitions, and examining the output statistics of the output parameters, i.e., KPIs (Nikolic & Ghorbani, 2011). Three levels of repetitions were analysed, namely 50, 100, and 500. This was done to see whether limiting the repetitions was an option, to limit the computational time. It was found that the skewness and kurtosis (i.e., indicators for the shape of the distribution and frequency of distribution, respectively) when the number of repetitions was set to 50 were close to the desired levels of 0 and 3 respectively, for all but the Affordability KPIs (see Appendix **E**). Due to time constraints, it was not possible to investigate this anomaly further. For the higher number of repetitions, the skewness and kurtosis did not alter greatly. Considering the computational time, the number of repetitions is therefore set to 50.

During the model implementation, several minor checks were also carried out but not documented. Since these checks were in essence necessary during modelling, these were considered part of the modelling process. After the execution of the verification steps described in the previous paragraphs, the model was considered verified and correctly representing the conceptualisations made in chapter **4**.

5.2 Model validation

The validation of the model concerns checking whether the outcomes of the experiments correspond with observed reality (Nikolic & Ghorbani, 2011). Since the policies are new in the State of New York, and no similar policies have been found in other regions, validating the model via this way becomes an impossible exercise. Moreover, no experts could be consulted who could have validated this research based on their experience. Another approach could be to start experiments in the real world, which could then be tested against the experiments performed in this research. This is however a time-consuming effort, not achievable in the time available for this research. One could come back in a year's time and review the results of the policies in the real world with the ones predicted in this study. However, the theories used, described in chapter **2**, have been used in decision-making in a lot of research.

However, this research is of course not a singularity, more research has been conducted into the electricity market in the United States, and ABM has been used to analyse emergence of community energy. To reiterate, community energy in the Netherlands and Western-Europe is different than community energy in the states. But, in general research has shown that implementation of decentralised energy generation is considered a viable solution towards fighting climate change within the United States, when implemented correctly (EPA, 2022c). Similarly, researchers have highlighted the true impacts of decentralised energy systems, as compared to centralised systems, arguing for more detailed research (Bauknecht et al., 2020). This is where this research fits into the scientific discourse of decentralised electricity generation. On using ABM as an approach, research has shown that the use of these types of models has been beneficial in showing the behaviours of actors within an energy system and that ABM lends itself to be adapted to fit different contexts (Fatras et al., 2022).

5.3 Sensitivity analysis

The motivation to perform a sensitivity analysis is threefold: i) to gain insight in how patterns and emergent behaviours are generated by the artefacts built into the model, ii) to examine the robustness of these properties, and iii) to quantify the variability of the outcomes that result from the model parameters (Ten Broeke et al., 2016). In this research it is chosen to perform a Global Sensitivity Analysis (GSA). In GSA the model outputs are analysed by ascertaining the contribution of variation of each input parameter, to the total variance of the output parameters (Ligmann-Zielinska & Sun, 2010). Within GSA a large sample is drawn from the input parameter space and fed back into the model. A benefit of GSA is that it represents real-world, as it allows for the variations of input parameters simultaneously (Zhou et al., 2008). This is preferred to a one-factor-at-a-time (OFAT) method as that does not consider the interactions between the input parameters. The most common indicators are the first and second order Sobol indices (Si and STi, respectively). The first order indices report the fractional contribution of the input parameter to the output parameter, disregarding the interaction with the other input parameters. The second order indices, combines the interaction with the other input parameters with the fractional contribution (Si). The higher these indices are the more influential they are in explaining the variance of the output variable, and the more they influence the model.

5.3.1 Setup GSA

The sample size is determined by the function *n**(2*p*+2) in which *n* represents the base line sample size and where *p* is the number of input variables. It is suggested that a base line sample (*n*) size of <1000 is chosen (Hadjimichael, 2020), however due to the long computational time a smaller *n* is chosen, namely a 100. Moreover, some research has shown that GSA with smaller numbers is feasible (Davis et al., 2017). The analysis will make use of the pyNetlogo package, developed by Jaxa Rozen & Kwakkel (2018). The GSA is performed on the average of each output variable over time, i.e., the average of the value for the entire model run.

A GSA will be performed for 3 artefacts in the model:

I. Household intent
II. Household finances
III. CSP finances

The first two artefacts are chosen since they are the main determinants for both households, that are not a part of the dataset provided by Wolske et al. (2017). The expectation is that the factors, described in Table **5.1**, are the factors that can have the greatest effect on the described output variable, the average intent, and the number of RPV-systems in the model.

Table 5.1

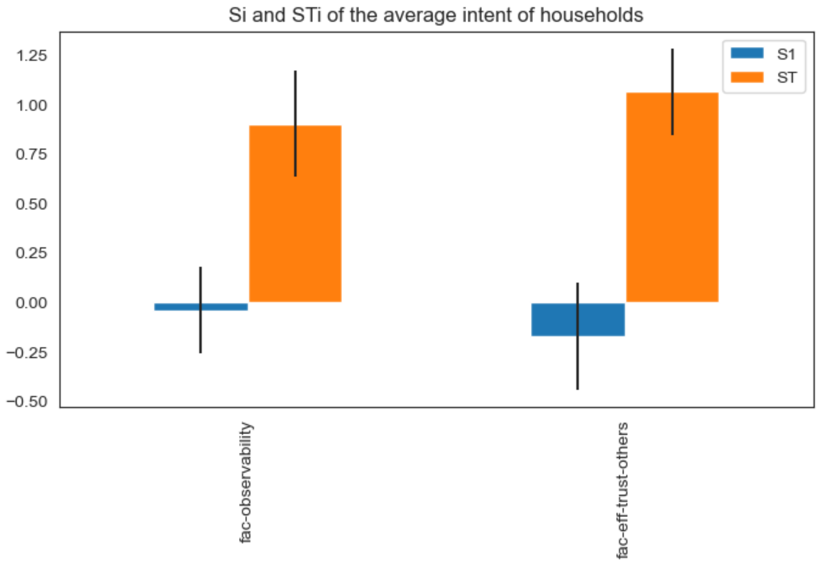
Artefact	Variable	Lower limit	Upper limit
Household intent	fac-observability	0.025	0.075
	fac-eff-trust-others	0.025	0.075
Household finances on #-RPV systems	MW-block-res	100	200
	MW-block-price-res	100	300
	fac-spend-rpv	2	6
	electricity-price	0.15	0.3
	kWh-kW	800	1100
	discount-rate	0.025	0.075
CSP finances on #-developers	MW-block-com	80	160
	MW-block-price-com	500	1500
	avg-cs-size	50	200

5.3.2 Results GSA

The first figure (Figure **5.1**) is the output of the GSA performed on the average intent of the households. Interestingly both factors, the factor of how observability and trust in others within the model have a negative direct (Si) effect on the intent of households. Secondly, the indirect effects of both factors are greater, and in the other direction, i.e., positive, than the direct effects. This is a logical effect of the modelling artefacts, as the two factors described in the figure do not directly influence households' intent, but do influence the attitudes a household has, that in turn determines the intent.

Figure 5.1

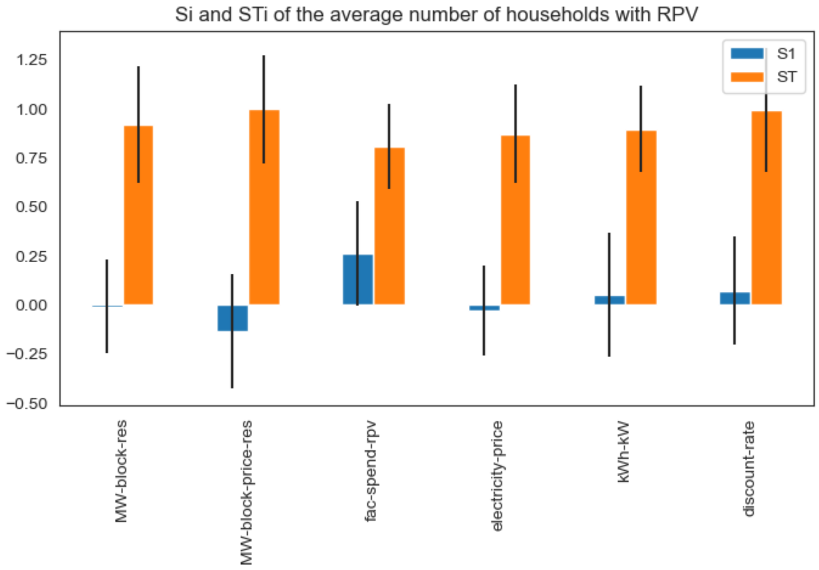
Si and STi of the average intent of households, averaged over the entire model run



The next figure (Figure **5.2**) shows the GSA that is performed on the average number of RPV-systems in the model. Again, as with the intent, most of the effects are indirect. Interestingly, the size of the MW-block does not have a direct effect on the amount of RPV systems being installed, indicating that the range chosen for the MW-block is sufficient for the households that have the intention of installing RPV-system. The prices of the rebates do have an effect, negatively direct, and positively indirect. This is not an anomaly, since both the size of the MW-block and the price, determine a households' willingness to install the RPV-system, but only one time step later they will install it. So, the willingness causes the indirectness of the effect. Logically, the factor of how much of their savings a household is willing to spend on the RPV does positively affect the number of installations.

Figure 5.2

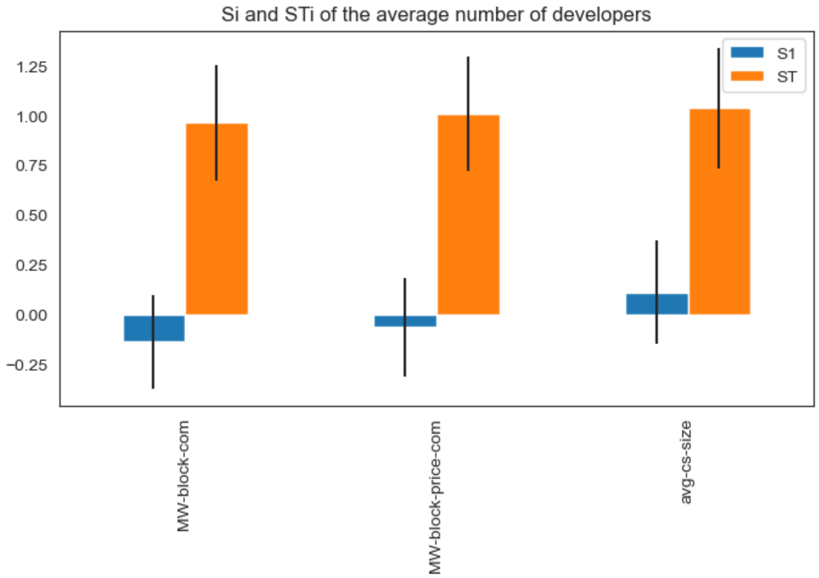
Si and STi of the average number of installed RPV-systems, averaged over the entire model run



The last figure (Figure **5.3**), shows the GSA performed on the average number of developers within the model. Again, the indirect effects are greater than the direct effects, since the modelling has been done in such a way that there is a step between the calculation of the profit margins (which determines a developer's decision to either start a project or stop pursuing one), before the actual initiation of the project. Interestingly, only the size of the project has a positive effect, indicating that a larger project is more beneficial, which could be related to economies of scale.

Figure 5.3

Si and STi of the average number of developers, averaged over the entire model run



5.4 Summary chapter 5

In this chapter the model was verified and validated. The verification steps were carried out in accordance with Van Dam et al. (2012). After a code walk through, agent recording and tracking, single agent testing, and interaction testing the conceptualisations were deemed to be properly translated into the model, and therefore the model has been verified.

6 Results

In this chapter, the result of the model implementation of chapter **4** will be analysed. Firstly, the base scenario will be described to make comparison with the interventions possible. The base scenario in combination with implementation of the interventions will be summarised into an experimental design. The results of the experiments will be analysed by looking at the model outputs of each scenario.

6.1 Experimental design

6.1.1 Base scenario

In the base scenario the parameters are defined as:

- No Expanded Solar-for-all program
- Net-metering is in place, meaning a kWh for kWh trade for households with rooftop solar delivering energy back to the grid.
- No CBC-charge for households with rooftop solar.
- No Community Solar projects.

For both the base scenario and the intervention scenarios the model will be run as follows:

The region that is chosen within the model is the ConEd. The data used within the model come mostly from the years 2020 and 2021. It is therefore assumed that the model represents the State of New York in the year 2021. Since the renewable energy goals set by the State of New York use 2030 as a reference (section **3.3**), it is chosen to set the running time of the model to 10 years. The model will therefore represent the time span 2021-2031. Granted, this is not fully in line with the deadline the State has set, but analysis of the results for 2031 will be considered sufficient. The number of repetitions of will be set to 50 (section **5.1**).

6.1.2 Interventions

In this section the implementation of all interventions will be explained. All the intervention scenarios include the option for households to join a CSP. The region that is once more ConEd, as in the base scenario.

6.1.2.1 Intervention 1

Intervention 1 pertains to the legislation that allows utilities to demand a percentage of the energy generated by CS projects, as a part of the Expanded Solar-for-all program (section **3.5.1**). It is estimated that to accommodate the goals of this legislation, the developers will have to reduce their profit margin by 10 percent. Three strategies that the utilities can opt for will be analysed:

1. Aggressive: After 10 years 100% of the energy generated by CSP's will be delivered to the utilities. Leading to a reduction of 10% of profits for all CSP's.
2. Moderate: After 10 years 67% of the energy generated by CS projects will be delivered to the utilities. Leading to a reduction of 10% of profits for two out of three CSP's.
3. Mild: After 10 years 33% of the energy generated by CS projects will be delivered to the utilities. Leading to a reduction of 10% of profits for one out of three CSP's.

In this scenario no VDER is implemented, and no CBC-charge is imposed on the households. The E-SFA policy will be analysed in isolation, in order to determine its individual effect on decentralised solar in the State of New York.

6.1.2.2 Intervention 2

Intervention 2 concerns the VDER scheme (section **3.5.2**). This will influence the savings made by households on their energy bill, since net-metering is a more profitable option. Two scenarios will be analysed:

> Low: In this scenario the expectation is that the per kWh market price is 60 percent of the base scenario. This number is based on the findings of Darghouth et al. (2011) and will be seen as a 'worst-case-scenario'.
>
> High: In this scenario the expectation is that the per kWh market price is 90 percent of the base scenario. This means that the effect of the policy is less than in the 'Low' scenario.

In this scenario no E-SFA is in place, and no CBC-charge is imposed on the households. The VDER policy will be analysed in isolation, in order to determine its individual effect on decentralised solar in the State of New York.

6.1.2.3 Intervention 3

Intervention 3 pertains to the CBC-charge (section **3.5.3**). The height of the charge differs for each region and whether the second intervention is in place, see Appendix **B** for a full overview of the charges per region. Since the model is built with only two options, " Upstate" and " ConEd", and the price of the charges found in Appendix **B** are specified towards a specific utility, the prices were averaged for the utilities who are active in either the Upstate and ConEd regions respectively. Since only the ConEd region will be analysed, only the prices applicable will in this region will be elaborated on. In Table **6.1**, the prices for when the second intervention is and is not in place are depicted.

Table 6.1

Prices of the CBC-charge for the ConEd and Upstate regions

Region	**CBC-price when VDER is not in place**	**CBC-price when VDER is in place**
ConEd	US$1,09 per kW installed	US$0,545 per kW installed
Upstate	US$0,8 per kW installed	US$0,4 per kW installed

However, in order to analyse the third intervention in isolation, the price will be set at US$1,09 per kW installed, as the VDER policy is not in place. Similarly, the E-SFA policy is not in place either.

6.1.2.4 Combining the interventions

As all the interventions will are implemented or will be implemented by 2023, the intervention will be analysed by combining all the options. The third intervention is constant, since the second intervention will be in place in across all scenarios, albeit it at different levels, but this has no effect on the CBC-charge. The CBC-charge therefore is kept constant at US$0,545 per kW of RPV installed.

In the Table **6.2**, an overview of the experiments can be found.

Table 6.2

Experiment table

Experiment	**Variable**	**Option**	**Replications**
Base	Run time	10 years	50
Intervention 1	Run time	10 years	50
	Utility-strategy	Aggressive; Moderate; Mild	
Intervention 2	Run time	10 years	50
	VDER-exp-rate	Low and high scenarios	
Intervention 3	Run time	10 years	50
	Height of charge	Constant: US$0,545 per kW installed	
Combined	Run time	10 years	50
	Utility-strategy VDER-exp-rate CBC-charge	All combinations of intv1, intv2, and intv3	

6.2 Results models runs

6.2.1 Results base scenario

General

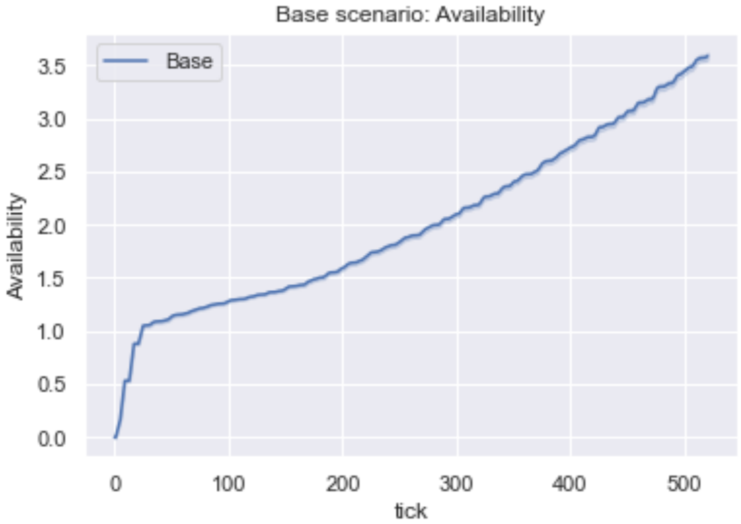
In the following section, the results for the base scenario will be described for each KPI. To reiterate, in the base scenario net-metering is in place, no CBC-charge is imposed, and there is no possibility of joining a CSP. The base scenario is run 50 times, the graphs show the mean (thick line) and the corresponding 95% confidence interval (hue surrounding mean line). Most KPI's do not have a great spread, indicated by the relatively small size of the surface of the confidence interval. This shows that most of the model runs perform roughly the same.

Availability

The first KPI, Availability, measures the amount of renewable electricity that is generated, and consequently consumed, as a percentage of the total electricity consumption. It can be seen that a sharp increase takes place from the start of the model (Figure **6.1**). This is because households will only start looking to considering their electricity procurement after an assigned number of weeks. This means that all households who have the intention to install RPV and the means to do so from the start of the model run, all are "waiting" for the number of weeks to be over. Consequently, they immediately install RPV when they can, causing a surge of RPV installations in the model, resulting in a steep increase of renewable electricity in the system. After this initial surge, a steady increase in renewable electricity can be witnessed, as a result of the increase of renewable electricity generated by RPV systems.

Figure 6.1

KPI: Availability in the base scenario



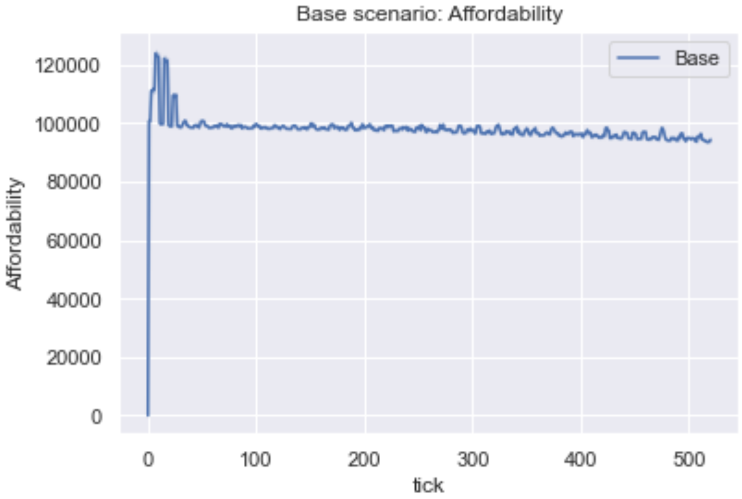
Note: Availability measured as percentage (%) of RE of the total demand in the model.

