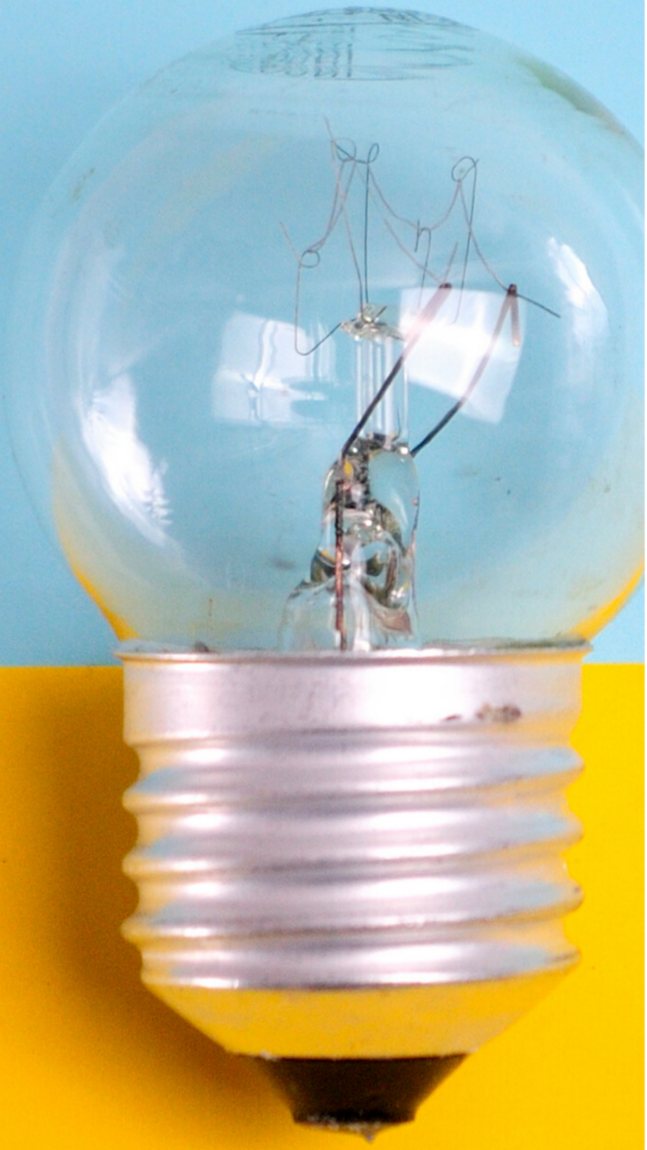

FINANCIAL INCENTIVES FOR THE DEVELOPMENT OF INDUSTRIAL ENERGY COMMUNITY SYSTEMS

Modeling of renewable energy generation in industrial clusters

Rafael Castelo Branco Ferreira Costa

MSc. Complex Systems Engineering & Management
Faculty of Technology, Policy and Management

This page was left intentionally blank

Financial incentives for the development of Industrial Energy Communities Systems

Master thesis submitted to Delft University of Technology

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in **Complex Systems Engineering and Management**

Faculty of Technology, Policy, and Management

by

Rafael Castelo Branco Ferreira Costa

Student number: 4735250

To be defended in public on June 16, 2020

Graduation committee

Chairperson	: Prof. dr. R.W Künneke, Economics of Technology and Innovation
First Supervisor	: Dr. A. Ghorbani, Engineering Systems and Services
Second Supervisor	: Prof. dr. R.W Künneke, Economics of Technology and Innovation
Advisor	: Ph.D. Candidate S. Eslamizadeh, Engineering Systems and Services

Preface

"Education is the most powerful weapon you can use to change the world."

Nelson Mandela

Nobel Peace prize winner 1993

Dear reader,

Welcome to my thesis, the final step on my journey to my master is in Complex Systems Engineering & Management degree at the Faculty of Policy, Technology, and Management at TU Delft. This study addresses the application of financial incentives in industrial energy communities for the generation of renewable energy. The path of developing this work was not gentle and with plenty of rocks on it, but I am very proud of the obtained result. This thesis is the result of a thrilling experience that started when I first received the opportunity to join the prestigious Technische Universiteit Delft. Moving to a new country, leaving behind family, friends, and a starting career was not an easy decision, but today I can affirm all the effort was worthy. Nevertheless, this realization is not the only mine, as I must thank everyone that helped me in this path.