Affordability

The second KPI, Affordability, measures the average spending of households on their electricity procurement, for each week (tick). This includes their electricity bill, and the costs of installing a RPV system. Again, the graph shows a sharp increase and some oscillation at the start of the run (Figure **6.2**). At time zero, households have not calculated their electricity bill and no installation costs are being made for RPV systems. After one week (one tick), household will all calculate their electricity bill, causing part of the spike in the Affordability KPI. The higher values at the beginning of the model, up to around thirty weeks, can be explained by the high number of RPV systems being installed. After thirty weeks, the KPI remains relatively the same, with some slight increases, caused by the installation of a small number of RPV systems. The overall downward slope the line follows, can be attributed the reduction of the electricity bills of households who have installed RPV systems. Part of the decrease could also be attributed to the decrease in the installation costs of PV systems (Equation **4.1**).

Figure 6.2

KPI: Affordability in the base scenario



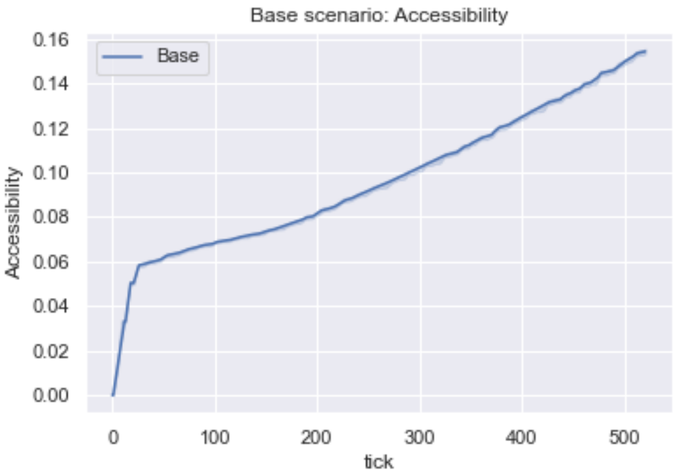
Note: Total spending on electricity procurement, in US$ per week.

Accessibility

The third KPI, Accessibility, measures the diversity index of the model, which is a number between zero and one. The higher the number, the more diverse the electricality production mix is. The graph shows an almost identical path as the Availability KPI (Figure **6.1**). This is due to the operationalisation of both KPI's, since the Accessibility KPI is a measure of the number of households installing a RPV system in the base scenario, and the Availability KPI measures the amount of electricity that is consumed by household using such a system, as a percentage of the total amount of electricity consumption in the model. These two KPI's are thus directly related to one another.

Figure 6.3

KPI: Accessibility in the base scenario



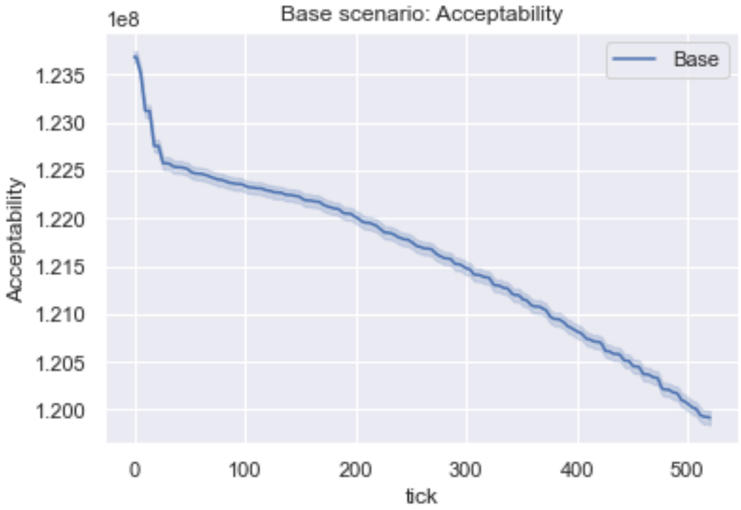
Note: Diversity index, number between zero and one.

Acceptability

The fourth KPI, Acceptability, measures the amount of GHGs in CO_2 equivalent that is emitted which can be attributed towards an average household electricity consumption each week. The graph shows a steep decrease in the first weeks of the model runs (Figure **6.4**). This again is linked to the surge of RPV installations in the first couple of weeks. This graph is in fact a mirror image of the Availability graph (Figure **6.1**) or Accessibility graph (Figure **6.3**). As the amount of RPV systems increase, the CO_2 emissions will decrease, as RPV systems on average generate one-fifth of the emission of traditional electricity mix in New York (IPCC, 2014; EIA, 2021b). To clarify, no GHGs are emitted during the generation of solar electricity, but there are lifecycle emissions associated with collar energy generation (IPCC, 2014). For instance, during production and transportation of the panels.

Figure 6.4

KPI: Acceptability in the base scenario

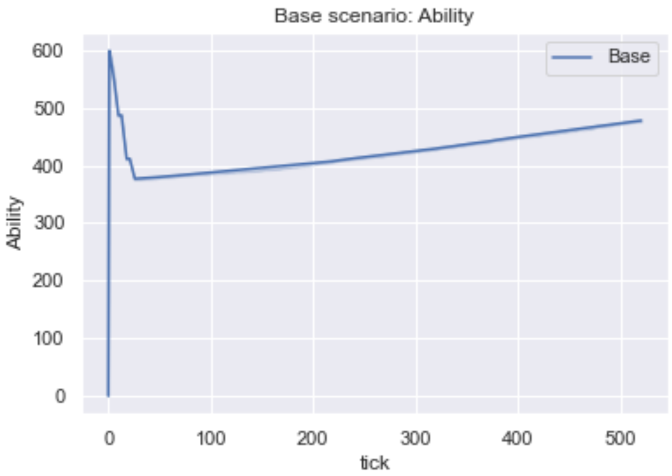


Ability

The fifth KPI, Ability, represents the number of households capable of installing a RPV system or join a CSP. In the base scenario there is no CSP option, so this will be left out of the equation. Again, a sharp increase can be seen at the start of the graph (Figure **6.5**). In the model, the project costs of households are initially zero, as household do not immediately evaluate their electricity procurement. However, they do have a positive savings account. This means that some households will be counted towards this KPI as being able to install their desired RPV system, while the costs are still zero. However, when the project costs are calculated, when the households consider their electricity procurement, it might turn out that these households are actually unable to install their desired RPV system due to limited savings. After this calibration, the model shows that around 300 households are able to make the investment. Thereafter, a steady increase can be seen, indicating that more households are able to make the investment. This can be attributed to the decrease in the costs of installation (Equation 4.1) and the increase in household savings.

Figure 6.5

KPI: Ability in the base scenario

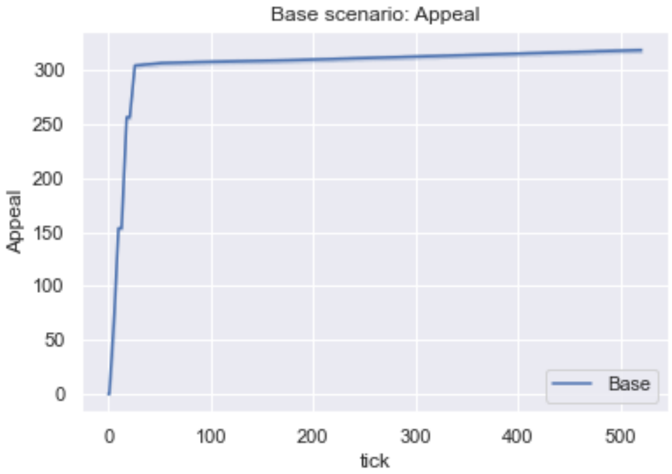


Appeal

The sixth KPI, Appeal represents the number of households who can make a positive return on their RPV investment, i.e., have a positive NPV, or CSP investment (for CSP the NPV is always positive as there is no initial investment needed, and bill reductions are guaranteed). In the base scenario there is no CSP option, so this will be left out of the equation. Again, the initial surge of people being able to make a positive return investment is caused by the "waiting" that is implemented (Figure **6.6**). Interestingly, the amount of people with a positive NPV seem to not increase as fast as the people being able to make the investment that is needed for a RPV system.

Figure 6.6

KPI: Appeal in the base scenario



6.2.2 Intervention 1

General

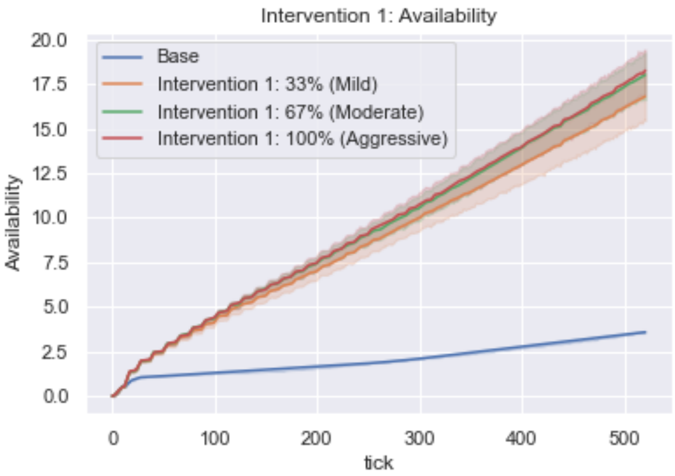
The first intervention allows the utilities to procure the electricity generated from the CSPs and is implemented in the model under three different scenarios as explained in section **6.1.2.1**, and represents the Expanded Solar-for-all (section **3.5.1**). As explained in the description of the results of the base scenario, the Availability, Accessibility, and Acceptability all follow a similar path, caused by the number of RPV systems in the model. It is therefore chosen to only from here on describe only one of these KPI's, Availability. Furthermore, the KPI Affordability, Ability, and Appeal will be discussed. All graphs for the other KPIs can be found in Appendix **E**.

Availability

In Figure **6.7** it can be seen that the amount of electricity produced by renewables is clearly higher than in the base scenario. The differences between the strategies (Mild: 33%, Moderate: 67%, Aggressive: 100%) represent the amount of electricity that will be bought by the utility after 10 years. This will lead to a reduction of income for the developers, as they need to reduce their margins to accommodate the utility (section **3.5.1**). Counter to what initially was expected, is that in the Aggressive scenario, when the utilities buy all the electricity of CSPs after 10 years, there is more RE production than when the Mild strategy is chosen. Since the expectation was that the business case for developers was less attractive, less developers would start a CSP, resulting in less RE generation. However, no noticeable difference can be seen between the Moderate and Aggressive scenarios. A large part of the higher availability percentage can be explained by the introduction of CSP. As can be seen in Figure **6.8**, when CSP would be added to the base scenario, the base scenario has a higher percentage of RE generation in the system.

Figure 6.7

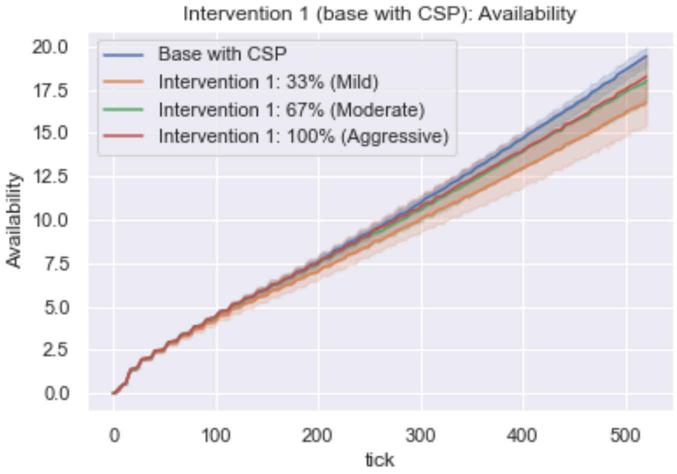
KPI: Availability with the first intervention in place



Note: Availability measured as percentage (%) of RE in the model.

Figure 6.8

KPI: Availability with the first intervention in place, and CSP is included in the base scenario



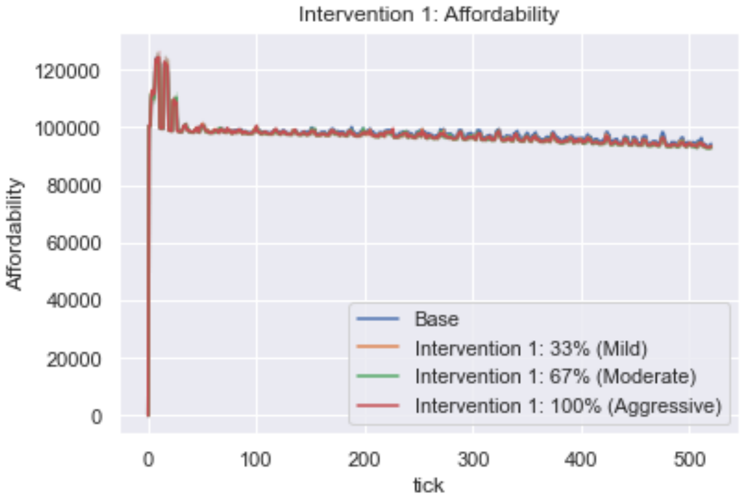
Note: Availability measured as percentage (%) of RE in the model.

Affordability

As can be seen in Figure **6.9**, nearly no differences are present in the Affordability KPI, indicating that there are no significant changes in the electricity procurement costs of households. The graph of the base scenario lies a little higher than the intervention scenarios. However, they are minute. This means that there are no significant financial effects felt by households when the Expanded Solar-for-all program and the option for CSP are implemented.

Figure 6.9

KPI: Affordability with the first intervention in place



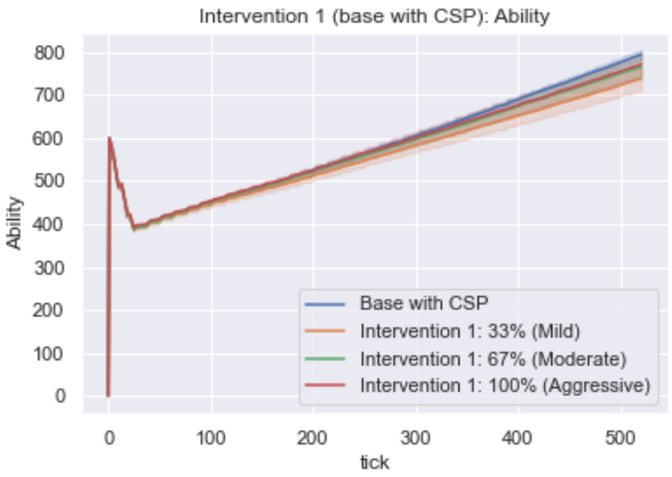
Note: Total spending on electricity procurement, in US$ per week.

Ability

As can be seen in Figure **6.10**, the number of people being able to install a RPV system or join a CSP is initially the same when the option for CSP is introduced, along with the strategies of the utilities to buy the electricity from the CSP. This is due to the fact that initially there are no CSPs in the model, resulting in only the counting of people being able to install a RPV system. Gradually, CSP developers will start projects, causing steady increase of households joining CSPs. The KPI is operationalised such that people joining CSPs are what differentiates the base scenario and intervention scenarios (Equation **4.10**). Again, the strategy of the utility with which only 33% of the electricity will be bought after 10 years (Mild strategy), results in less people joining a CSP than when the utilities opt for the 67% or 100% strategy (Moderate or Aggressive strategy).

Figure 6.10

KPI: Ability with the first intervention in place

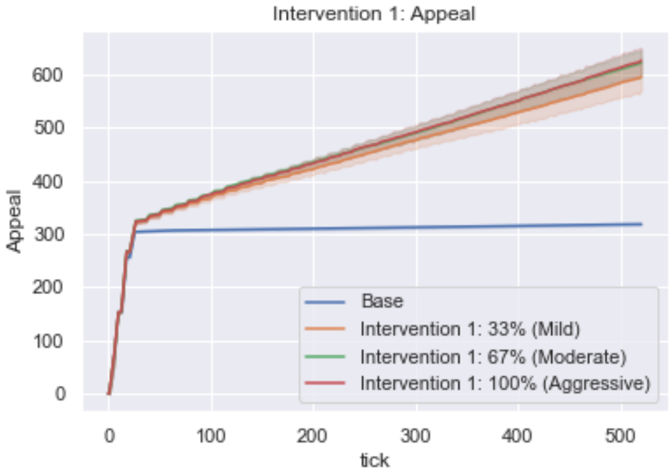


Appeal

Similar as with the Ability KPI, the path that the graph follows at the start of the model with the first intervention in place, is the same as in the base scenario, as a result of no CSPs being present in the system (Figure **6.11**). Again, just as in the Ability KPI, after the first CSPs start to be developed by the model, a steady increase of people joining CSPs can be witnessed.

Figure 6.11

KPI: Appeal with the first intervention in place



6.2.3 Intervention 2

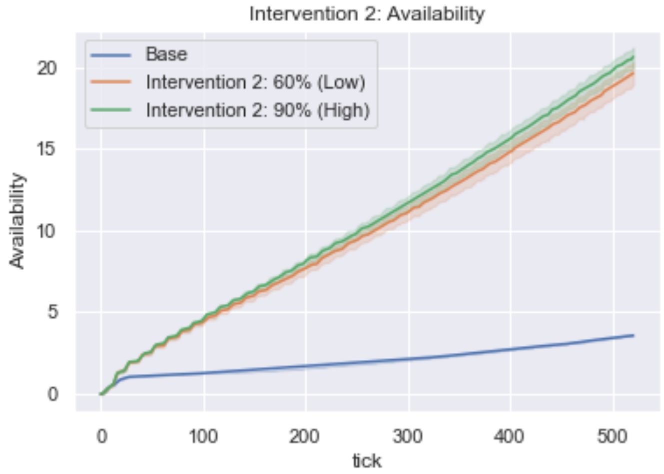
The second intervention represents the introduction of the VDER scheme into the model under 2 different scenarios as explained in section **6.1.2.2.** A low and high scenario are analysed. In the low scenario it is expected that the electricity households produce is only worth 60% of the base scenario. For the high scenario, this is 90%. As with the first invention, only the Availability, Affordability, Ability, and Appeal will be discussed. All graphs for the other KPIs can be found in Appendix **E**.

Availability

In Figure **6.12**, it can be seen that the percentage of RE in the system steadily increases over the model run. Again, a large part of this increase can be attributed to the introduction of CSP, as can be witnessed when the option for CSP is included in the base scenario (Figure **6.13**). However interestingly, the implementation of the second intervention leads to a higher percentage of RE in the system. This is counter to what was expected but could be explained by the potential increase in people wanting to join CSPs. If the households able to install RPV but experience a decrease in potential benefits due to the VDER, they might opt for joining a CSP. This results in a higher potential profit for CSP developers, as more households are willing to join a CSP, strengthening the position for CSP developers. However, this is only the case in the scenario where the value of a households own produced electricity is 90% off the base scenario. Therefore, it can be explained that a too large reduction in the benefits of households who want to install RPV, the increase in households joining CSPs, resulting in an increase in RE in the model, will be offset by the reduction in RPVs.

Figure 6.12

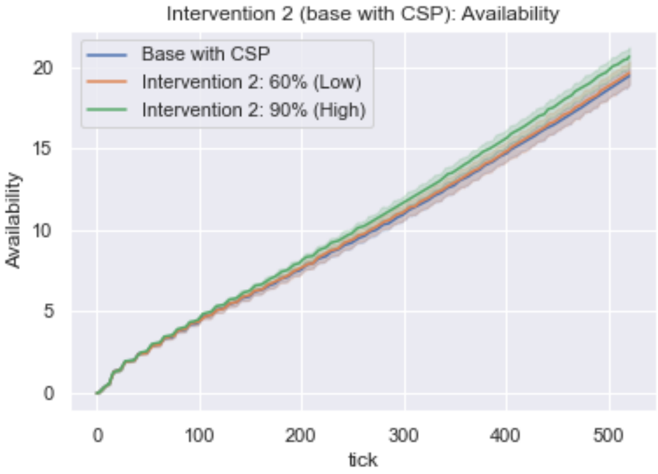
KPI: Availability with the second intervention in place



Note: Availability measured as percentage (%) of RE in the model.

Figure 6.13

KPI: Availability with the second intervention in place, and CSP is included in the base scenario



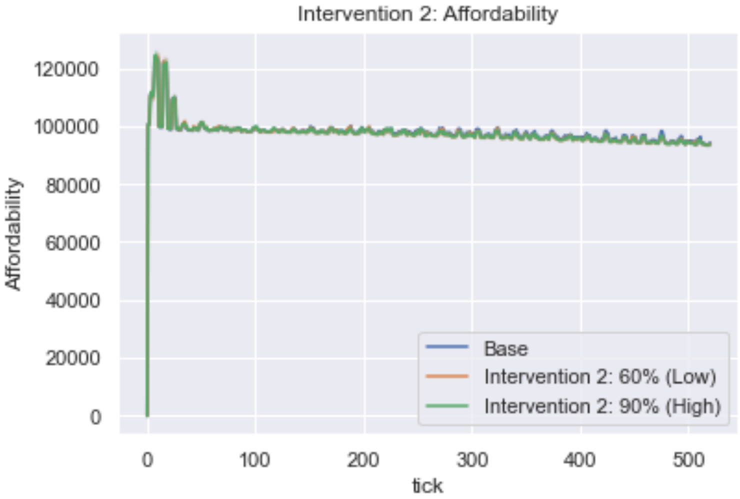
Note: Availability measured as percentage (%) of RE in the model.