Firstly, I am very grateful for my lovely wife, Karoline, who is my greatest supporter in all steps I took. She was the original drive for our academic career development, as she incited our move to the Netherlands and studies at TU Delft. Having her on my side was the main contribution to my achieved and future success. This thesis is also a way for me to honor my grandfather Joaquim Osório de Carvalho Costa, who unfortunately passed away while I was developing my studies. He was my greatest inspiration for studying engineering and will never be forgotten. My parents, Claudia and Fernando, along with their partners João Batista and Inara and my parents-in-law Sonia and Kurt, were also of immense support on our new life phase. However, in my academic life, I am immensely grateful for my grandparents Lena and Floriano, both University professors, who showed me how science and education could change the world. Mine aunts, uncles, sisters-in-law, brother-in-law, and cousins also gave me much support during my academic career.

I also want to thank my Committee. Amineh Ghorbani for accepting me as her student and bringing plenty of light and directions throughout this thesis development. Our conversations never failed to make me reflect appropriately on what needed to be done. Rolf Künneke for the lovely lectures during the master thesis, significant contributions for the understanding of the IAD Framework, and fantastic feedback. Sina Eslamizadeh gave me great insights and always a delightful conversation over the thesis and life. Every conversation with Sina was pleasant and refreshing. I could not have concluded this master without all of you. Thank you very much. I want to thank my colleagues in EY for all support and consideration of my work/study balance. Despite this thesis not being sponsored by the company, their comprehension of my challenges was crucial. Finally, I want to thank all my friends across the globe who became part of my life and are safe havens regardless of where I am. It is too unfair only to name a few, however, their support, feedback, and joyful moments together gave me strengths to overcome my challenges.

I hope you enjoy reading this work as much as I enjoyed writing it.

Rafael Castelo Branco Ferreira Costa

Delft, 16th of June, 2020

Executive Summary

The development of energy communities across the globe is a landmark for the development of decentralized generation, supporting the transition to renewable energy sources (Bauwens, 2016). With most of the energy being generated through depletable and pollutant sources, countries across the globe are facing increased difficulties to provide energy security of supply and attain to the environmental concerns. (International Energy Agency, 2019). Alternatives to the problem may be on energy communities. Energy communities following the Community Energy System model operate by forming local cooperative-like structures that enhance each member's potential, thus transforming consumers into prosumers, who produce and consume the energy generated at the communities (Koirala, Koliou, Friege, Hakvoort, & Herder, 2016).

Nevertheless, existing energy communities are focused on households despite the industrial sector being the largest consumer of energy globally. There is little attention given by governments and the literature on the development of industrial energy communities. Most of the research on the topic focus on Industrial Symbiosis and the physical exchange of resources between different industries (Hein, Jankovic, Farel, & Yannou, 2015). An alternative is to research such industrial communities with the same framework as Community Energy Systems. Such communities are Industrial Community Energy Systems (InCES). The core difference between InCES and Industrial Symbiosis lies in what is being managed. While Industrial Symbiosis focuses on the goods being exchanged, Communities Energy Systems focus on the managerial aspect of the community. With countries facing difficulties with increased risk in energy security of supply and environmental concerns, Industrial Community Energy Systems promotes more benefits by diversifying energy sources (Yergin, 2006), promoting renewable energy generation, and increasing flexibility in the system (Koirala et al., 2016).

However, unlike what happens in households, industries are business, and they need to be profitable. Economic feasibility is a vital aspect of any business, and companies do not embark on activities they do not expect profit (Boardman, Greenberg, Vining, & Weimer, 2012). With the increased pressure on governments on providing renewable energy sources, an action they can take to promote the energy generation in InCES is to offer financial incentives. A central issue is a lack of understanding of how different types of financial incentives influence the development of renewable energy in such communities, as current research and policies focus only on energy generation and exchange.

Therefore, this thesis proposes to evaluate the impact of financial incentives in Industrial Energy Community Systems through economic and community metrics, comparing how different policies perform under different environments. The three most common financial incentives applied globally and evaluated in this research are *Feed-in-tariff*, *Tax Incentives*, and *Tradable Green Certificates*. In doing so, this thesis developed a social-technical model that assesses how the application of those incentives changes the energy production within InCES. The comparison occurs between the incentives and a scenario where no incentive is applied. This model aims to understand how the elements of such a complex system interact with renewable energy diffusion through an economic perspective.