Affordability

Similar as with the implementation of first intervention, the Affordability KPI does not change significantly when the second intervention is in place (Figure **6.14**). Again, the graph of the base scenario lies a small fraction higher than in the intervention scenarios. This indicates that households will not experience a significant reduction on their electricity procurement costs.

Figure 6.14

KPI: Affordability with the second intervention in place



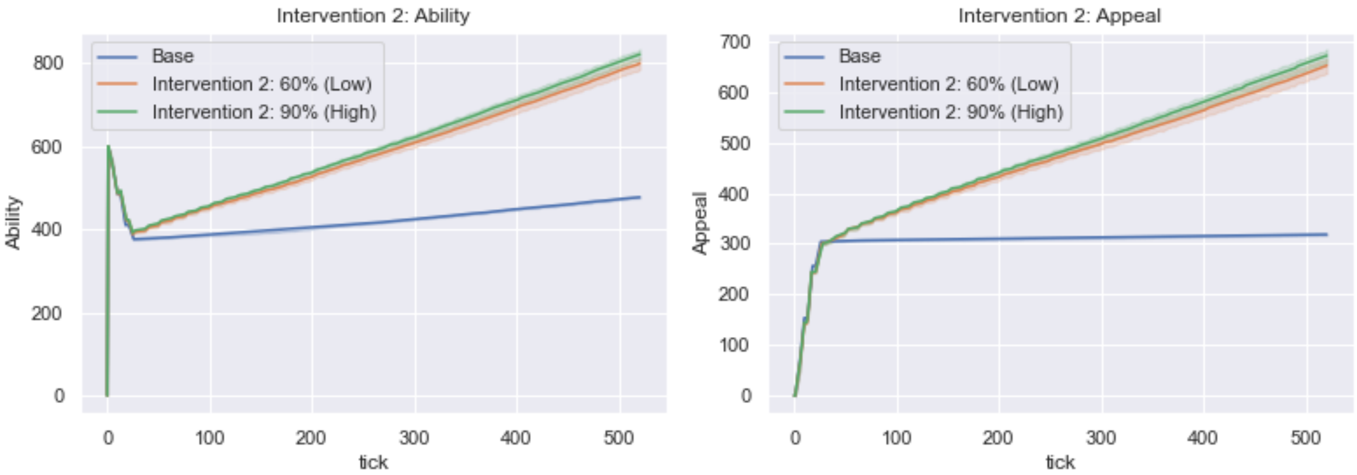
Note: Total spending on electricity procurement, in US$ per week.

Ability and Appeal

As can be seen in Figure **6.15**, a steady increase can be seen for both KPIs in both scenarios of the second intervention. As expected, in the scenario where the VDER causes a bigger loss in value for a households' own produced electricity, i.e., the "Low" scenario, the KPIs scores lower than in the scenario where the loss is not as significant, i.e., the "High" scenario. However, it is interesting that this occurs, since households who do not have the means of installing an RPV system still have the option to look for a CSP. As explained in the Availability section of this intervention, this can indicate that the position of the CSPs can be strengthened by an increase in the potential of households wanting to join a CSP, but if the loss in value reaches too high a point, the cumulative number of households installing RPV or joining CSP will decrease. This shows that there is an optimisation possible when it comes to implementing the height of the VDER rates. Similar as with the Ability KPI, it can be seen in the right graph in Figure **6.15** that the "High" scenario results in more people either installing RPV or joining a CSP.

Figure 6.15

KPI: Ability and Appeal with the second intervention in place



6.2.4 Intervention 3

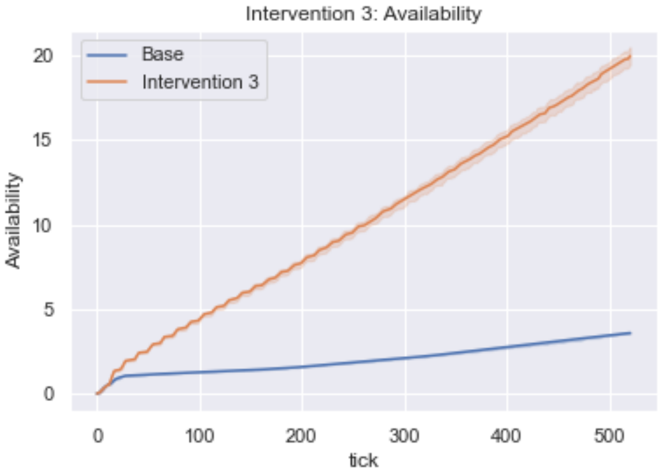
The third intervention represents the introduction of the CBC charge, as explained in section **6.1.2.3.** After implementation of the third intervention into the model, a difference across all but the Affordability KPI can be seen when comparing the model in which intervention 3 in place with the base scenario. However, this can again mostly be explained by the introduction of the CSPs. If we consider the base scenario with the possibility of CSP, between the base scenario and the intervention 3 scenario, only marginal differences can be observed. Only the Availability KPI will be used as an example in this section. All graphs for the other KPIs can be found in Appendix **F**.

Availability

As can be seen in Figure **6.16**, an increase in RE in the model is present when the CBC-charge is implemented, in combination with the option of CSP. However, as can be seen in the Figure **6.17**, the differences between the base and intervention 3 scenarios are almost non-existent with the introduction of CSP in the base scenario. This indicates that the effect of the CBC-charge has little effect on the amount of RE in the model. Nevertheless, interesting to highlight is the fact that the introduction of the charge does seem to result in a higher percentage of RE in the model, however minutely.

Figure 6.16

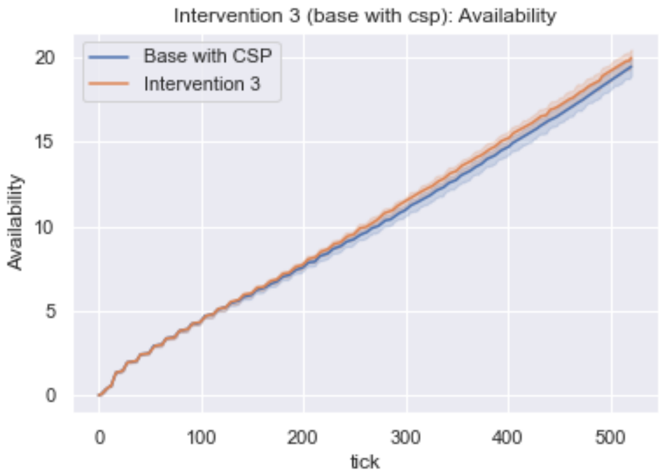
KPI: Availability with the third intervention in place



Note: Availability measured as percentage (%) of RE in the model.

Figure 6.17

KPI: Availability with the second intervention in place, and CSP is included in the base scenario



Note: Availability measured as percentage (%) of RE in the model.

6.2.5 Combined interventions

Since the implementation of the policies do not happen in isolation in the State of New York, but will be in effect simultaneously, analysis of the combination of the intervention will be conducted. As explained in section **6.1.2.4**, all of the combinations of the three interventions have been run in the model. However, since this results in a total of six policy scenarios (3 x 2 x 1), describing all differences between all six scenarios is deemed unnecessary. It is therefore chosen to reduce the number of scenarios to four. As explained in the description of the first intervention the scenarios for the Moderate (67%) and Aggressive (100%) score relatively the same across all KPIs. Therefore, it is chosen to only analyse the Mild and Aggressive scenarios, in combination with the Low and High combinations of the second interventions. The third intervention is constant, since the second intervention will be in place in across all scenarios, albeit with different effects. The value of the CBC-charge is set at US$0,545 per kW installed (Table **6.1**).

An overview can be seen in the table below (Table **6.3**). The difference across the combinations will be described for each of the KPIs that were analysed during for the description of the first and second interventions: Availability, Affordability, Ability, and Appeal.

Table 6.3

Combinations of interventions used for further analysis.

Combinations	**Intervention 1**	**Intervention 2**
1	Mild	Low
2	Mild	High
3	Aggressive	Low
4	Aggressive	High

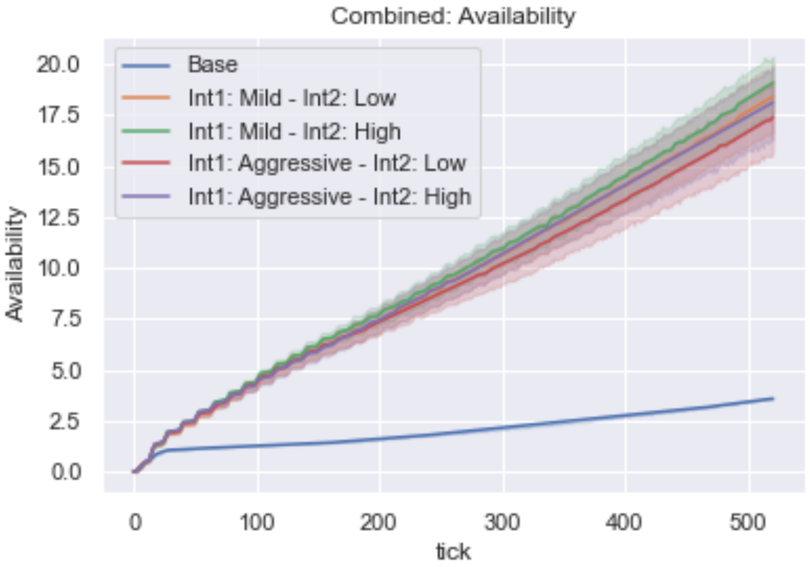
Availability

When just the first intervention was in place the Mild scenario, in which the utilities only bought 33% of the electricity generated by CSPs after 10 years, resulted in a lower percentage of RE in the system than when the Aggressive (100% after 10 years), was in place. However interestingly, as can be seen in Figure **6.18**, the Mild scenario scores better in combination with the second intervention, both in the High and Low scenarios. Admittedly, in the Mild-Low scenario the differences are minute. For both the Mild-High and Mild-Low scenarios the percentage RE in the system lies between 17,5 and 20 percent, where this was between 15 and 17,5 percent when just the first intervention was in place (Mild). This indicates a form of tipping point within the model, when where both interventions are in place households and developers respond differently than when the intervention is analysed in isolation. It is important to note that not only the Mild scenario scores a higher percentage when combining interventions, the Aggressive scenarios seems to remain at the same percentage (around 17,5%) as when the intervention was analysed in isolation. Indicating that in that scenario the second intervention has less impact.

For the second intervention the High scenario results in a higher percentage RE in both scenarios of the first intervention, which is what was expected after analysing the results of the second intervention.

Figure 6.18

KPI: Availability across the four scenarios



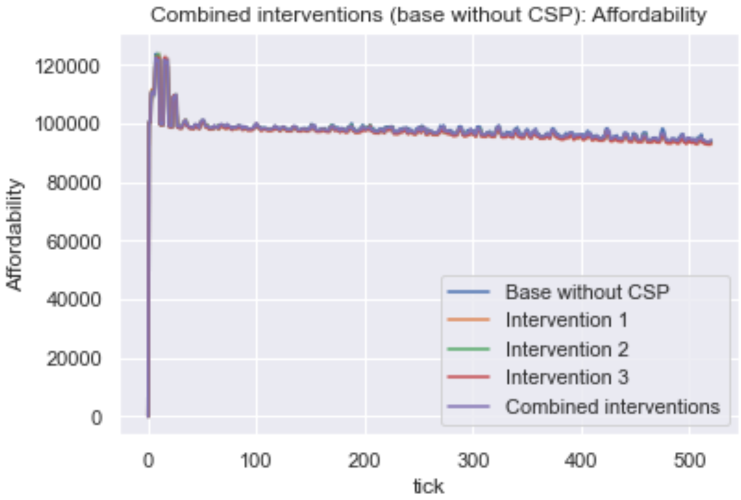
Note: Availability measured as percentage (%) of RE in the model.

Affordability

As can be seen in Figure **6.19**, the differences across the four combination scenarios are minute. Indicating no differences in the finances when the interventions are combined.

Figure 6.19

KPI: Affordability across the four scenarios



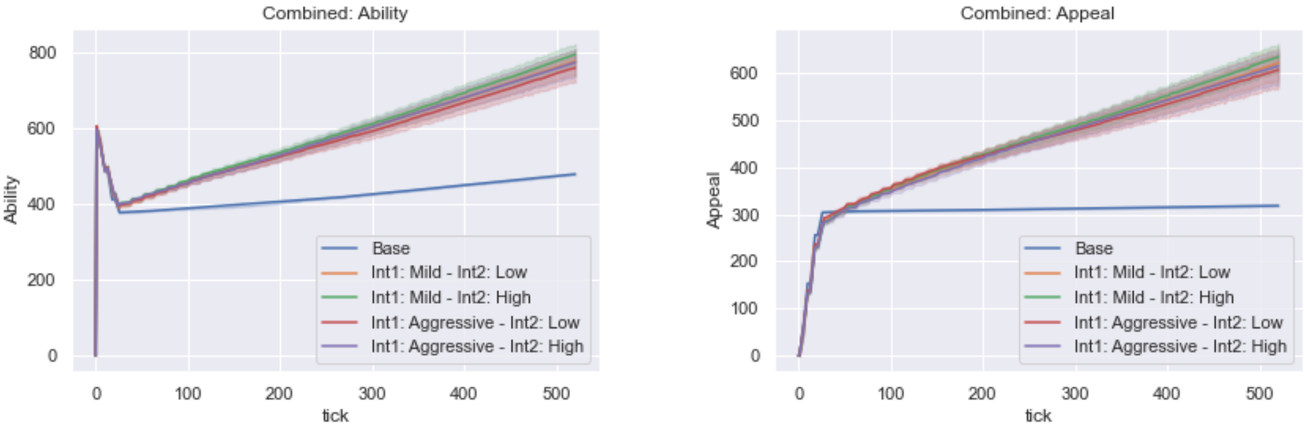
Note: Total spending on electricity procurement, in US$ per week.

Ability and Appeal

For both the Ability and Appeal (Figure **6.20**) KPIs, a similar reasoning can be given for the fact that the Mild scenario scores better, as with the Availability KPI.

Figure 6.20

KPI: Ability and Appeal across the four scenarios



6.3 Summary chapter 6

The sixth chapter presented the model results of the experiments which were run in the model. For the comparison of these experiments to the current, business as usual, scenario a base scenario was run, of which the results were elaborated on. It was found that the Availability, Accessibility, and Acceptability followed a similar path, caused by a modelling artefact. Thereafter, the experiments were run. These experiments represent the three policy instruments proposed by the State of New York and were implemented across different scenarios. In order to test the effect of singular instruments, the policies were first introduced into the model in isolation. Finally, the instruments were simultaneously introduced in the model to analyse whether there were interaction effects between them. Further interpretation of and reflection on the results will be done in section **7.1**.

7 Discussion

In this chapter the choices made within this research will be reflected on. The methodology chosen will first be elaborated on to provide context and consideration when interpreting the results in the subsequent section. The results will be reflected on which will aid in the understanding of how these results came to be. The discussion will be concluded with how this research has contributed to the scientific literature.

7.1 Interpretation and reflection on the results

The biggest changes across all scenarios can be attributed to the introduction of CSP into the model. Naturally, the operationalisation of the Ability and Appeal KPIs, which include the number of households who are signed to a CSP, score higher in the policy scenarios as compared to the base case. However, availability, accessibility, and acceptability score also better when CSP is introduced. As laid out in section **6.2.2**, these three KPIs seem to be following a similar path, indicating that they are based on the same modelling artefact, just on different scales. Interestingly, the affordability of electricity procurement does not seem to change for households with the introduction of CSP.

Apart from the introduction of CSP, it is the first intervention that leads to the most significant changes within the model. As mentioned, the interesting aspect is that when the utilities are able to obtain all of the RE from CSPs over the course of 10 years (the 'Aggressive' scenario), RE will be more abundant in the system. This could be explained by households who are unable to join a CSP, who will wait out until their business case for a private RPV system becomes positive. Unlike the other two scenarios however, under this scenario the amount of RE in the system is lower than in the base case (if CSP is available in the base case). This shows that that no matter how the E-SFA is implemented, a reduction in RE within the system will be present. To reflect, the goal of this policy was to make it possible for LMI-households to profit from the generation of RE by CSPs. As the model does not include these households specifically, they are not represented as such in the results. However, an interpretation could be made on how these LMI-households are affected. The aggressive scenario implies that all the electricity from CSPs is spoken for by the utility, who will in turn redistribute the benefits to LMI-households. This means that the RE, that is not generated by RPV, can be indirectly attributed to LMI-households. So, in terms of achieving this goal the utility, the utility can be seen as successful. However, households that are currently within the model could also be LMI-households, who are able to join CSPs without the utility as a middleman. This could lead to the utility essentially 'double-counting' the progress they have made in making RE available for a broader demographic.

The scenario in which the second intervention was put in place, did show the interesting result of the importance of the impact the VDER-scheme had on household financials. In both cases (high and low) an increase could be seen in RE within the system. This indicates a shift from RPV to more CSP in the model, as RPV becomes less attractive. However, whilst the shift to CSP is able to recover the reductions of RE generation within the system and even add RE generation. However, a too big a decrease in the value of kWh's generated by RPVs almost fully negates this effect. To reflect, this policy is meant to make the rebate structure of uploaded electricity generated by RPVs fairer. This means that several aspects of the electricity that is generated is included, such as when and where. In the model of this research this aspect of the VDER is not included however, only the expected financial impacts this policy instrument has, has been taken into account.

The introduction of the third intervention, does not have a significant impact on the model outcome across all KPIs. This can be explained by the size of the payment households have to make monthly when the CBC-charge is implemented. Households have on average a relatively small RPV-installation, and the price per kW installed is around US$0.50. Meaning even if a household has an installation which is exceptionally large, e.g., 20 kW, their CBC-charge only amounts to US$10. However, a slight increase can be seen in terms of RE within the system with the introduction of this charge. RPV systems do become less attractive for households, which can lead to households broadening their horizon and opting for joining a CSP. To reflect, the goal of this intervention is to reduce some of the losses that utilities experience due to limited recovery of fixed costs from households who generate their own electricity. Since the utilities do recover fixed costs when households are signed to CSPs, as this is merely an administrative subscription and the electricity will still be provided by the utility, the utility will achieve its goal for retrieving some of the fixed costs. Firstly, by the direct CBC-charges income they receive by households, and secondly through the households who opt for joining a CSP instead of RPV in the new scenario.

When combining all three interventions, the most interesting result was that when the utilities opt for a mild tactic when implementing the E-SFA policy, meaning that only 33 percent of the electricity generated by CSPs, in combination with the VDER structure, will lead to a better outcome than when an aggressive approach is chosen. This indicates that there is a trade-off between the two instruments.

The results also can provide some reflections on the goals set by the State of New York, as described in section **3.3.1**. In terms of reaching the goal of 50% of the state's energy coming from renewables, the introduction of CSP helps to getting closer to that goal. However, the combined implemented policies do hinder the reaching of this goal. This is especially the case in the scenario where the utilities opt for an aggressive strategy, claiming a lot of the CSP's electricity, combined with a low expected value for the VDER. In that scenario only 17% of the State's electricity will come from solar. This does not mean of course that the goal cannot be reached, as other renewable sources are an option, but still, this needs consideration. Even in the best scenario, the State of New York will only have 20% of their electricity coming from decentralised solar. Similarly, the implementation of CSP will lead to a step in the right direction for reaching the climate goals of reducing GHG-emissions by 40% in 2030. In the best scenario there will be a reduction of 16% of GHG emissions and in the worst case 14%. See the graphs in the Appendix **F** for reference.

Interestingly no differences in affordability were observed across all policy scenarios, including the scenario in which the policy instruments were combined. This could be explained that the greatest financial benefits could be made by installing RPV systems. This is an option in the base scenario, as well as in the policy scenarios. The CSP option provides considerably fewer financial benefits and makes up for only half of the populace participating in RE generation, shown by the Ability and Appeal KPIs. The financial benefits are averaged across the entire population, 2000 households, rendering the effects of the policy instruments are unnoticeable.