The proposed model was developed following the collective action IAD Framework developed by Elinor Ostrom in combination with Game Theory, Organizational Culture theory, and Cost-Benefit Analysis. Additionally, the model was data-driven, so to be generic and replicable. To achieve the expected generality, it is required to test the model in a different socio-economic context. Therefore, some countries were selected to provide their parameters. Sufficiently cultural and economic different nations were

chosen for this research, Australia, Brazil, Iran, Japan, the Netherlands, and the United States. However, without considering the simplifications of the proposed model, such a straightforward comparison may produce diverged observations. Therefore, the simulation was built with similar characteristics mock countries, named respectively Alpha, Beta, Gamma, Delta, Epsilon, and Zeta. The model was applied on an Agent-Based Modeling Simulation performed on the MESA package for Python, and the results interpreted with support of a Python Data Analytics code.

The obtained results indicate that the utilization of financial incentives does promote an increase in the amount of energy generated in industrial energy communities. When *Tax Incentives* and *Tradable Green Certificates* were applied, communities were able to produce more electricity, attracted more members, and provide energy at a lower Levelized Cost of Energy in most countries. Differently than expected, when *Feed-in-tariff* were applied, communities delivered the most unfavorable results, except for Epsilon.

Also, the results prompted questions regarding the goals of such policies. Depending on whom the policy analyst considers, the result may change. Such a policy can find choosing a policy for supporting either the communities or the government. Through the results, this research concludes that *Tax incentives* may be the best option if the policy goal is to increase energy production while reducing costs for communities. At the same time, *Tradable Green Certificates* showed better values if the goal is to increase energy production while reducing costs for governments. The last financial incentive, *Feed-in-tariff* only showed favorable values in Epsilon when governmental expenditure is considered.

This research also indicates that choosing between different types of financial incentives is a twisted path. The various incentives start from different premises, which implies different implementation methods and demands for expenses by the government at different times. For a proper analysis of which incentive to be used in a country, this research only provides results for the first step. Finally, this research contributes to supporting the development of policy analysis on promoting renewable energy by comparing the effects of different incentives on a simulated environment.

Table of Contents

List of Figures and Tables

Figures

Tables

List of abbreviations

ABMS	Agent-Based Modeling Simulation
CBA	Cost-Benefit Analysis
CES	Community Energy System
DG	Decentralized Energy Generation
FIT	Feed-in-Tariff
IAD	Institutional Analysis and Development
InCES	Industrial Community Energy System
IRENA	International Renewable Energy Agency
IS	Industrial Symbiosis
kW	Kilowatt
KWh	Kilowatt-hour
LCOE	*Levelized Cost of Energy*
MWh	Megawatt-hour
NPV	*Net Present Value*
OM	*Operations and Maintenance*
RE	Renewable Energy Generation
ROI	*Return on Investment*
Scenario 0	Baseline scenario with no incentive applied
Scenario 1	Scenario with the *Feed-in-Tariff* incentive applied
Scenario 2	Scenario with the *Tax Incentive* applied
Scenario 3	Scenario with the *Tradable Green Certificates* incentive applied
TGC	Tradable Green Certificate

Chapter 1 – [Introduction]

1 Introduction

This chapter introduces the general thesis view by providing an overview of the motivation for developing this study and overall thesis structure. The motivation for the topic choice is presented in section1.1. It leads to the research question, which is presented in section 1.2, and the report structure is presented in Section 1.3.

1.1 Motivation

Industries are a major contributor to economic development, but they are largely dependent on energy and its availability at the grid. Most nations generate energy mainly through hydrocarbon-based sources, namely oil, gas, and coal – also known as Fossil fuel. Such an energy matrix provides Energy Security of Supply (ESS) or the process of guaranteeing that consumers receive the needed energy when demanded. The concept of ESS was continuously evolving and became a vital aspect for the functioning of modern economies (Ellabban, Abu-Rub, & Blaabjerg, 2014; Enerdata, 2019; Farah & Rossi, 2015; IRENA, 2018; Kilian, 2008; Negro, Alkemade, & Hekkert, 2012; Yergin, 2006). Fossil fuel main characteristics are reliability, availability, easiness to stock, and distribution, making it the preferred energy source globally (Fattouh, 2016; Yergin, 2006). However, they are also a high pollutant and a depletable energy source (United Nations, 2015). Thus, relying on fossil fuel as the main source of energy will advance into an unsustainable scenario of complete depletion. Several countries are already facing this problem through higher costs of acquisition and guarantee of supply issues (Dincer, 2000; Farah & Rossi, 2015; International Energy Agency, 2019; Toke & Vezirgiannidou, 2013; Yergin, 2006). A lack of secure energy sources induces a scenario of deteriorating energy infrastructure, aged technology, transmission issues, instability rise which consequently hinders industrial development, directly affecting people's lives and the economy (Szulecki & Kusznir, 2018). Since industries consume a large share of the energy produced, uncertainties about ESS prompts a certain apprehension over developing industrial activities and consequently risk management strategies (Abdelaziz, Saidur, & Mekhilef, 2011; El-Katiri & Fattouh, 2015; Wheeler & Desai, 2016). To deal with such a problem, Renewable Energy (RE) sources are gaining traction as a feasible substitute for fossil fuel on energy matrixes (Bauwens, 2014) since they are non-pollutant and naturally replenishable sources (IRENA, 2018; Nasa, 2019). In other words, the industrial consumption of energy is susceptible to supply risks of fossil fuels, and renewable energy generation is perceived as a very promising solution.

Renewable energy sources like wind and solar energy became popular and economically feasible in several locations around the globe being contemplated as sources of significant future economic dividends and an important mark for future energy grids. This shifts the previous trend where for decades, RE sources were not considered as mass generation energy sources as they were not economically feasible (EPIA & AT. Kearney, 2010; EU, 2018a; Negro et al., 2012; Nordhaus, 2007; Staudt, 2011). Besides, wind and solar energy, when properly incorporated on the energy grid, can also contribute to a more reliable energy provision system (Koirala et al., 2016). Nevertheless, despite the observable advantages of RE, the adoption rate of such energy sources is slow, and several countries are failing short at implementing RE sources, due to its management complexity. Generating RE energy requires more sophisticated management and control systems when compared to fossil fuels (Bauwens, 2014; Negro et al., 2012). This creates a social-technical challenge for the expansion and diffusion of renewable energy. This challenge is intensified when it is questioned how to supply industries with renewable energy sources (Bauwens, 2014;

Ellabban et al., 2014; Negro et al., 2012; Toke & Vezirgiannidou, 2013; US Department of Energy, 2015). There is little hesitation in affirming the future of industrial energy consumption will diversify its sources to renewable ones (Dincer, 2000; Yergin, 2006). The major concern surrounding this topic is related to how to transition from our current situation to one where all energy is generated through renewable energy without disrupting reliability and providing economic feasibility (CMS, 2016; El-Katiri & Fattouh, 2015; Llop, 2018; Wheeler & Desai, 2016).

The most recent experiences in national energy matrixes that transitioned its core energy source bring to light some of those challenges and provides some good indication of how such a transition could occur. A crucial aspect of providing ESS is to provide a diversified energy source (Yergin, 2006). In countries leading renewable energy production, decentralized-small scaled projects act as key-drivers for their transition (Negro et al., 2012). Such projects were observed to be most efficiently promoted through a bottom-up approach, meaning in this case, that the people initiate the process (Van Der Schoor & Scholtens, 2015).

Among several possibilities on how to develop bottom-up approaches, the development of distributed energy generation through Community Energy Systems (CES) is promising, as it is capable of efficiently generate renewable energy with flexible demand while integrating different sources. Community Energy Systems are collectively organized energy generation systems for supplying a local community and its energy requirements. They focus on delivering high-efficiency co-generation of renewable energy technologies and demand-side management measures (Mendes, Ioakimidis, & Ferrão, 2011). A major advantage of using the Community Energy System approach is that they are better placed for understanding the local needs, demands, and individual autonomy. They are also better at dealing with trust in the system and among members (Bauwens, 2014, 2016; Koirala et al., 2016; Ostrom, 2010; Van Der Schoor & Scholtens, 2015; Veneman, Oey, Kortmann, Brazier, & De Vries, 2011; Wade, 1987; Warbroek & Hoppe, 2017). Nevertheless, most focus so far was set on how to develop households energy communities (Bauwens, 2014, 2016; Dincer, 2000; Ellabban et al., 2014; EU, 2018a; Koirala et al., 2016; Negro et al., 2012; Van Der Schoor & Scholtens, 2015; Warbroek & Hoppe, 2017). The literature little has published on how to develop Community Energy Systems composed of industries or, following the terminology, Industrial Community Energy Systems (InCES). As industries are important economic actors, providing more reliability and cheaper costs to industry will only benefit the nation (Darby, 2016; Kilian, 2008; Leemans & Vellinga, 2017; Llop, 2018). At this point, it is clear that to properly transition from fossil fuels to renewable energy, understanding how to develop industrial energy communities is a key element.