7.2 Reflection on the methodology

In this section the decisions for opting for the ABM approach, the chosen interventions, the case of New York, and the theoretical background will be reflected on. All these aspects where a part of the Design Science Research framework explained in section **1.3**. The use of this framework was mainly used as a method to structure this research, which also served as a self-edification method.

7.2.1 Agent-based modelling

The motivation to choose an agent-based modelling approach, as explained in section **1.3**, was to analyse the impact of individual agents on the system level. Part of the reasoning for choosing ABM, was that it allows for agents in the model to interact with each other and their environment. This can result in unexpected emergent behaviour, which could lead to new insights (Van Dam et al., 2012). However, the interactions that were modelled are limited. This partly explains the limited differences in the model outcomes under each policy scenario. The model has not produced any emergent behaviour that is visible based on the KPIs.

Moreover, ABM allows for the analysis on different scales (Gilbert, 2019). In the model of this research this would entail household- and developer characteristics, as well as on the system level, i.e., the electricity market of the State of New York. In this research this is not used however, only the final impact on the system level has been analysed using the six KPIs. The characteristics of the population within the model, i.e., the households, follow a normal distribution. This means that during every initiation of the model a similar population is generated. The additional value of ABM is the allowance of creating different populations, which could lead to the model responding differently under the set of policy scenarios. This has not been utilised in this research.

Nevertheless, the use of ABM has still had its benefits. It allowed for the creation of an environment that represented the households of New York, along with the regulations that effect the households' decision making. Although the number of interactions was limited, these interactions still created a form of social interactions through which decision-making was influenced. This led to the households not only making decisions based on a cost-benefit analysis using the rebate structures and incentives present in the State of New York, but on their surroundings as well.

Furthermore, two types of agents were used in the model: households and developers. The focus of this research lied on the households. The developers responded to the intentions of households of joining a CSP and the policies in place, creating a form of market response. The developers were modelled with a pure opportunistic and capitalistic approach. Developers only used a cost-benefit as a basis for their decision, no environmental concerns were considered. It has been shown that companies not only have making a profit as motivations but also other factors such as social impact (Parry, 2012; Bansal & Roth, 2000). However, for the purpose of this research it was deemed sufficient to only include a financial motivation. This is in part done for simplification of the model, but also since no literature was found that looked at the motivations of such developers. Moreover, an argument could be made concerning the philosophy of the United States economy. Roger L. Martin (2020) called it an 'obsession with economic efficiency'. In this efficiency view, the social responsibility of a firm is to increase their profits (Friedman, 1970), without limits other than the ones provided by the law or common decency (Jensen, 2010). Rodriguez et al. (2002), argue that a shift is needed from the focus of profits towards a focus that also includes sustainable practices. However, profits remain an important factor of a firms' raison d'être. This was deemed a sufficient justification for modelling the decision-making process of CSP developers a purely financial one.

7.2.2 Case of the State of New York

The choice for the case of the State of New York was in part chosen as it is one of the leading states in the US, in terms of renewable energy production. Decentralised solar electricity generation is no longer a technological niche innovation, but a more a market niche with an established market share (Schot & Geels, 2008). The fact that the decentralised solar market has been established, allowed for easy data collection on subjects as installed capacities, future predictions, and subsidy schemes. Moreover, scientific interest in this market has caused the body of literature concerning decision-making of New York households concerning their electricity supply more abundant.

7.2.3 Interventions

The decision to analyse the three policies in this research is to a certain extend arbitrary. These policies were subject of the discourse on relevant websites on the internet. These interventions were at the time of this research, proposed and partly put in place by the state government, and therefore at the forefront of political and professional discussion. This makes the decision to analyse these policies, a decision based on contemporary relevance more than anything else. However, as will be explained in section **7.3**, the chosen policies instruments are in hindsight of relevance, not only for the analysis of the New York case, but of relevance within scientific literature.

7.3 Scientific contributions

The approach in this research was the design science research of Hevner & Chatterjee (2010), as explained in section **1.3**. Part of this approach was grounding the research in relevant theories and experiences, as part of the Rigor cycle. The reasoning being that in doing so, the gaps within these theories can be identified in addition to the gaps described in section **1.2**. These gaps pertained to: i) using the energy security framework of the APERC on case of the State of New York, ii) how households are effected by policy changes. What follows is how this research has tried to fill these gaps.

The theories that were used in this research were the Theory of Planned Behaviour (TPB) (Ajzen, 1991), Value-Belief-Norm Theory (VBN) (Stern et al.,1999), and the Diffusion of Innovation Theory (DOI) (Rogers, 2003). These theories have been used to complement each other. For instance, TPB is mainly focussed on the consumer behaviour in general, VBN theory has a strong focus on the aspect of values concerning the environment and its impact on a households' decisions. These theories describe the process within an individual more aptly than it does the process of evolution of a specific technology through a society. This is where the DOI of Rogers adds value. Granted, TPB acknowledges the impact of subjective norms, as perceived by the individual, but disregards the impact of communication between individuals in the forming of these norms. This is an aspect thoroughly described in the DOI of Rogers (2003). These theories have been combined by Wolske et al. (2017), into one framework. They have used this framework as a basis for their questionnaire that was aimed at finding determinants for opting for RPV in the US, which has been a fruitful exercise.

This research uses the definition of energy security defined by APERC (2007), which differentiates across the four dimensions. For the operationalisation of these dimensions the approach by Fouladvand et al. (2022) was used. However, with the insights gained by reviewing the questionnaire results of Wolske et al. (2017), it was found that the definitions needed additions. Wolske et al. (2017) found that environmental concerns were not significant determinants for households' decision to install an RPV system in the State of New York. Therefore, additions were made to the KPIs that were based on an environmental approach as seen in Fouladvand et al. (2022), in the form of a financial concern of households. The first being the Ability KPI, which indicates a household's ability to make the initial investment. Similarly, the choice was made to add the Appeal KPI, which measured the potential to make a profit by households on their investment. Additionally, Fouladvand et al. (2022)

used the response of households to potential blackouts, caused by shortages of energy production by a community, as an indicator for Availability. The decision was made to alter the definition of the Availability KPI towards a mere percentage of RE within the system. This is based on the assumption that the grid is always to provide electricity when households are in need of it, as well as the assumption that the households want to make use of the grid when they are in need. This research shows that the use of the KPIs as defined by the APERC, can be adjusted accordingly to accommodate the context of the research in question.

As mentioned in section **7.2.3**, the decision to opt for the three policies in this research was mainly one based on contemporary relevance. However, the analysis of the policies put in place are deemed important when we consider the nature of these policies. For instance, the choice of the state of New York to implement the VDER structure is of relevance. The choice between opting for a net-metering structure or a feed-in-tariff like structure has been a subject of much research, across different contexts or countries (Poullikkas, 2013; Yamamoto, 2012; Górnowicz & Castro, 2020), or even in the United States (Darghouth et al, 2011). Since the policies are recent, and to the best of the researchers' knowledge, no research has been conducted into the shift in rebate structure in the State of New York, the analysis of this policy is of not only contemporary relevance but of scientific relevance as it adds to the scientific body of research by analysing these different structures in a new context.

8 Conclusions and recommendations

In this chapter the central questions of this research will be answered. To achieve this goal, the sub-research questions will be answered first, after which the main research question will be answered. To provide some reflection on the process of this research, the limitations of this study will be elaborated on. The concluding paragraphs will provide some recommendations for policy makers and further research.

8.1 Answering the sub-research questions

In this section the five sub-research questions will be answered.

1. How do households make decisions concerning their electricity supply?

Based on several theories from the academic disciplines in psychology and social sciences, being Theory of Planned Behaviour (TPB) (Ajzen, 1991); the value-belief-norm theory (VBN) (Stern et al.,1999); and diffusion of innovations theory (DOI) (Rogers,2003), conclusions can be drawn on how households make decisions concerning their electricity supply. Firstly, the influence of peers is of significance in the formation of a person's attitude towards environmental behaviours. This can be through the perception of social norms (TPB) or through personal communication (DOI) within one's social network. Secondly, the level at which an individual is informed on decentralised renewable electricity generation is linked to certain demographic factors such as education and socio-economic status (DOI). Thirdly, this information will be processed based on the value set an individual has towards environmental behaviours, such as joining a CSP or installing RPVs (TPB), VBN, and DOI). Lastly, the perceived control an individual has over successfully accomplishing the desired environmental behaviour determines whether an individual will engage in the decentralised renewable electricity generation (TPB). These aspects are related to each other and have been combined into a framework by Wolske et al. (2017), as presented in section **2.2**. This framework has been used in this thesis. Outside of these theories it was found that a major driver were the financial characteristics of the investments that need to be made when acquiring electricity.

2. What does the current electricity market in which community solar and RPV-systems operate in the State of New York look like?

Based on the analysis of the context in which decentralised solar electricity generation in the State of New York, most noticeably is the fact that utilities still hold a great deal of power. Their motives mainly being financial gain, they have the incentive to maintain at the centre of the system. They leverage their market power into political power seemingly limiting the growth of distributed renewable electricity, by actively lobbying against policies that increase market liberalisation in the state. The policy that is relevant to CSPs is mainly the MW-block structure and its accompanying adders. These provide great incentives for developers, as the rebates per kW are favourable. This is also true for households, the MW-block provides bountiful opportunities for households who want to install RPV. In addition, the tax-incentives made available by both the state and the federal government, make for an even more attractive business-case for households.

3. How can energy security be defined in the State of New York?

With the use of Fouladvand et al. (2022), the four dimensions of energy security have been operationalised into KPIs to evaluate the energy security in the State of New York. Since Wolske et al. (2017) have shown that the environmental concerns of New York households are not significant, additions were made to the KPI operationalisation of Fouladvand et al. (2022). Acceptability was defined by using CO_2-emissions as a proxy by Fouladvand et al. (2022). So, it was decided to add the

Appeal KPI to reflect the more financial driven motives of households, by defining it as the amount of households who can make a positive return on their investment. This meant households able to make a positive net-present value on their RPV installation, plus the households who were signed up to a CSP. Similarly, affordability is not only a term of how much money is spend on weekly electricity procurement, therefore it was decided to add another KPI. This was defined as the number of households who were able to make the initial investment that is needed for their RPV system, plus the households who were signed up to a CSP.

4. What are the proposed policy instruments, and how will they affect the decision-making process of households?

Three policies have been proposed and partially implemented in the state.

I. The Expanded Solar-for-all (E-SFA) program: an effort to provide cheaper electricity for low-to-middle income households. This comes at a cost for the CSP developers, resulting in less profits.
II. The Value of Distributed Energy Resources (VDER) structure. Currently net metering is in place, but this new VDER resembles a feed-in-tariff structure.
III. Customer Benefit Contribution (CBC). A monthly charge imposed on households with RPVs.

These three policy instruments were found to have mostly a financial impact on households or CSPs.

5. What is the impact of decentralised solar electricity generation on energy security under different policy scenarios?

After the experiments have been run, some conclusions can be drawn. First and foremost, the introduction of CSPs has a positive effect on all but the affordability KPI. This can be, in part, attributed to the additional demographic that can be reached with the inclusion of CSP, being households that do not have sufficient funds or are hindered by practical factors such as unsuitable housing.

The E-SFA seems to the biggest impact on the availability of RE in the system. It reduces the amount of RE in the system, across all scenarios. However, the choice of strategy by the utility is of importance. The implementation of the VDER structures resulted in a slight increase of RE energy in the system, and the CBC-charge had almost no effect. All three policies have no impact on the average costs for electricity procurement of households.

However, as the policies have already been implemented, it would be of more value to discuss the impact of the policies when they are implemented simultaneously. The key takeaway is that these policies have a mediating effect on each other. When utilities opt for a mild strategy, i.e., only 33% of the electricity generated by CSPs will be sold to utilities, the results show that more RE will be produced in the system compared to an aggressive strategy (100%), when combining the three interventions. This is the other way around when the E-SFA is put in place in isolation.

8.2 Answering the main research question

This research set out to analyse the decentralised solar electricity generation system in the State of New York. Two main goals were important: i) how can the system be analysed in terms of energy security, and ii) how will household decision making be affected under different policy scenarios. This culminated into the following main research question: '*What are the effects of selected policy instruments concerning* ***decentralised solar electricity generation*** *on energy security in the State of New York?*'

This question is twofold, first the current system in which decentralised solar is situated needed to be described. This in part includes the households involved in this system, and the decisions that they make concerning their electricity procurement. Several theories from the field of psychology and social sciences were used to construct a framework that depicted the decision-making process that households go through. It was found that social interaction, demographic factors, values, and perceived control were important factors in determining people's behaviour. These households' decisions do not happen in isolation and are context specific, in this research it is the electricity market in State of New York, with its policies and other actors outside of households themselves. It was found that in the state, centralised utilities still hold a great deal of power, which they are actively trying to maintain. This results in policies that seemingly strengthen the centralisation in the state rather than promote decentralisation. This leads to the aspect of the policy instruments mentioned in the main research question. Three policy instruments were selected: the Expanded Solar-for-All program, the Value of Distributed Energy Resources, and the Customer Benefit Contribution.

The second part of the question relates to the term energy security. The term has been operationalised to be applicable to the case of New York State. Initially being defined across four dimensions: availability, affordability, accessibility, and acceptability. After further inspection, it was found that environmental factors were not strong determinants for households in the state, it was mostly financial factors that determined household behaviour. Therefore, two KPIs were added to better represent the households within the State of New York.

After implementation into an ABM-model, some conclusions can be drawn on how the three policies effect the energy security in the state. The E-SFA program is expected to have the biggest influence on availability of RE in the state. The introduction of this program will reduce the amount of RE, however the choice of strategy by the utilities determines the size of the impact, a mild strategy leads to a bigger reduction of RE in the model as compared to an aggressive one. The implementation of the VDER structure will lead to a slight increase of RE in the system. The CBC-charge does not have a significant impact. After combining the three policies, the results show that a mild strategy by utilities leads to a better result when the VDER is also in place. This shows the interconnectedness of both policies, and that households react differently when multiple policies are implemented.

Not included in the model, but a result of the description of the context in chapter **3**, the E-SFA program and the CBC-charge both benefit the utilities the most. The E-SFA ensures that utilities remain at the centre of the electricity generation market in the State of New York and the CBC-charge increases the income for utilities. It could be debated that in terms of decentralisation this is actually a step in the wrong direction.

8.3 Limitations

This research, as with any research, has its shortcomings, weaknesses, and general constraints. In this section these limitations will be explained and ways to interpret them will be laid out. As a caveat, the problem when writing down limitations is that only the limitations that are known, i.e., the known unknowns, are written down. Unfortunately, we cannot be aware of the things we are not aware of. Therefore, this list of limitations in and of itself consists of limited information.

8.3.1 General

When performing any tasks, some general limitations will arise during the process. At risk of becoming too transparent, if there is such a thing, I would like to mention the fact that the lack of external input from experts or people familiar with the context made for a solitary and somewhat difficult challenge, which at times was detrimental to my motivation. However, it might also be my general attitude towards performing this research, being that it in fact should be a feat accomplished with one's own set of knowledge and skills. That being said, some other general limitations should be mentioned.

- Lack of knowledge of the system, limiting the amount of knowledge of current relevant policies. Moreover, policies implemented within the model might already be outdated at the time this research is being presented. The lack of knowledge on certain analytical methods also limited the progress of this study. Mainly, during the sensitivity analysis when the use of Netlogo in combination with R was needed.
- Lack of computational power for full scale range of implementation scenarios of policies. When implementing the experimental design, a lot of model runs were needed, taking a lot of time to run. Therefore, it was chosen to implement the interventions only at limited levels. Preferably smaller steps were taken between the minimal and maximal implementations of interventions 1 (E-SFA) and 2 (VDER).
- Since I did not have the opportunity to collect my own data, and am not a resident of the state, the use of secondary was essential. The choice for the case of the State of New York also provided some logistical and practical roadblocks. The lack of contacts within the field of solar electricity in the State of New York, or the United States, slowed down the process of acquiring relevant information. As a result of not having the opportunity of expert consultation, expert validation of both the conceptualisations and model results has not been possible. This is also true for the verification steps

8.3.2 Modelling

> ~All models are wrong, but some are useful~
> George Box

Models are, by definition, not a complete representation of reality; they are an approximation at best. However, this does not mean building models is quintessentially futile. What follows first are some of the main assumptions made within the model, after which some reflections on the modelling process within this research will be discussed.

Assumptions within the model:

- Households:
    - I. When households have the intent to join a CSP, they are always able to locate a CSP. Meaning that they have total awareness of the CSPs in the area, which in reality is unlikely. However, when the CSP is fully subscribed, households are not able to join.
    - II. Households are unable to return on their decision to either join a CSP or install an RPV system. Once they have made their decision, they stick to it throughout the duration of the model. In reality, households can decide to switch from CSPs to RPV systems, however it is unlikely people will switch from RPV to CSP as the installation of a RPV system is a long-term investment, which requires at least 5 years to become profitable.
- CSPs:
    - I. Just as households are able to find a CSP, CSPs are able to locate potential subscribers. This means that CSPs have a perfect knowledge of the potential market. In reality developers are unlikely to have full information on the demands of potential customers.

The relevance of this research in terms of its ability to aid in policy making is debatable. The policies in this research are viewed in isolation, however some other rebates and incentives were introduced in the model. The policies in the real-world do in fact interact with other policies and governance structures outside the scope that is maintained in this research. New policies could have been introduced, or old policies could only just now show their impact on the decentralised solar electricity generation in the State of New York. However, this is in the nature of modelling, since decisions based on scope need to be taken. Moreover, it is debatable whether the inclusion of all policy within the State of New York, or the United States for that matter, will lead to more significant or robust results.

In hindsight, the impact of the intervention could have been modelled more extensively. The effect of the intervention in terms of the theories used (TPB, VBN, DOI) have not been taken into account fully. The theories were mostly used as a basis to create the population within the model. The descriptive statistics of the variables within Wolske et al. (2017) were represented on a five-point scale, and the determinants were presented as standardized coefficients. This led to the characteristics of households in the model of this research being assigned following a normal distribution, resulting in the generation of a similar population every model run. The determinants were also modelled in a relatively linear way, in accordance with the coefficients provided by Wolske et al. (2017). Moreover, the theories used do not consider impulsivity, emotional processing, or the aspect of self-control (West & Brown, 2013). Mitchie et al. (2011) provide a framework which can aid in the improvement of the model, more on this in section **8.5**.

8.4 Recommendations for policy makers

As part of Hevner and Chatterjee's (2010) Design Science Research, a description of the context or environment was laid out. This was done in order to have relevant input into the model, such as policies and CSP developer options, but also to provide structured recommendations based on the results of the model. This section therefore gives some recommendations for policy makers in the State of New York, or can be seen as examples for other states, thereby closing the relevance cycle.

- Even as the results of implementing the policy instruments have not led to great difference in the outcome, it should be noted that the changing of policies could lead to unrest among households. Changing policies too often might cause households to find the process of installing RPV or joining a CSP too confusing, as legislation, rebate-structures, and incentives are seemingly changing constantly. The implementation of clear and consistent policy would be my main recommendation, at the lowest cost possible.
- Make sure that the VDER rebate structure does not lead to a too big of a reduction, a small reduction might even lead to more RE in the system. Implementing the policies with caution and at several different levels, can lead to a better outcome within the state.
- While implementing the MW-block structure into the model, it was found that the rebates per kW are generous. Meaning that when households do implement an RPV system, their costs are significantly reduced, and in some cases zero. This could be an error made when researching the incentives in the State of New York, but reconsideration concerning the height of each MW-block is advised. For households having the intention to install an RPV system, a 100 percent refund on their investment is of course what you would call a 'no-brainer'. But money could be diverted towards efforts that increase the number of people installing RPVs, with each household getting a lower rebate.
- Limiting the power of utilities within the state or realigning the goals of the utilities with those of the State of New York. This is linked to the results of the third chapter in which it was laid out that the Joint Utilities of New York are actively opposing or hindering the progression of RE within the state, especially when it comes to decentralised solutions. This of course is not mere a matter of policy, but also that of politics.
- As mentioned in the limitations, the households need to be properly informed of their options for either joining CSP or installing RPV. As explained by Rogers (2003) education of

individuals can have a positive effect on the adoption of technologies. Educating New Yorkers on not only solar solutions, but also on sustainability in general is recommended.

8.5 Ideas for further research

This research has used several theories and translated them into an ABM model for the exploration of household decision making concerning electricity procurement in the State of New York. However, the system of New York is way more complex, as is the decision-making process of households. Therefore, it is advised that further research should be conducted into several directions.