Performing a smooth transition goes through developing suitable energy policy, planning, and implementation. Policies describe how a procedure should be dealt with by actors and flirting over how to incentivize the desired behavior from society (Kingdon, 2013). A tool largely utilized by governments to promote such expected behavior is financial incentives, as they make the desired actions financially attractive (Bolderdijk & Steg, 2015; DellaVigna, 2009). Money is one of the most powerful sources of motivation and has the potential to reinforce certain behaviors, with the implicit assumptions that it will be effective in any circumstances. However, that is not always reality. Financial incentives are not always effective and sometimes might produce the opposite result (Abolhosseini & Heshmati, 2014; Bolderdijk & Steg, 2015; Furey, 2013; Palley, 2012). The three types of financial incentives most widely used by governments to promote renewable energy are *Feed-in-tariffs,* which is an incentive where the government buys renewable energy at a fixed price, *Tax Incentives,* where the government abdicates total or partially taxes applied in buy and/or installing renewable energy technology and *Tradable Green*

Certificates where bond-like certificates are issues for every certain level of energy production which can be traded just like stocks (Abolhosseini & Heshmati, 2014).

The success in the application of such policy can only be reached through proper planning and preparation, as there are no guarantees on how society will behave, since every individual may behave differently after assessing this new rule (Kingdon, 2013). Several techniques can be used to assess and attempt to predict how a policy impact on business. Perhaps the most common one is the Cost-Benefit Analysis (CBA). A CBA is a policy assessment method that quantifies in monetary terms the value of all consequences of a policy. It evaluates if it will be financially better to change or keep the *status quo* (Boardman et al., 2012), aiding decision-makers to choose the more efficient allocation of resources (Boardman et al., 2012; Bolderdijk & Steg, 2015).

Finally, policy analysts are recurring to modeling and simulation techniques, as they can provide a good structure for testing scenarios and possible outcomes. Despite all preparation, implementing a new policy may culminate in negative results. Modeling seeks to avoid such issues as it lays the structure to test scenarios within a simplified environment, where only the characteristics that matter is in place (Ma & Nakamori, 2009; Romero & Ruiz, 2014; van Dam, Nikolic, & Lukszo, 2013; Veneman et al., 2011).

1.2 Research Question

From the presented above, it becomes clearer that (i) renewable energy is a promising alternative for supplying industries, (ii) financial incentives can induce new behaviors, and (iii) there is little research on Industrial Energy Communities. Therefore, there is a gap in understanding how financial incentives may promote the creation of industrial communities to produces renewable energy. Hence, the goal of this research is to propose a model and evaluate how financial incentives can promote the generation of renewable energy through Industrial Communities Energy Systems. The hypothesis in this research is that the application of financial incentives enhances energy production in industrial energy communities if compared to a base scenario of no incentives. Also, it is expected that different types of financial incentives will produce different results when applied. Thus, the main research question which emerges from the above argumentation is:

Which type of financial mechanisms can incentivize industrial energy communities to enhance their energy production?

For answering the main question, this research must also answer some sub-questions:

A) What is a definition of the community energy system for industries?

This question aims at providing context on energy communities and what an industrial energy community would be. Such definition sets the background for the model development.

B) Which of potential financial incentive can be applied to industrial energy communities?

The literature on governmental incentives indicates that there are many types of possibilities and variations in each country. However, categorizing them, three main financial incentives classes are observed. As there is no way to test effectively test all variations, this research will focus on investigating the classes in different country environments.

C) How industries make decisions?

The decision process for industries is different than how individuals decide. To assess the impact of this difference, this research uses the Cost-Benefit analysis method along with Agent-Based Modeling and Simulation technique.

D) How does the interaction between industries influence their decision process to join community energy projects?

The literature on networks indicates that industries are connected, just like individuals, in a small network, where peers may influence the decision-making process. For the study of community development, how peers influence each other is an essential addition to the model.

E) What predefined metrics can be used to compare different financial incentives?

Comparing different incentive mechanisms is possible by applying them into a standard environment and assessing how some predefined metrics resulted from changing the incentive variables.

When dealing with models, it is essential to identify common factors, behaviors, and the interdependence between the model components; otherwise, the model will be impaired and not supportive (van Dam et al., 2013). Therefore, a first step in creating a valid model is to define the core element of what the model will replicate. The concept of energy community is the central node to this research, and from its optics, the other concepts can be further assessed. Bauwens define energy communities *as*

"formal or informal citizen-led initiatives which propose collaborative solutions on a local basis to facilitate the development of sustainable energy technologies and practices" (Bauwens, 2016).