- An important aspect of ABM is its ability of analysis on multiple scales. This means that changes on a system level could be analysed when alterations take place on a household level. By doing so, several populations could be analysed, which could indicate what type of household or society will perform more successfully in terms of energy security. This has been done by Fouladvand et al. (2022) and De Bruin (2021), and these could be used as example for exploring for this purpose.
- Expanding the sensitivity analysis, for better understanding of the uncertainties and determinants within the model.
- Future research should be done towards the dependant variable. The survey conducted by Wolske et al. (2017) had a different dependant variable than the one in this research. It was argued that the use of this survey still was relevant, however more precise data could be gathered, in which the dependant variables are installing a RPV system or joining a CSP, within the State of New York. This could lead to a more robust study, with which policy advice could be made more accurate and/or relevant.
- The effect of electricity price volatility could be taken into consideration. With the energy crisis of 2022, which has continued into 2023, prices of energy have gone through a tremendous fluctuation, increasing the uncertainty for households when it comes to making decisions concerning electricity procurement. Van der Wal et al. (2018), have looked at sustainable consumer behaviour under uncertainty. They highlight that consumers tend to make more conservative choices under uncertainty, for instance opting for traditional electricity generation, however this behaviour can be remedied by educating consumers about the direct benefits of sustainable behaviours. This ties into the aspect of education by Rogers (2003) within this research. Therefore, I suggest the exploration of uncertainty and its relation to consumer behaviour to be included in further research.
- The electricity grid has been modelled as an external input, i.e., it is assumed that the grid can deliver electricity constantly. However, this could be included in further research along with hours of sunlight, blackouts, system losses, and other external factors. I suggest looking at the literature review done by Ringler et al. (2016), to get a clear overview of what the possibilities are when using ABM.
- As mentioned, several aspects of household's reactions towards policy instrument implementations were not considered in this research. Michie et al. (2011) can provide relevant additions for this. They consider behaviour to be comprised of three components: motivation, capability, and opportunity. They argue that certain policies affect one or more of these components. The policy instruments used in this research could then all three have different effects on the households, other than the ones that have been analysed in this research.
- Finally, as described in chapter **3**, an important aspect is the power that traditional utilities hold. This research has only done a desk-review of the relationship between the utilities, policy makers, and consumers, but further in-depth research is required. These relationships could be modelled using methods such as institutional modelling.

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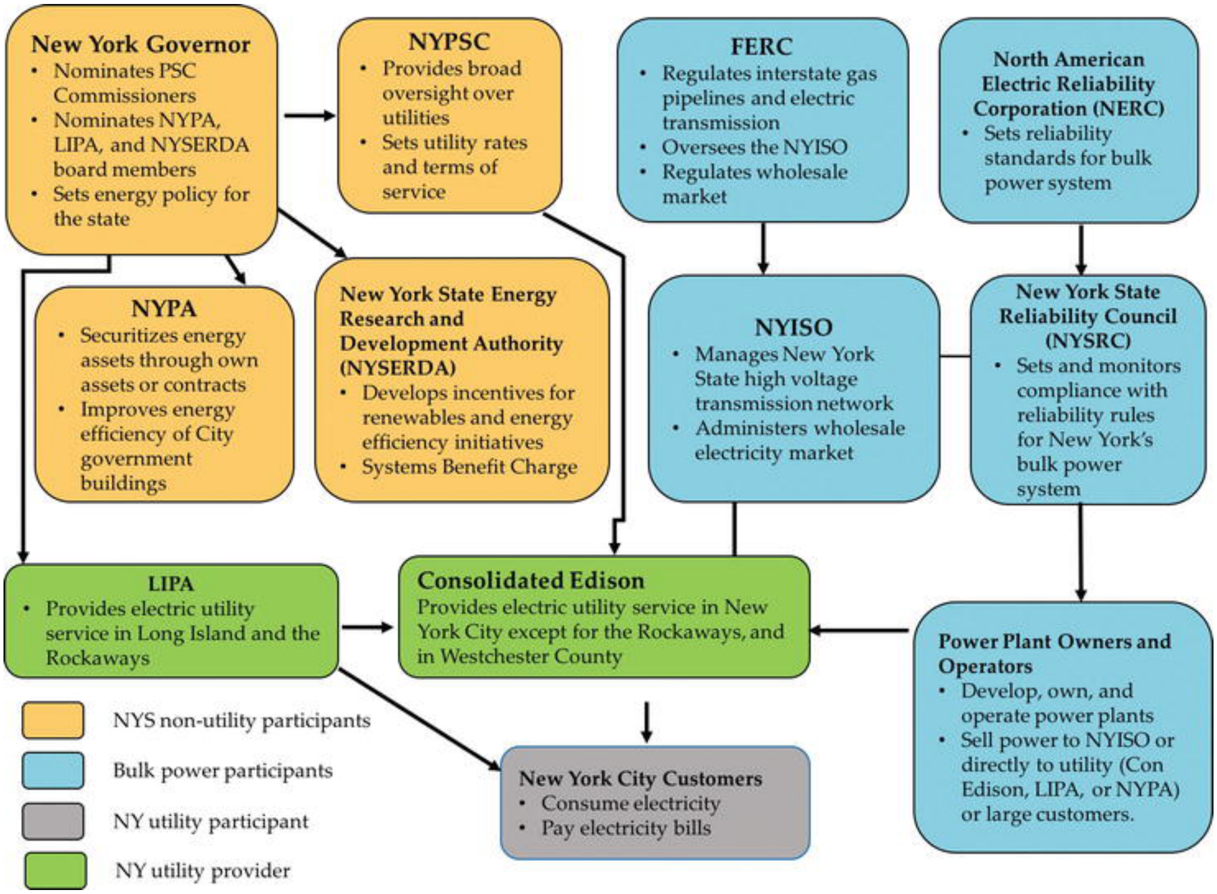
Appendix A

Figure A.0.1

New York's energy players

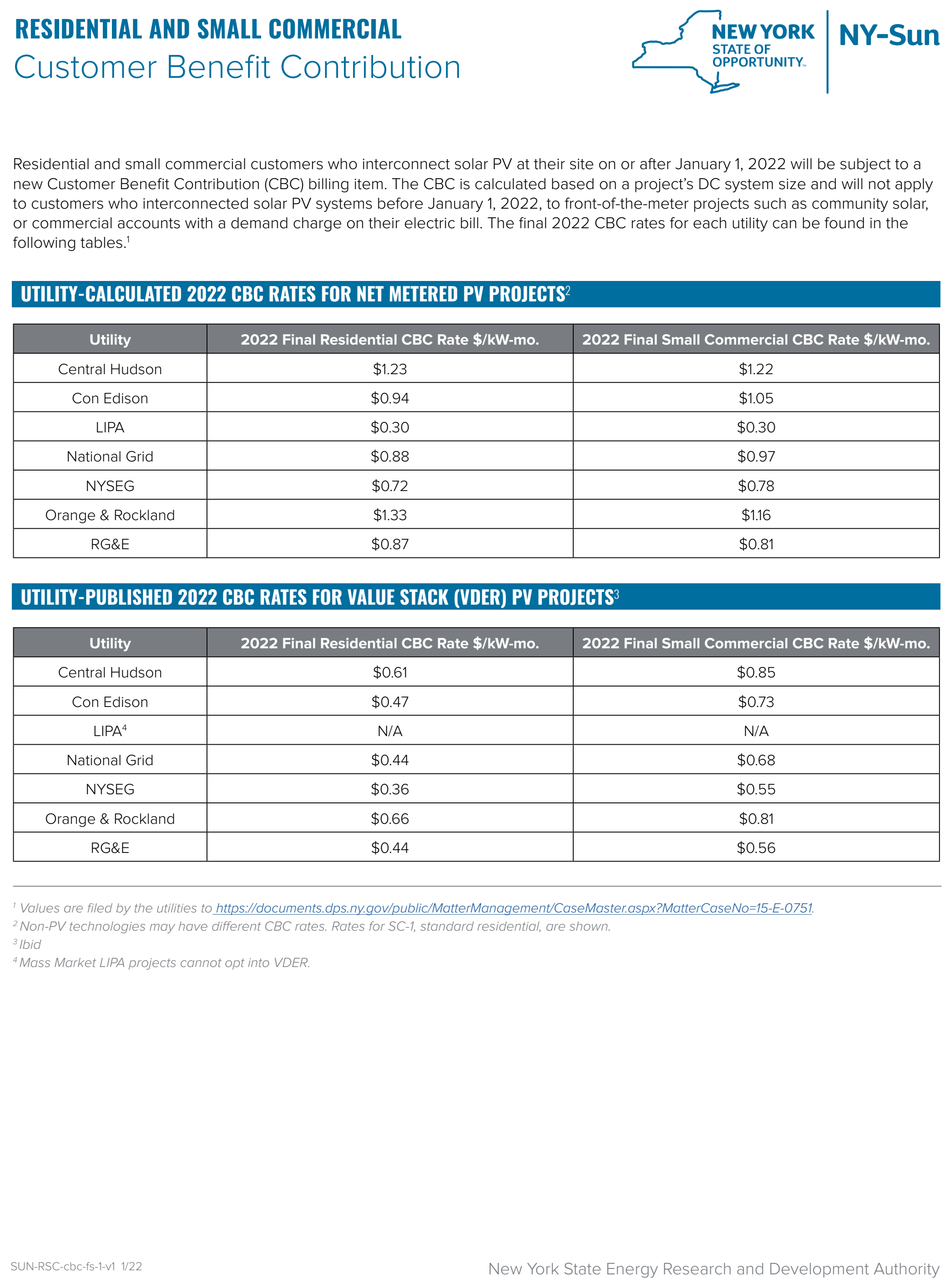


Note: From Nyangon & Byrne, 2018

Appendix B

Figure B.0.1

CBC billing overview



RESIDENTIAL AND SMALL COMMERCIAL
Customer Benefit Contribution

Residential and small commercial customers who interconnect solar PV at their site on or after January 1, 2022 will be subject to a new Customer Benefit Contribution (CBC) billing item. The CBC is calculated based on a project's DC system size and will not apply to customers who interconnected solar PV systems before January 1, 2022, to front-of-the-meter projects such as community solar, or commercial accounts with a demand charge on their electric bill. The final 2022 CBC rates for each utility can be found in the following tables.[1]

UTILITY-CALCULATED 2022 CBC RATES FOR NET METERED PV PROJECTS[2]

Utility	2022 Final Residential CBC Rate $/kW-mo.	2022 Final Small Commercial CBC Rate $/kW-mo.
Central Hudson	$1.23	$1.22
Con Edison	$0.94	$1.05
LIPA	$0.30	$0.30
National Grid	$0.88	$0.97
NYSEG	$0.72	$0.78
Orange & Rockland	$1.33	$1.16
RG&E	$0.87	$0.81

UTILITY-PUBLISHED 2022 CBC RATES FOR VALUE STACK (VDER) PV PROJECTS[3]

Utility	2022 Final Residential CBC Rate $/kW-mo.	2022 Final Small Commercial CBC Rate $/kW-mo.
Central Hudson	$0.61	$0.85
Con Edison	$0.47	$0.73
LIPA[4]	N/A	N/A
National Grid	$0.44	$0.68
NYSEG	$0.36	$0.55
Orange & Rockland	$0.66	$0.81
RG&E	$0.44	$0.56

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[1] *Values are filed by the utilities to https://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=15-E-0751.*

[2] *Non-PV technologies may have different CBC rates. Rates for SC-1, standard residential, are shown.*

[3] *Ibid*

[4] *Mass Market LIPA projects cannot opt into VDER.*

SUN-RSC-cbc-fs-1-v1 1/22

New York State Energy Research and Development Authority

Appendix C

Table C.0.1

Model inputs

Topic	Variable	Default	Source
General	kwh-KW	978 kWh/kW/month	Project sunroof (Google, 2022)
	region	ConEd	
	density	0.70	
Incentives in the state	MW-block-res	150 kW	NYSERDA (2022)
	MW-block-com	120 kW	
	MW-block-price-com	1 $/Watt	
	MW-block-price-res	0.2$/Watt	
	NY-tax-incentive	0.25	Dept. of Taxation and Finance
	federal-itc-incentive	0.26	Office of Energy Efficience & Renewable Energy
Pricing	electricity-price	0.224/kWh	NYSERDA (2022)
	avg-electricity-price	0.187/kWh	
	VDER-exp-rate	0.8	
	CBC-charge	VDER: 0.545 Net-Metering: 1.09	Solarreviews (2022)
Emissions	CO2-kWh-avg-em	275.372/kWh	Energy Information Administration (2021)
	CO2-kWh-solar-pv	41/kWh	IPCC (2014)
	CO2-kWh-solar-cs	48/kWh	
Effects	effect-intv1	1	
	effect-intv2-trust	0.05	
	effect-intv3-trust	0.05	
	fac-eff-elec-price	10	
	fac-observability	0.05	
	fac-eff-trust-others	0.5	
	fac-spend-rpv	4	
	MW-mult	1	
Community Solar	avg-cs-size	115 kW	NY Solar Energy Industries Association (2021)
	avg-cs-cost-kW	Random: N(2460, 200)	
	avg-cs-benf-kW	Random: N(2460, 200)	
	cs-adder-block	400	NYSERDA (2022)
	cs-adder-price	0.2$/kW	
General	counter-checking	Random: 4	
House characteristics	own-usage	Random: N(973, 200)/month	EnergySage (2022)
	has-rooftop?	Random: 2	

	PV-kW-price	<5 kW: 3.3$/W; 5 kW< pv-size<9 kW: 3.19$/W; >9 kW: 2.97 $/W	Solarreviews (2022)
	kW-installable	Random: Exp(7) + 1	Project sunroof (Google, 2022)
Finances	init-savings	Random: Exp(16990$)	CISION (2022)
	init-be-time	10	
	discount-rate	0.05	

Appendix D

Verification of the model

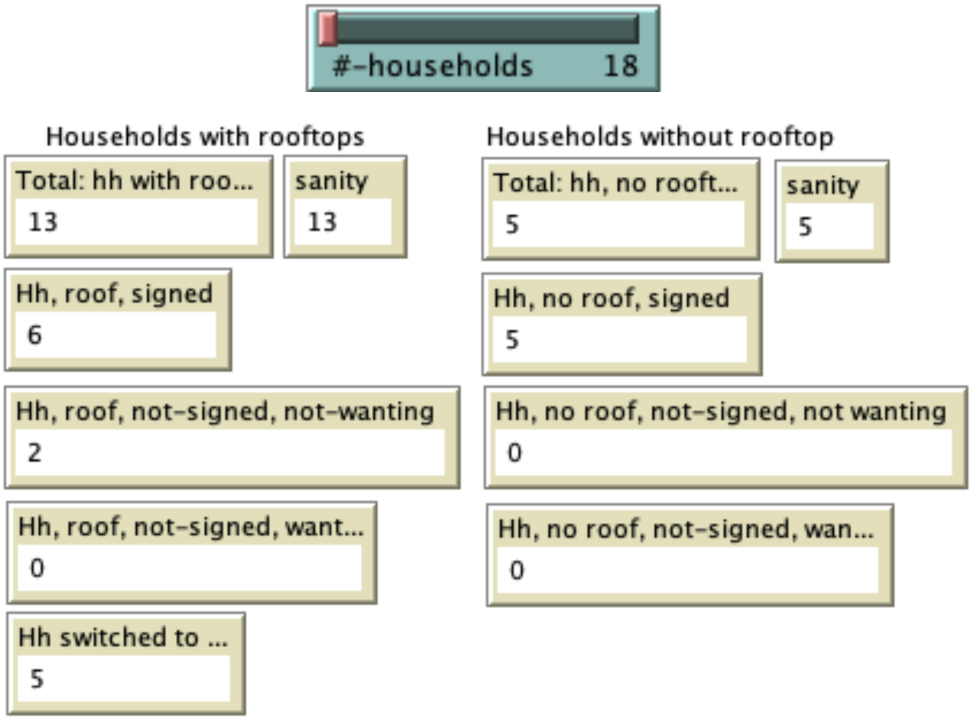
In this section the steps that were performed to verify the model will be explained in further detail.

Code walk-through

Several sanity checks were implemented, such as a check whether all households were either signed up to a CSP, have had installed RPV, or did neither (Figure **D.0.1**). This was done to prevent households from remaining stuck in loops that were unintentionally built into the model.

Figure D.0.1

Sanity check number of households



#-households 18

Households with rooftops

Total: hh with roo... 13

sanity 13

Hh, roof, signed 6

Hh, roof, not-signed, not-wanting 2

Hh, roof, not-signed, want... 0

Hh switched to ... 5

Households without rooftop

Total: hh, no rooft... 5

sanity 5

Hh, no roof, signed 5

Hh, no roof, not-signed, not wanting 0

Hh, no roof, not-signed, wan... 0

Several "print" statements in combination with "who" statements were incorporated into the code in order to check at which stage a specific turtle (household or developer) was, or to report certain data of that turtle.

Recording and tracking of agent behaviour

Some behaviours of households were tracked during the model run.

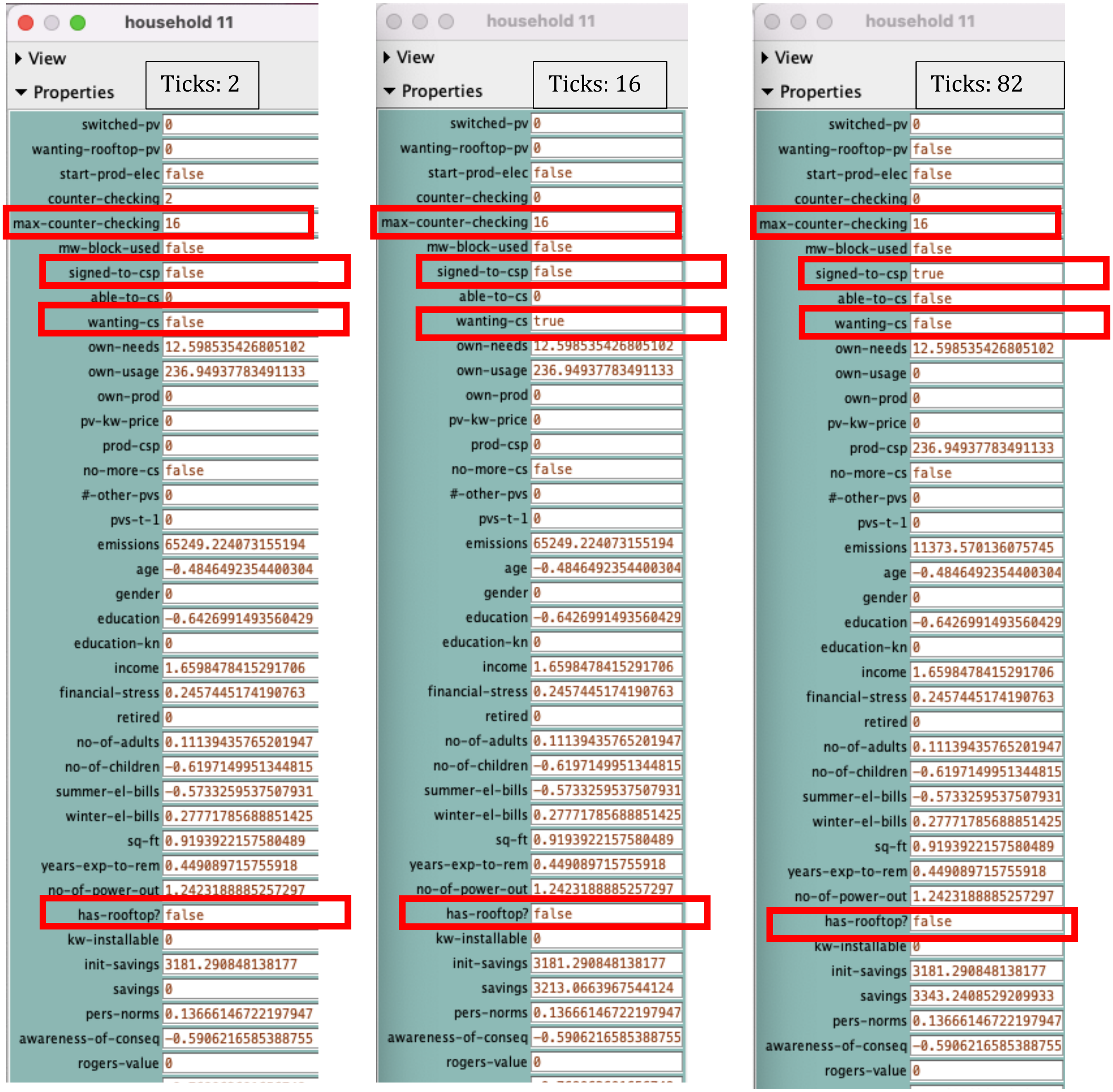
Process: The electricity procurement of a household without a rooftop, who has a positive intent will want to find a CSP project:

- **Expectation:** Initially, a household will not want to join a CSP. A household will consider their stance on their electricity procurement every X number of weeks, based on their education level (Rogers, 2003), represented by the variable "max-counter-checking". If a household has a positive intent, they will want to sign up to a CSP. If there is a CSP available, the household would want to sign up.
- **Verification:** An example of the tracking of the behaviour of the agent can be seen in Figure **D.0.2**. Initially, the household does not want to join a CSP. After 16 weeks, the household

wants to join but is unable to. After 70 weeks a developer has created a CSP and joining a CSP is made possible for households.

Figure D.0.2

Steps followed by a household without a rooftop. Screenshots after 2 weeks, 16 weeks, and 82 weeks



household 11

View

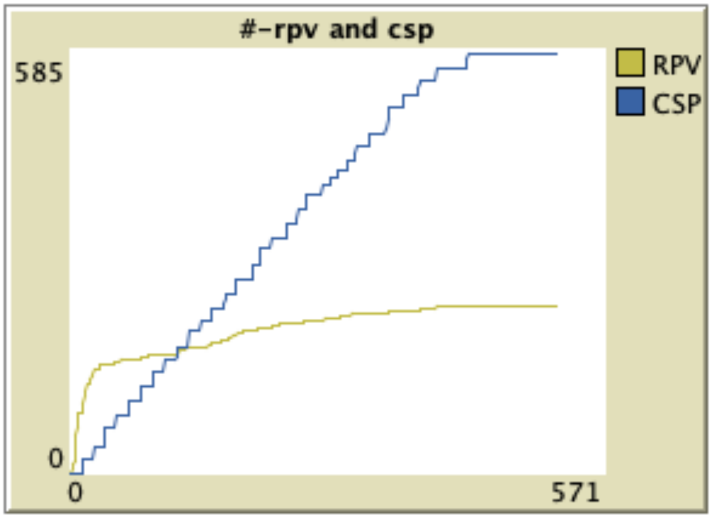
Properties

	Ticks: 2	Ticks: 16	Ticks: 82
switched-pv	0	0	0
wanting-rooftop-pv	0	0	false
start-prod-elec	false	false	false
counter-checking	2	0	0
max-counter-checking	16	16	16
mw-block-used	false	false	false
signed-to-csp	false	false	true
able-to-cs	0	0	false
wanting-cs	false	true	false
own-needs	12.598535426805102	12.598535426805102	12.598535426805102
own-usage	236.94937783491133	236.94937783491133	0
own-prod	0	0	0
pv-kw-price	0	0	0
prod-csp	0	0	236.94937783491133
no-more-cs	false	false	false
#-other-pvs	0	0	0
pvs-t-1	0	0	0
emissions	65249.224073155194	65249.224073155194	11373.570136075745
age	-0.4846492354400304	-0.4846492354400304	-0.4846492354400304
gender	0	0	0
education	-0.6426991493560429	-0.6426991493560429	-0.6426991493560429
education-kn	0	0	0
income	1.6598478415291706	1.6598478415291706	1.6598478415291706
financial-stress	0.2457445174190763	0.2457445174190763	0.2457445174190763
retired	0	0	0
no-of-adults	0.11139435765201947	0.11139435765201947	0.11139435765201947
no-of-children	-0.6197149951344815	-0.6197149951344815	-0.6197149951344815
summer-el-bills	-0.5733259537507931	-0.5733259537507931	-0.5733259537507931
winter-el-bills	0.27771785688851425	0.27771785688851425	0.27771785688851425
sq-ft	0.9193922157580489	0.9193922157580489	0.9193922157580489
years-exp-to-rem	0.449089715755918	0.449089715755918	0.449089715755918
no-of-power-out	1.2423188885257297	1.2423188885257297	1.2423188885257297
has-rooftop?	false	false	false
kw-installable	0	0	0
init-savings	3181.290848138177	3181.290848138177	3181.290848138177
savings	0	3213.0663967544124	3343.2408529209933
pers-norms	0.13666146722197947	0.13666146722197947	0.13666146722197947
awareness-of-conseq	-0.5906216585388755	-0.5906216585388755	-0.5906216585388755
rogers-value	0	0	0

To verify whether these steps were performed correctly by all households, graphs were used that represented the number of households either signed up to a CSP or have had a RPV system installed (Figure **D.0.3**).

Figure D.0.3

Number of households signed up for a CSP or having a RPV system installed, over time

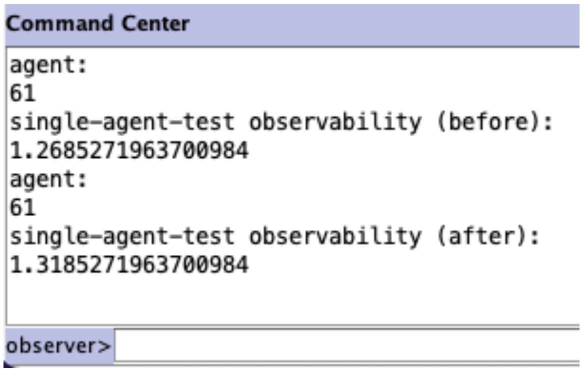


Single-agent testing

Similar to agent tracking and the code run walk through steps, single agent testing was used by inspecting an agent. This was done for both the households and developers. For the households their intent and finances were verified. Households can update their intent based on their social network, if other households within this network have installed RPV and have a positive attitude towards PV, the household will increase their own trust in the PV market (model variable: “trust-pv”). Similar with their neighbours, if a household sees others in their close vicinity having installed RPV, the observability of PV will increase (model variable: “observability”). This was tested by printing the value of their “trust-pv” before looking within their social network and after. The same was done for the value of their “observability” variable. See Figure **D.0.4** for an example.

Figure D.0.4

Households value for the variable “observability” before and after looking at its neighbours.



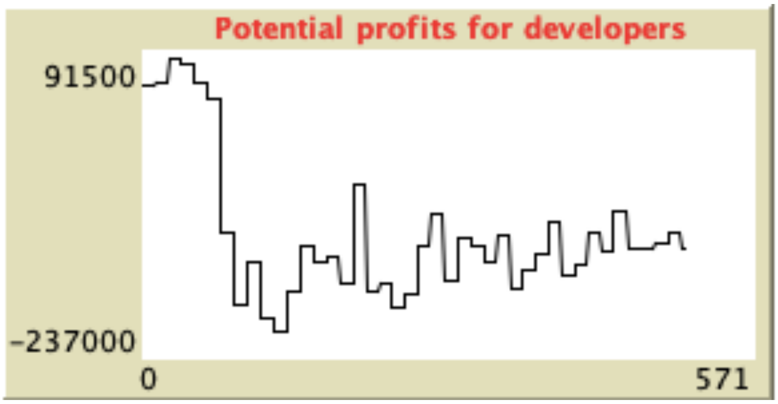
```
agent:
61
single-agent-test observability (before):
1.2685271963700984
agent:
61
single-agent-test observability (after):
1.3185271963700984
```

For verifying a household’s finances, the MW-block price was increased to an excessive amount. This led to households immediately being able to implement their desired RPV system, since all households RPV systems will have a positive net present value.

For developers their finances were tested. This was done by graphing the potential benefit a developer could have when starting a project, at time X (Figure **C.0.5**). At the start of the model the profits are high as the MW-block incentive is still in place, but as over time the MWs are spoken for, the profits will drop. Then slowly increasing over time as the price of installation of PV systems decreases.

Figure C.0.5

Potential profits to be made by developers.



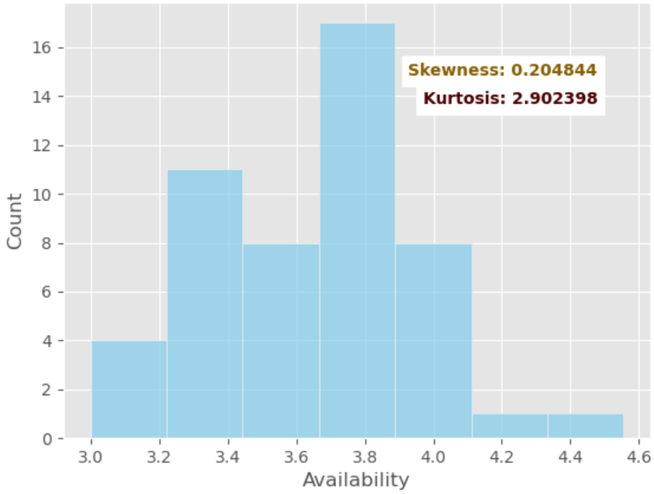
Interaction testing

The minimal number of households for the model to run without an error is 4, as at the initialisation of the households are asked to create a social network with up to 4 households (chapter **4.3**). If a smaller number is chosen, an error will occur in a large percentage of the model initialisations. Running the model multiple times with 4 households showed that no developers initiated any projects. This showed that in order for developers to start building CSP's, a critical mass of households was needed. This is a result of the model artefact that defines when it becomes profitable for developers to start a project, which is based on an average project size of 115kW. If the potential market, i.e., the summation of the needs of households wanting to join a CSP, is lower than the average CS size.

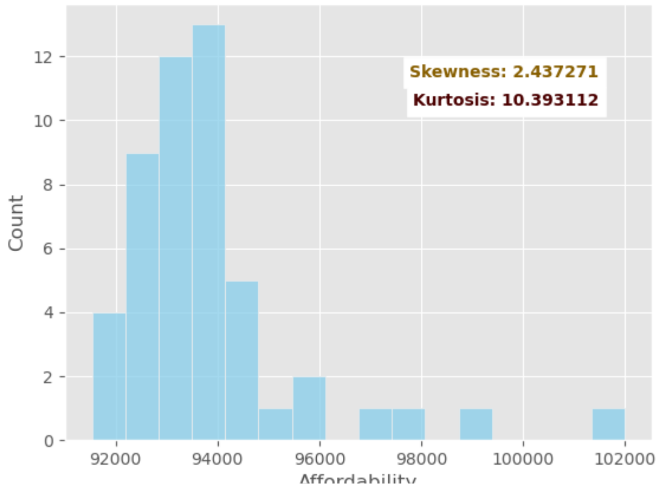
Appendix E

The following graphs show the skewness and kurtosis of the output parameters, i.e., the KPIs, when the number of repetitions of the model run is 50. The output parameters are analysed at the last step of the model, i.e., after 10 years.

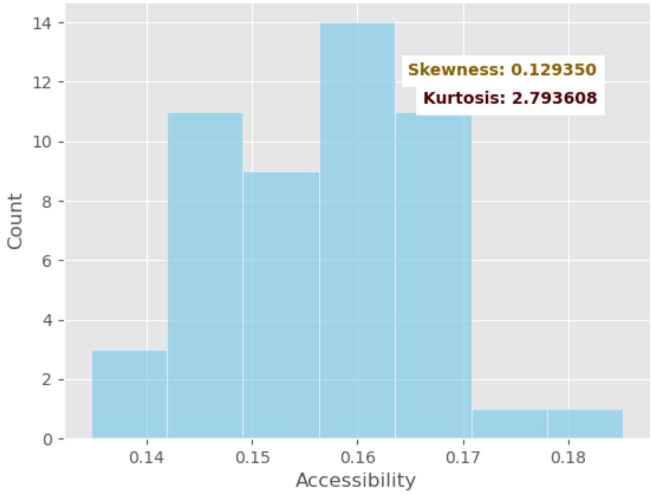
Number of runs: 50, KPI: Availability



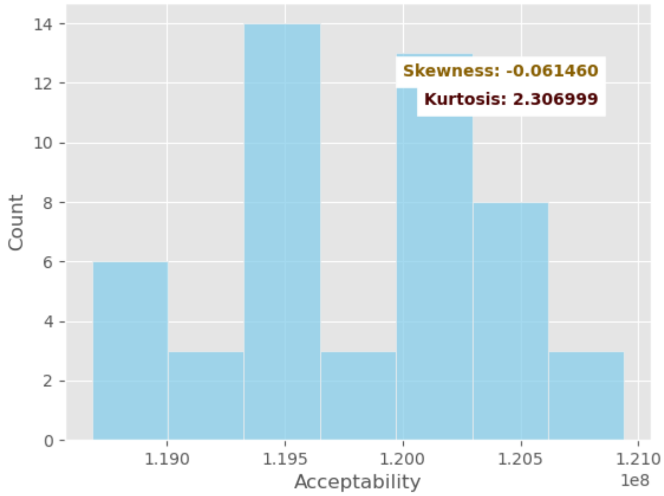
Number of runs: 50, KPI: Affordability



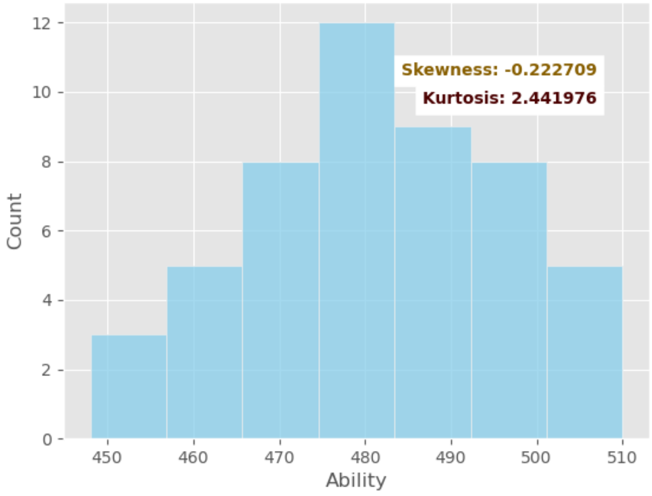
Number of runs: 50, KPI: Accessibility



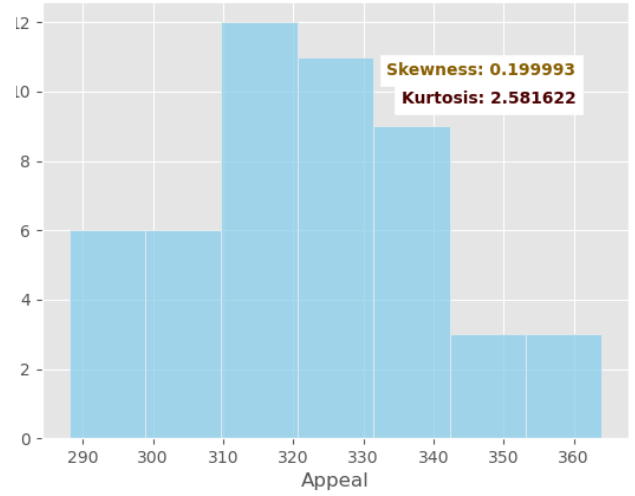
Number of runs: 50, KPI: Acceptability



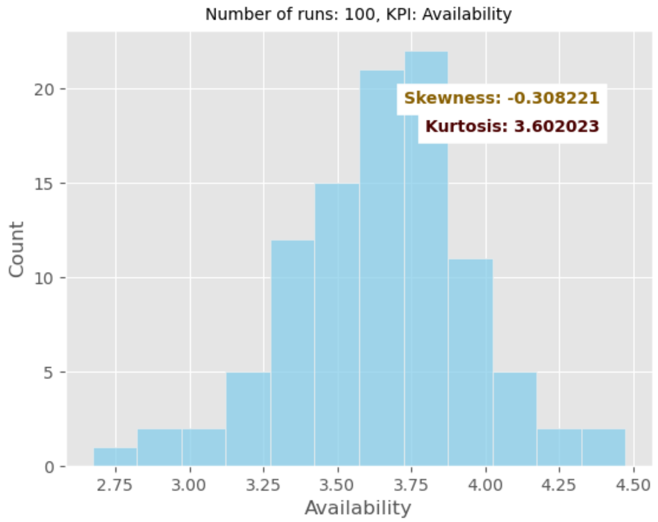
Number of runs: 50, KPI: Ability

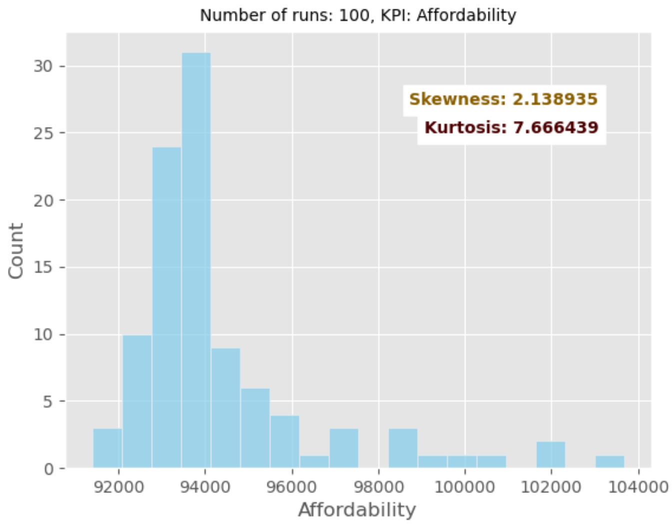


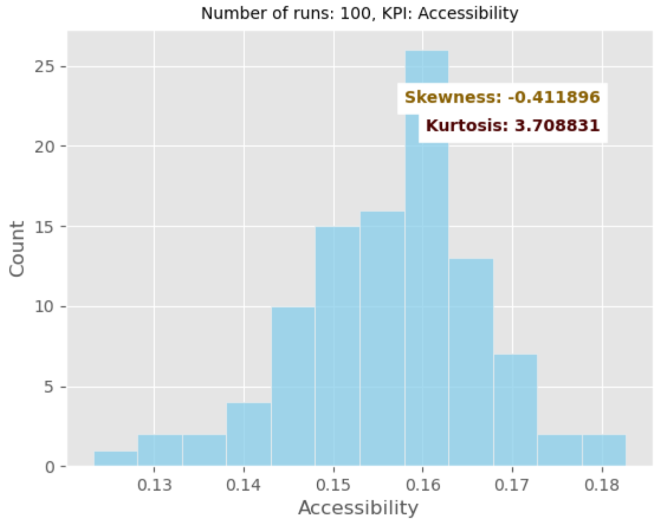
Number of runs: 50, KPI: Appeal

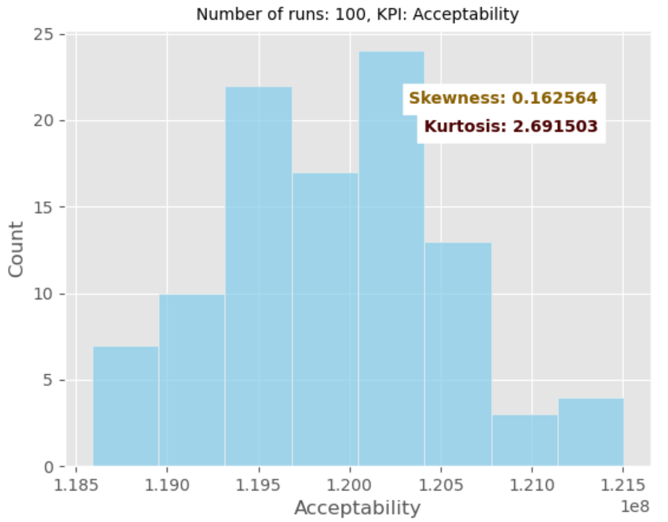


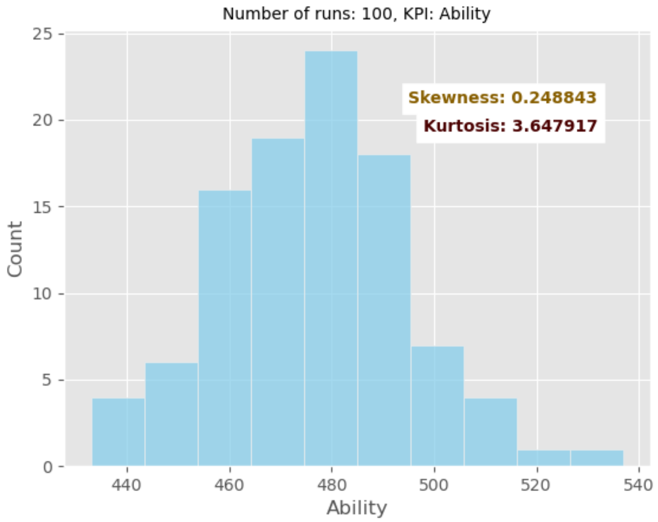
The following graphs show the skewness and kurtosis of the output parameters, i.e., the KPIs, when the number of repetitions of the model run is 100. The output parameters are analysed at the last step of the model, i.e., after 10 years.