The emergence of communities, as described by Bauwens, occurs through citizen initiatives, but this does not mean that no other party is excluded. This thesis goal focuses precisely on this aspect, where a government, seeking to understand such behavior, evaluates how it can assist such initiatives. Bauwens' definition leads to several areas of study that, in conjunction, support the research. The citizen-led initiative stands for an initiative that was originated by the population, and they are the core of Ostrom's work (Ostrom, 2005). The described situation can be further developed using the IAD Framework, which has the core feature of studying how actors behave when dealing with resource management(Ostrom, 2010). This actor's arena is in close connection to game theory, where Scharpf argues that citizen-led not necessarily means a single individual. However, actors can be a composition of individuals (Scharpf, 1990), and each actor (composite or not) has a respective decision-style preference (Scharpf, 1988). Looking over the possible modeling development methods, Agent-Based Modelling (ABM) presents several advantages for supporting business modeling, this research case. ABM is necessarily pertinent for studies over improving the decision-making of socio-technical systems as it considers the cognitive dynamic over the interaction of peer actors (van Dam et al., 2013). The combination of the above research areas can, therefore, bring some light over the research gap and aid the understanding of how actors react to different financial incentives and, therefore, identify its main bottlenecks.

In conclusion, considering a bottom-up approach for the energy transition, although there is a vast body of literature on energy communities, they focus on the development of communities made of households, but not on industrial communities or how financial incentives may affect such communities.

This work intends to fill in this research gap by suggesting a model on the formation of InCES. For that, some scenarios were created based on real-world data while utilizing a behavioral approach, where each actor takes decisions as the simulation advances. Ultimately, this can provide insights into the establishment of these initiatives and aid in designing better energy policies.

1.3 Report structure

The structure of this report continues with a literature review in chapter 2, where the industrial sector, energy communities, and renewable energy generation is analyzed with more details. Subsequently, the theoretical approach is presented in chapter 3, where the industrial decision-making process is presented along with the bedrock IAD Framework, followed with Game Theory, Organizational Culture Theory. The chapter also presents the economic theories introducing the financial incentives and the cost-benefit analysis. Lastly, the chapter also presents the research methodology. In chapter 4, the model is detailed, connecting all elements presented in the thesis and describing the storytelling of the simulation. Chapter 5 expands the simulation understanding by describing the experimental setup and presenting the real-life data collected. Later, chapter 6 displays the results from the simulation by detailing the obtained results of each metric. Finally, chapter 7 presents the conclusions with a summarization of the thesis, discussions over the results, and a personal reflection from the author.

Chapter 2 – [Literature Review]

2 Literature Review

This section presents out a literature review on industrial energy consumption, renewable energy, decentralized energy production, and energy communities, focusing on the literature about industrial energy communities. Section 2.1 widens the understanding of the industrial sector's unique characteristics. Section 2.2 briefly talks over renewable energy and the choice of utilizing only wind and solar energy in this study. Section 2.3 goes over with briefly explaining Decentralized Energy Generation, section 2.4 develops over what Industrial Community of Energy Systems are, and finally, section 2.5 presents some assumptions used on developing the model.

2.1 Industrial sector energy consumption

To date, the industrial sector has been the largest consumer of energy globally, yet it is also the slower sector to transition to Renewable Energy (Abdelaziz et al., 2011; El-Katiri & Fattouh, 2015; Wheeler & Desai, 2016). Energy is a primary resource need for different purposes in industrial facilities, being a crucial element of development. In 2015, only 14% of all consumed energy by the industrial sector had its origin from a renewable source (IRENA, 2018). Nevertheless, the industrial activity utilizes energy-intensive processes that require a series of complex tasks, making a transition to RE, not a simple activity. Even so, there is a significant potential for improving efficiency in the industrial sector. By adopting energy-saving policies, best available energy-saving technology, demand management, and renewable energy generation, the global consumption of fossil fuels can be drastically reduced (Abdelaziz et al., 2011; IRENA, 2018).

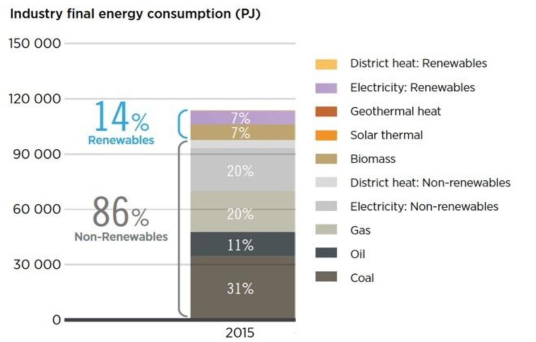

Figure 1 - Industrial energy consumption (Abdelaziz et al., 2011)