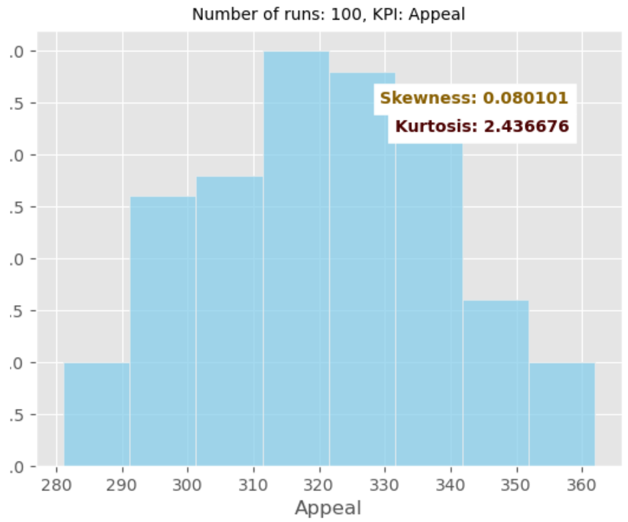




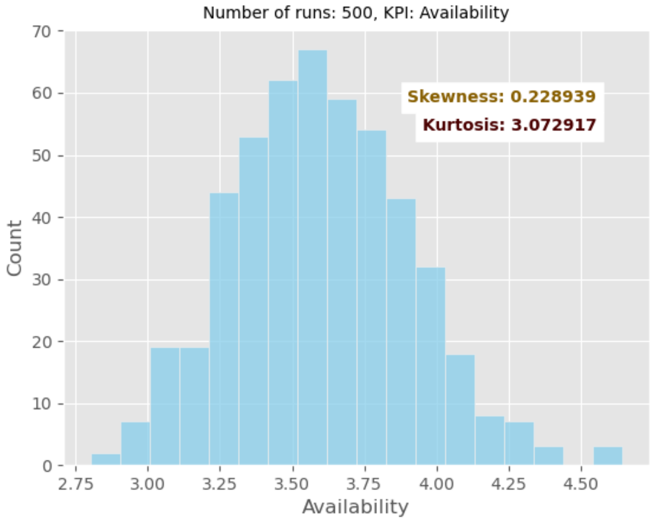


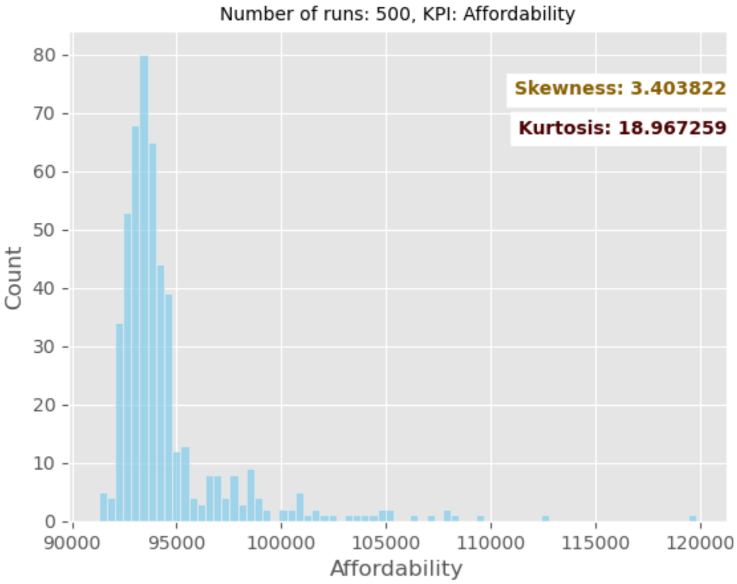


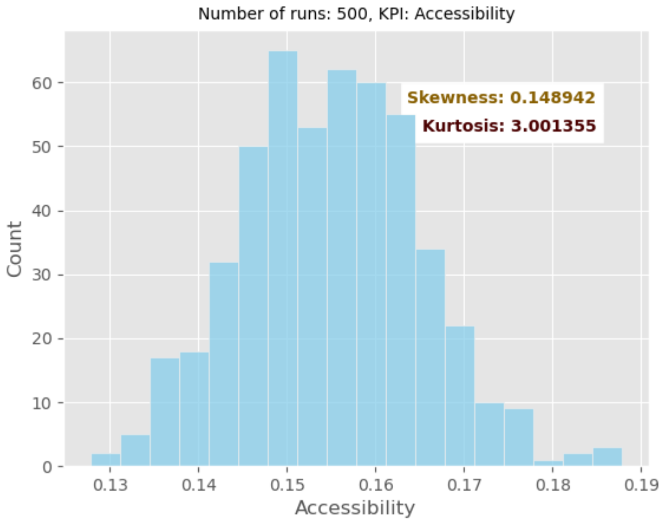


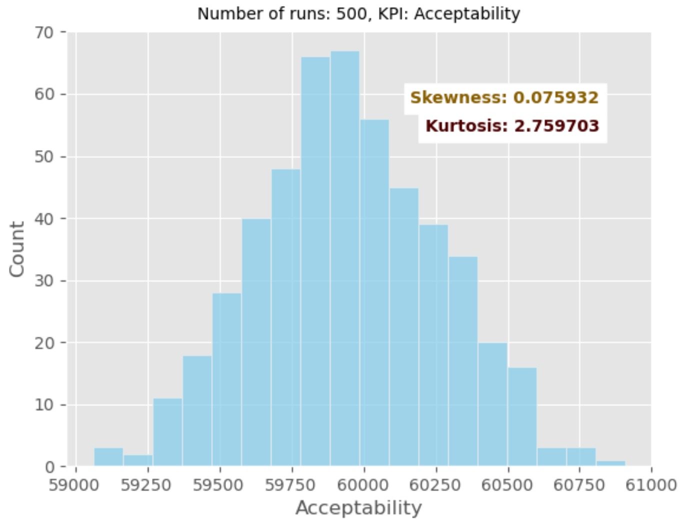


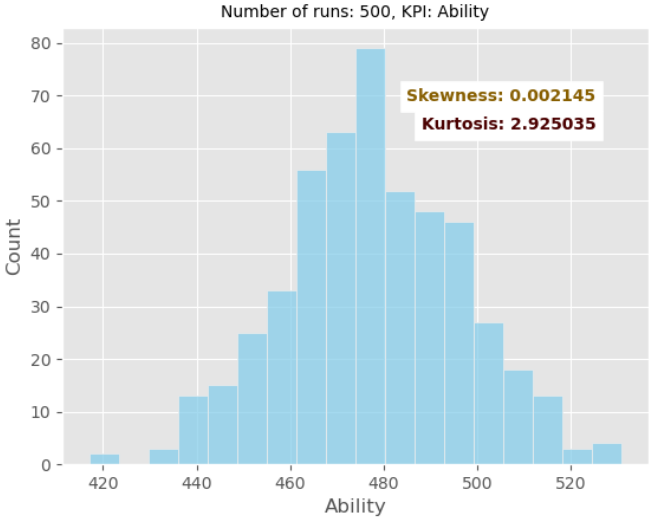
The following graphs show the skewness and kurtosis of the output parameters, i.e., the KPIs, when the number of repetitions of the model run is 500. The output parameters are analysed at the last step of the model, i.e., after 10 years.

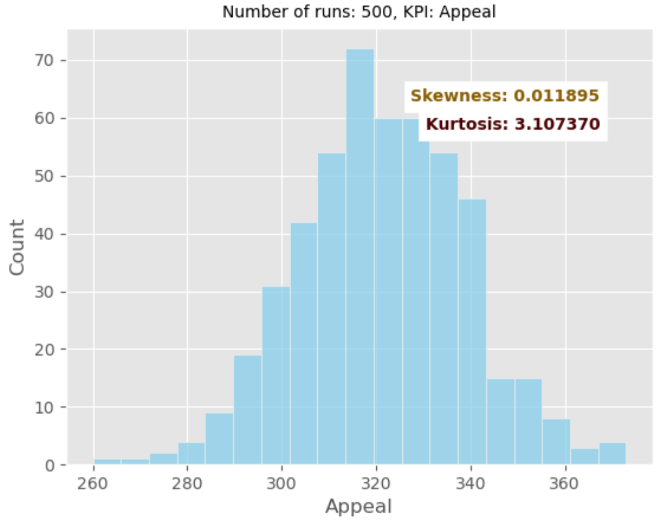






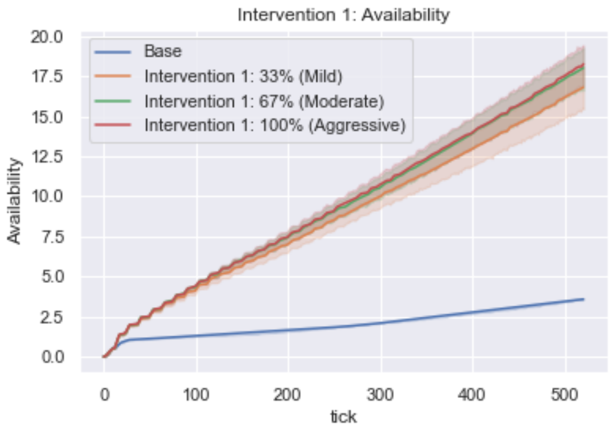


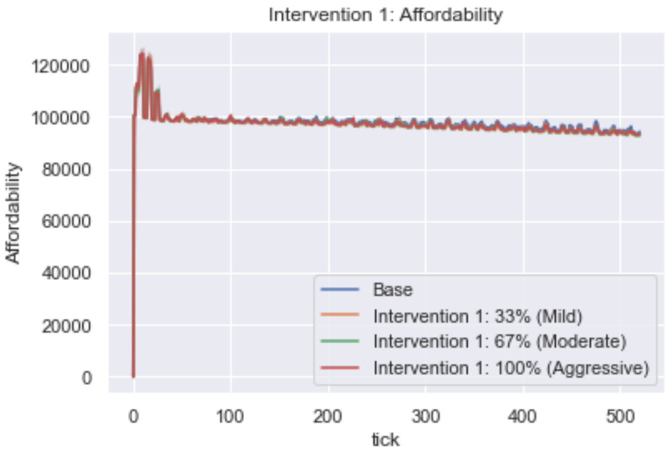


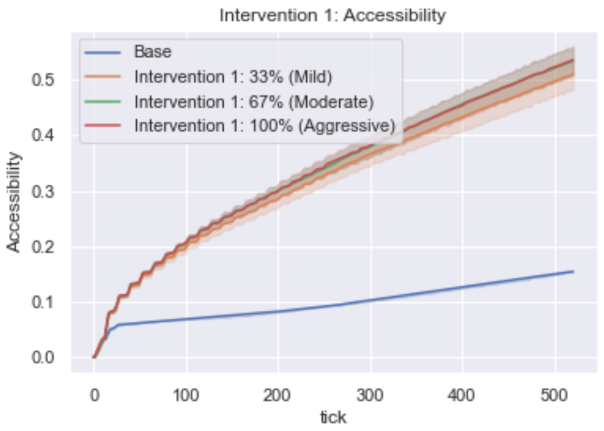


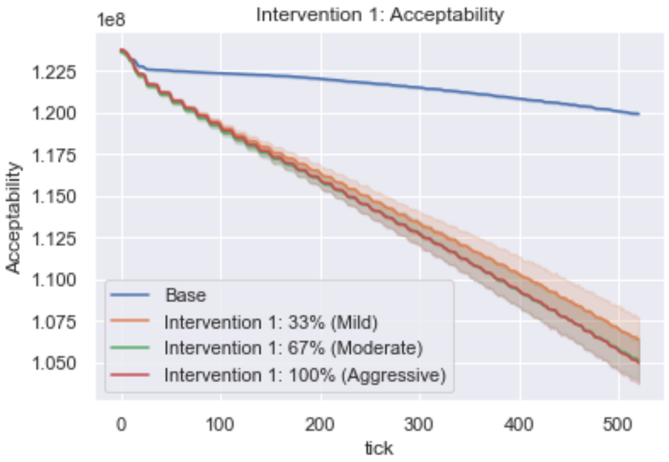
Appendix F

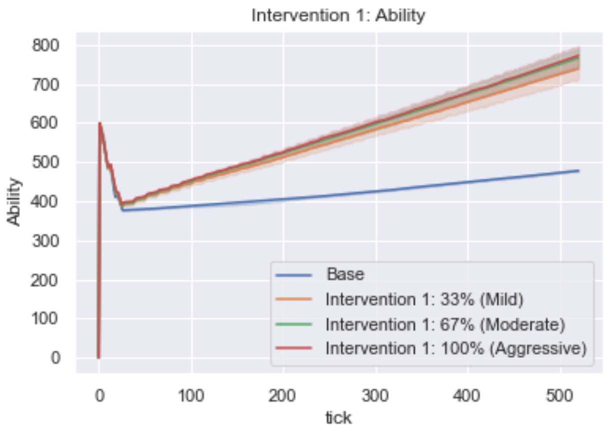
Intervention 1 scenario compared to base scenario

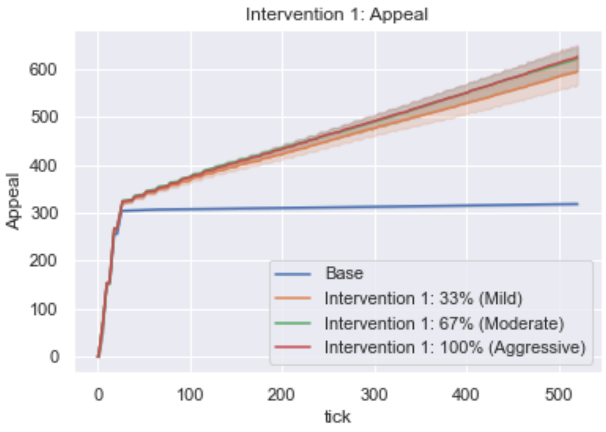




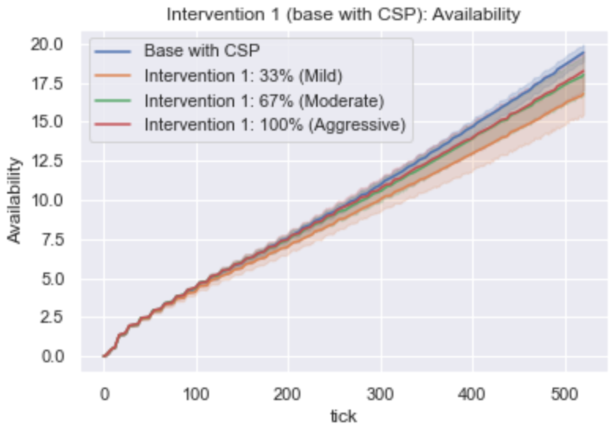


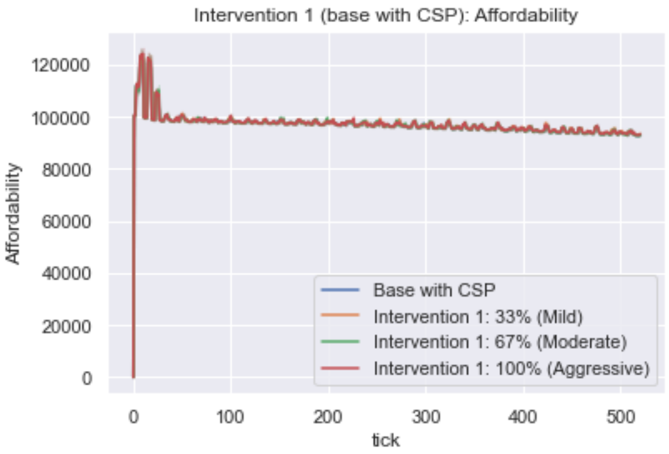


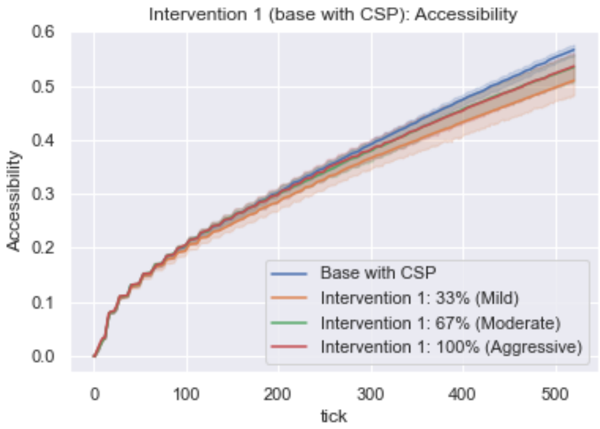


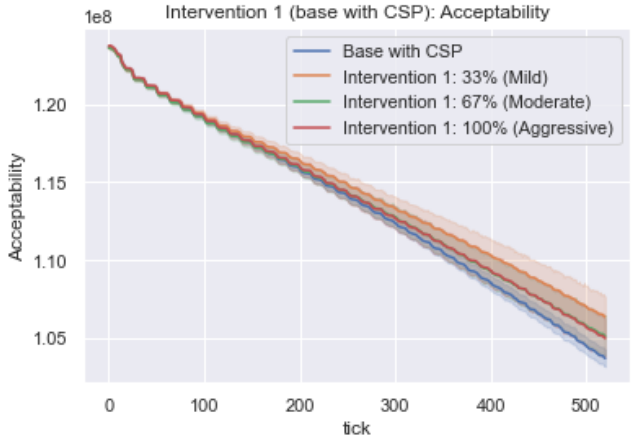


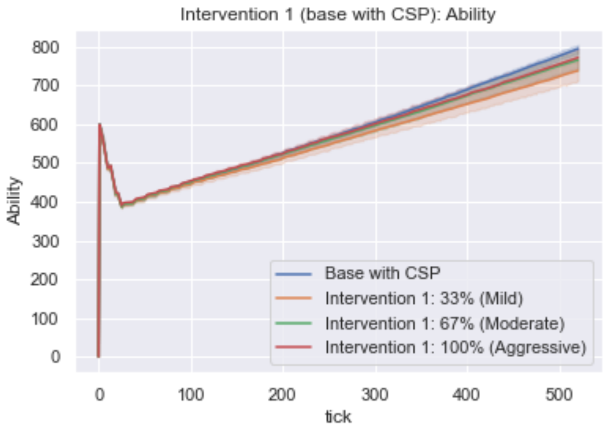
Intervention 1 scenario compared to base scenario with CSP