Due to its importance, industries have a robust procurement system in place to guarantee the security of supply and minimize the risks of not having available energy when needed, besides adding flexibility for sourcing energy (Yergin, 2006). Previous experience has demonstrated that to provide security (i) energy sources must be diversified, (ii) the managing system in place must be resilient, (International Energy Agency, 2019; Yergin, 2006). However, this is not a reality observed. Most national energy matrixes rely heavily on hydrocarbon-based (non-renewable/ fossil fuel) sources, such as oil, gas, and coal. In 2018, the primary energy sources globally were all non-renewable, with Oil as the most used source of energy - 32%, followed by Coal - 26%, and Gas - 23% (Enerdata, 2019). These sources have some downsides such as being depletable and highly pollutant, despite having easy access and relatively low cost (United Nations, 2015). Besides, some national systems in place are flawed by old design premises, which also hinders energy security (Toke & Vezirgiannidou, 2013; Van Der Schoor & Scholtens, 2015).

In sum, industries have a high demand for energy, with some hassle to guarantee the supply needed from fossil fuel sources, the primary energy sources in the world, creating insecurity for future planning. Renewable sources, on the other hand, can be procured and installed in combination with other renewable sources to minimizes the risks related to energy availability. Firstly, renewable generation plants can quickly harvest energy from non-depletable sources like the sun and wind. Additionally, they can be installed closer to the consumption location, minimizing the distribution risks, and with some managerial system in place, wind and solar energy can also ensure a reliable energy provision (Koirala et al., 2016).

2.2 Renewable Energy

Renewable energy is a broad definition of several technologies that produce energy from sources that are naturally replenishing (EIA, 2019). The most common RE technologies across the globe are wind, solar, biomass, hydropower, and geothermal energy. Such sources can help reduce climate variations while ensuring a reliable and (relative) cost-efficient energy (IRENA, 2018), providing significant dividends for our energy security and is an essential mark for future energy grids (Staudt, 2011). Therefore, transitioning to a RE supply is strategically important, but doing so is not a simple task. Depending on geopolitical variables such as geographical location, grid management, and monetary policies, energy availability, and production cost may not be as cheap as fossil fuel (Ellabban et al., 2014). However, not all renewable energy sources have the same feasibility, and they can significantly differ in terms of approach, production, and economics (Nordhaus, 2007); thus, not all technologies are feasible for being applied in any country context. For example, Biomass, Hydroelectric, and Geothermal energy have substantial limitations over installation locations, which severely hinders any feasibility analysis on locations where it cannot be installed (Koirala et al., 2016).

As national grids were built on supplying energy when demanded and with demand varying by the minute, wind and solar energy burden the issue of intermittency (Farris, 2016; Koirala et al., 2016). Solar energy is only able to generate energy during daylight hours, and wind energy is vulnerable to the climate and wind forecast. Both technologies do require a more sophisticated level of generation and distribution management when compared to fossil fuels (Bauwens, 2014; Negro et al., 2012). On the other hand, both technologies have minimal geographical limitations, with the wind generation being possible in most of the globe and solar energy finding feasibility even in high latitudes (EPIA & AT. Kearney, 2010; Negro et al., 2012). Contributing to the development of renewable energy, in recent years, concerns over protecting and preserving the environment started to emerge, pushing governments to review their position over their energy matrix. Transforming the access to affordable renewable energy is a vital activity to guarantee a better environment along with functioning economies, being this a significant concern for nations (Ellabban et al., 2014; Farah & Rossi, 2015).

2.3 Decentralized Generation

Energy production has been historically a centralized process organized by national governments. However, more recently, the idea of investing in locally developed systems has gained traction among researchers and grid operators as it increases system efficiency. This concept is known as Decentralized Energy Generation (DG), where instead of large power plants supplying several locations, smaller distributed energy producers supply individual (or clustered) locations (Koirala et al., 2016). As traditional fossil-fueled generation plants are reaching the end of life or being retired, new generation sources are needed to cover energy needs (Bauwens, 2016; Koirala et al., 2016). DG provides many advantages when compared to a centralized generation. For example, DG has a much higher degree of flexibility for generation and easiness to expand the energy park due to its modularity (GE Power, 2018). Also, by having producers and consumers closer together, transmission and infrastructure costs are reduced, enhancing feasibility (Bauwens, 2016; GE Power, 2018; Koirala et al., 2016). Besides, current research indicates a government acting alone does not lead to the successful development of DG projects, there is the need of support from firms and the population (Hein et al., 2015). Nevertheless, as this approach requires an active citizen involvement, transitioning to these decentralized energy generations presents itself as a social-technical problem, being studied mainly in recent years through the field of energy communities (Bauwens, 2014; Van Der Schoor & Scholtens, 2015).