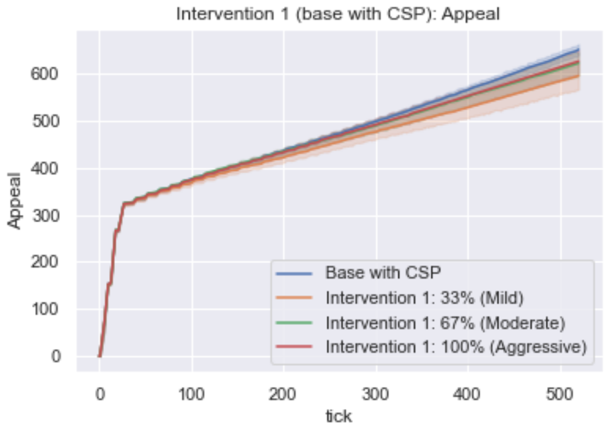




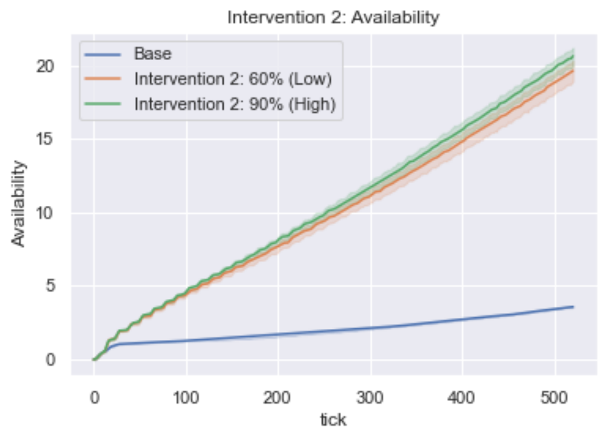


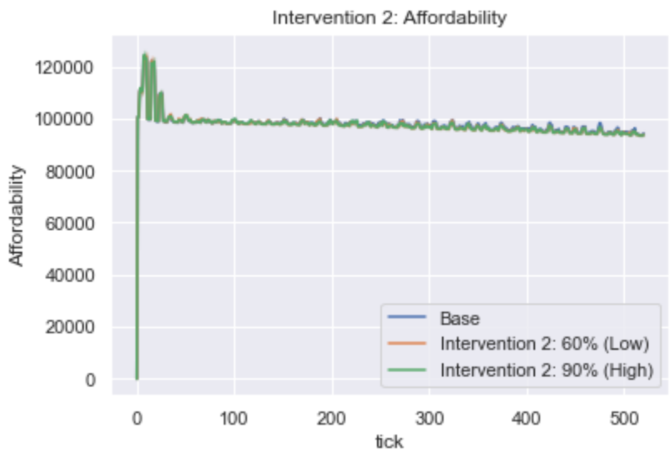


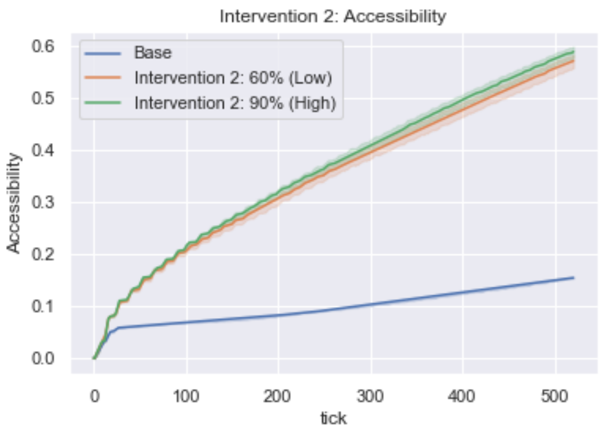


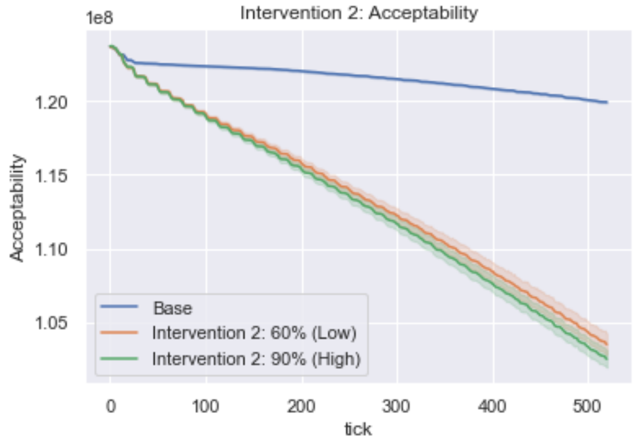


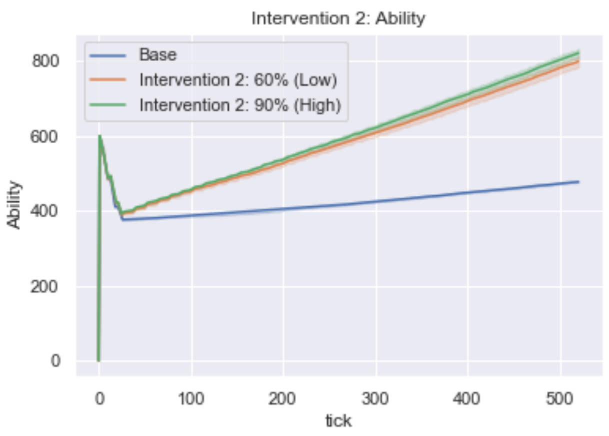
Intervention 2 scenario compared to base scenario

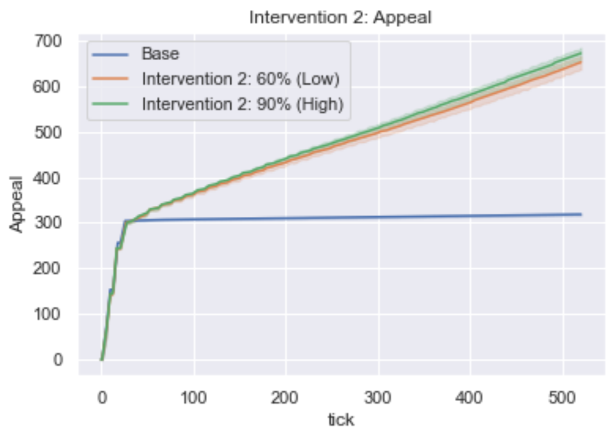




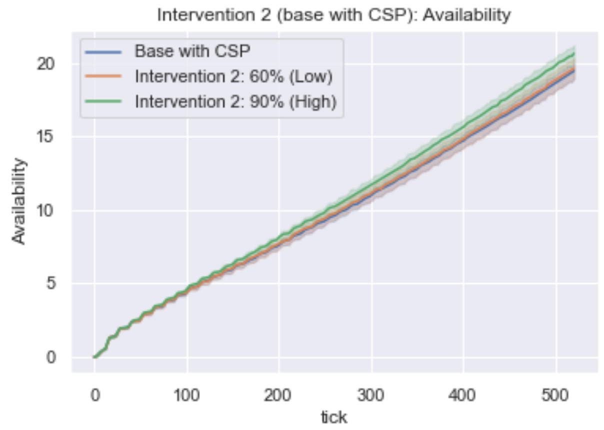


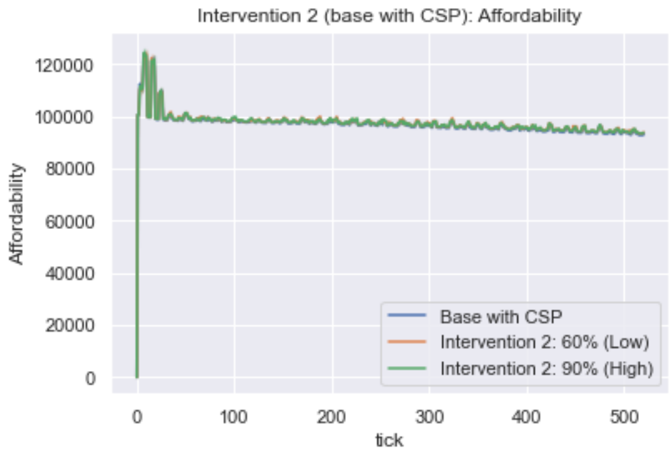


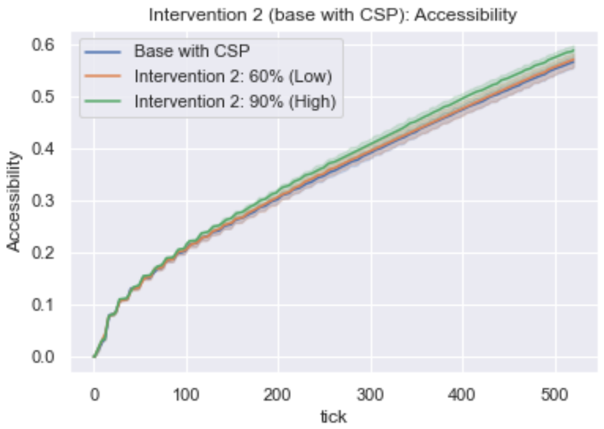


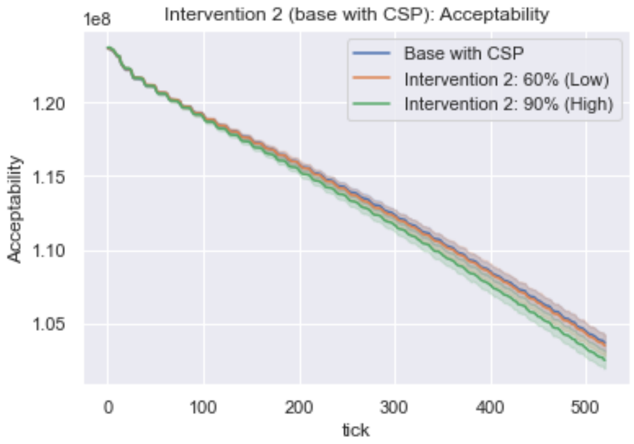


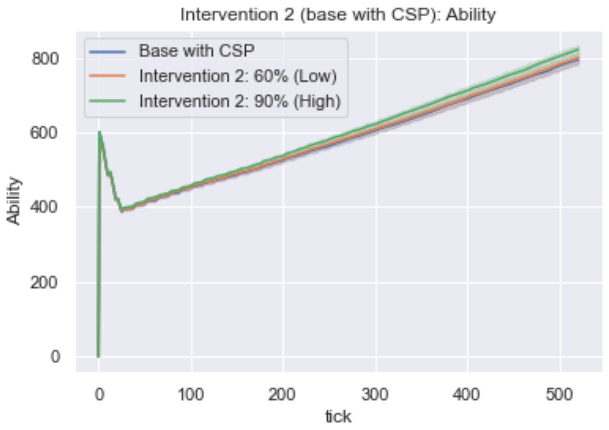
Intervention 2 scenario compared to base scenario with CSP

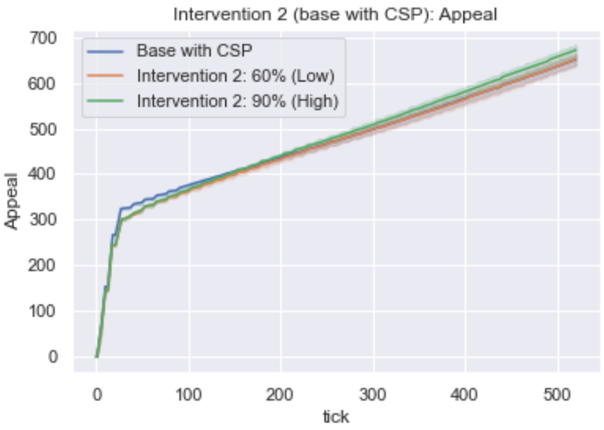




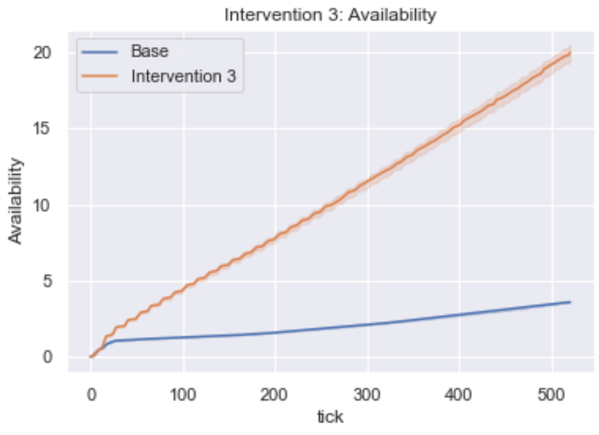


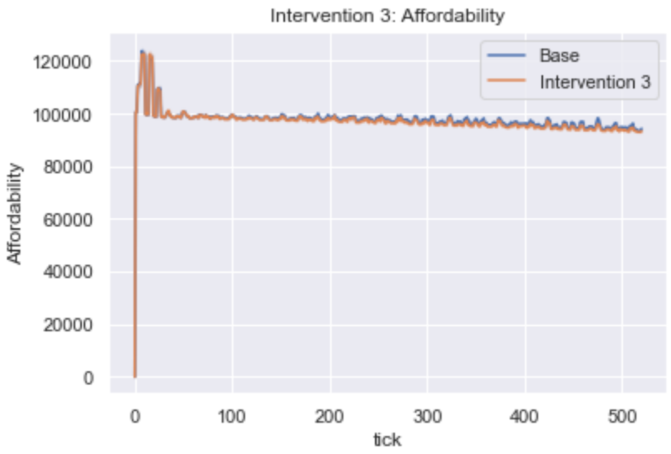


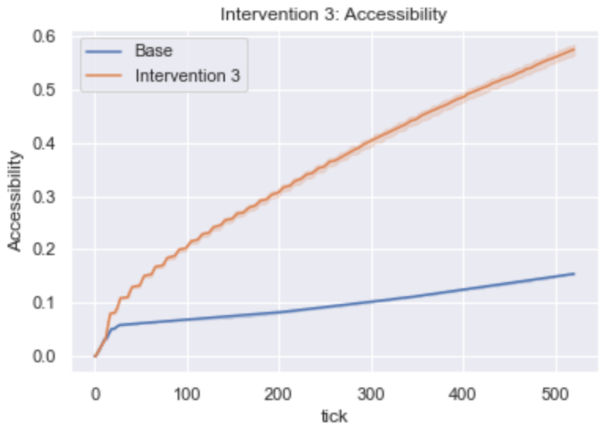


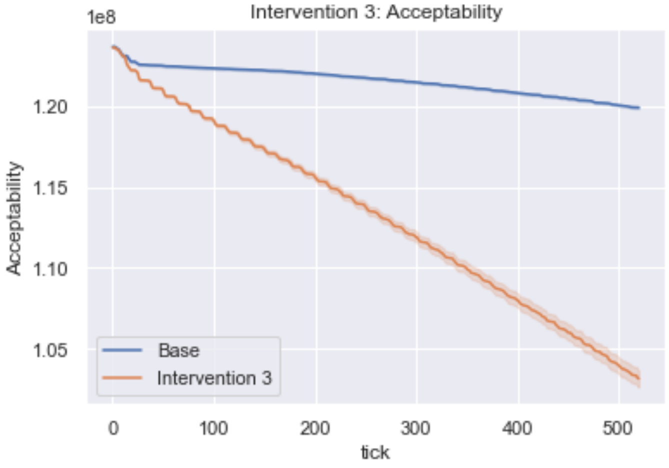


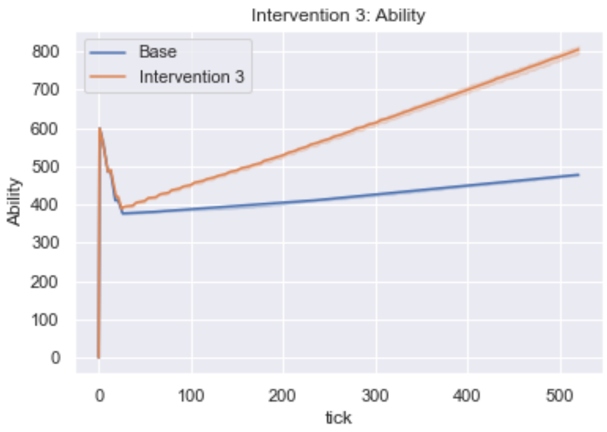
Intervention 3 scenario compared to base scenario

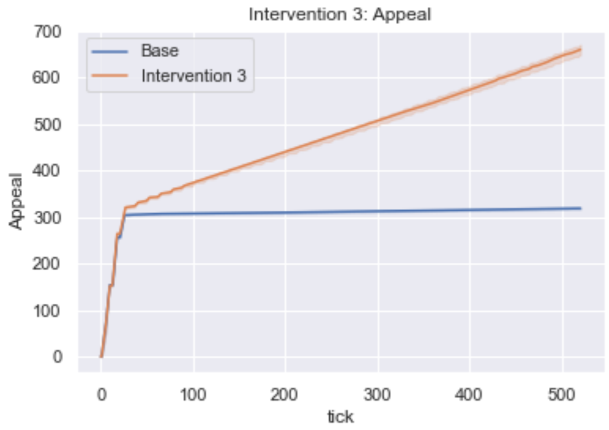




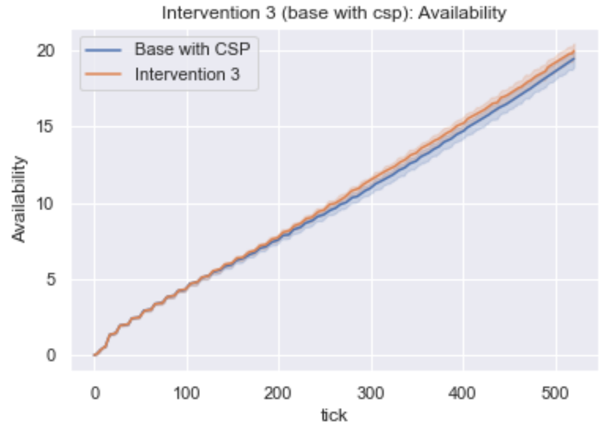


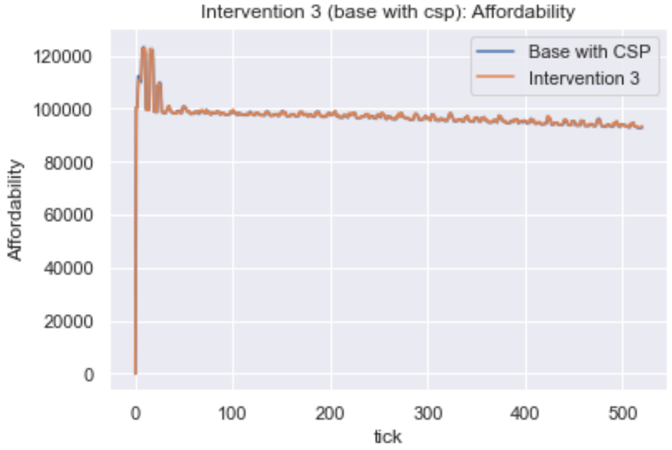


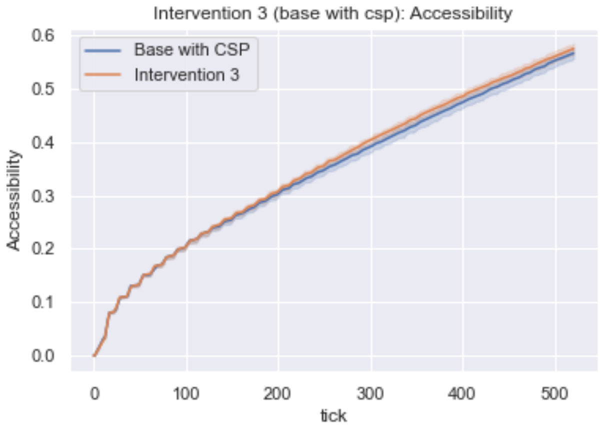


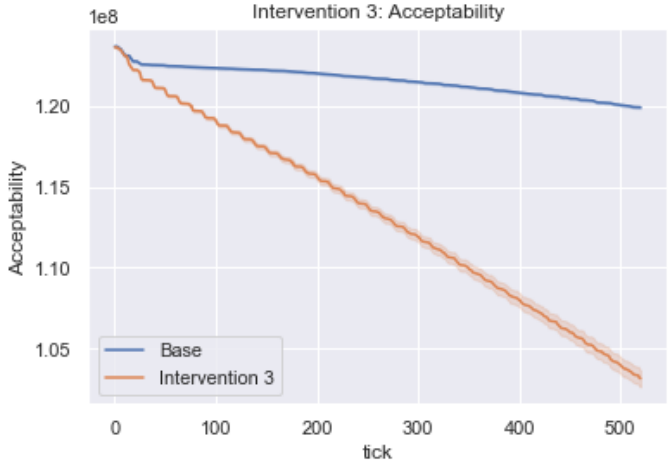


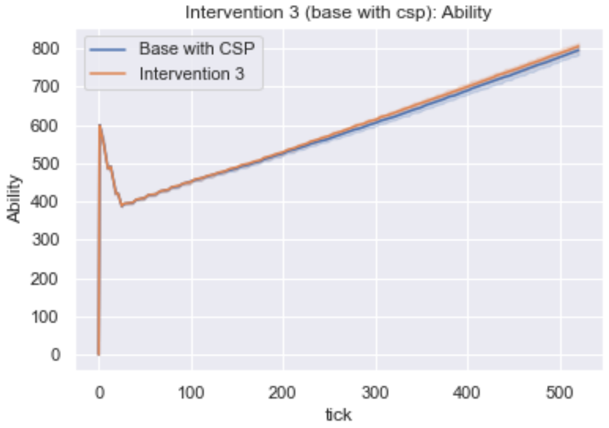
Intervention 3 scenario compared to base scenario with CSP

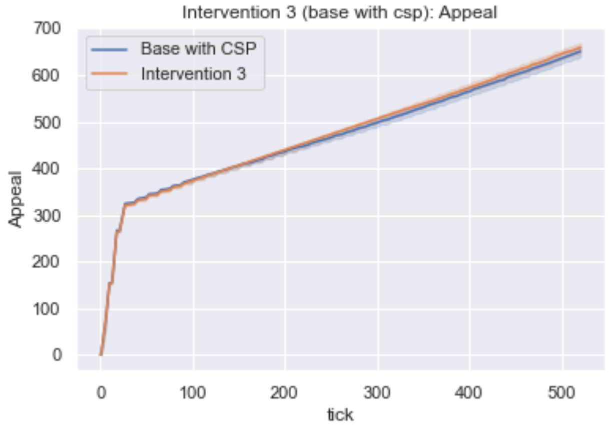












Combined interventions scenario compared to base scenario