2.4 Community Energy Systems

Energy communities following the CES model operate by forming local cooperative-like structures that enhance each member's potential, thus transforming its members from consumer to prosumers, who produce and consume energy. This model is surging plenty of interest from researchers and governments across the globe for its advantages (Koirala et al., 2016). Part of such success lays in the community-ownership structure, which is demonstrating to be suitable for promoting engagement, enhancing awareness and promoting a more reliable and cleaner energy supply, by focusing on the organization management of the community (Bauwens, 2014; Koirala et al., 2016; Negro et al., 2012; Van Der Schoor & Scholtens, 2015). CES promotes its members to work together in the community, enhancing individuals' benefit when compared with their performance alone (Romero & Ruiz, 2014). Such communities can organize themselves either by 1) supplying cheap(er) energy to its members (compared with a large energy supplier) or by 2) selling energy production to the market and yield financial income to its members as stakeholder dividends (Bauwens, 2014).

The motivation to produce renewable energy, and consequently, to join an energy community vary widely per individual, undeniably being related to self-regard. Motivations may range from simple ideological believes to complex financial returns (Bauwens, 2016). Such communities also attract the interest of the population by widening the range of possible energy projects. Members in energy communities can expand their investments into more significant, more sustainable, and more profitable projects (Bauwens, 2014, 2016; Negro et al., 2012). Independently of motivation, joining an energy community brings economic advantage as such communities are capable of reducing member's expenditures in their projects. When dealing in cooperative-like structures, soft costs can be unified and simplified, enjoying economy of scale advantages and reducing the overall costs of community-wide projects (Bauwens, 2014; Hein et al., 2015; IRENA, 2019; Strupeit, 2016). Examples of soft costs are analogous expenditures such as planning, designing, permits, legal fees, management, financing, and other activities not related to the installation itself.

Despite the benefits of community-owned infrastructure, this approach is still underappreciated in many locations and sectors, such as the industrial sector (EU, 2018a), and the literature on the development of energy communities is mainly focused on households (Bauwens, 2014). There is plenty of literature on topics CES topics such as their key-issues, members motivations and the role of CES on distributed generation (Bauwens, 2014, 2016; Dincer, 2000; Ellabban et al., 2014; EU, 2018b; Koirala et al., 2016; Negro et al., 2012; Van Der Schoor & Scholtens, 2015; Warbroek & Hoppe, 2017). Still, studies on industrial energy communities are the exception, despite industries being the more significant energy consumers globally. The limitation on literature has to do with the differences that make industries unique, as it is presented in Section 3.1.2. Nevertheless, in contempt for the lack of research, some ventures are being developed in this field.

2.4.1 Industrial Community Energy Systems

Industrial Community Energy Systems can be seen as CES with industries as its members. Having the literature deepening how energy communities may benefit decentralized generation, in particular on small household generation, it still lacks more understanding of how the same principles can be applied to more significant energy consumers like industries. The existing literature on industries' energy communities is primarily focused on the physical exchange of energy, either by transferring heat, potential energy, or biomass (Hein et al., 2015). This type of community is known in the literature as Industrial Symbiosis (IS), which is a topic gaining traction as it introduces a concept on how industries may combine efforts to optimize resources (Chertow, 2000; Hein et al., 2015). Industrial Symbiosis is a research area from industrial ecology that seeks to understand how industries can best deliver value through improving resource management and processes having the environment as a stakeholder. The core of IS goes through combining input and output of different industries so to minimize by-products and inefficiency (Hein et al., 2015). As with any novel research area, a concise definition of IS is not yet ultimately settled. A widely cited definition is that

"*Industrial Symbiosis engages traditionally separate industries in a collective approach to develop a competitive advantage involving a physical exchange of materials, energy, water, and by-products, aiming long-term availability of critical resources"* (Chertow, 2000).

The definition above exposes the significant difference between Industrial Symbiosis and Community Energy Systems. The first aims at the physical exchange of materials while the latter on how members can cooperate in supplying the energetic needs of its members (Koirala et al., 2016). The core of the IS model appraises for value generation and physical objects management, while the members' inter-relationships are not even considered. The essence lies in physical goods (Chertow, 2000; Hein et al., 2015). Despite such difference, there are successful elements from IS that InCES can be inspired. The most prominent one is the advantages of the physical organization model described in IS, here translated into the industrial park design. Industrial Symbiosis is getting notoriety for its capacity to physically organize industrial parks by placing the role of navigating informal relationships and defining the strategy for the physical location of industries within the park. This makes Industrial Symbiosis better prepared for dealing with industrial park development issues than any central power management (Saleman & Jordan, 2014).

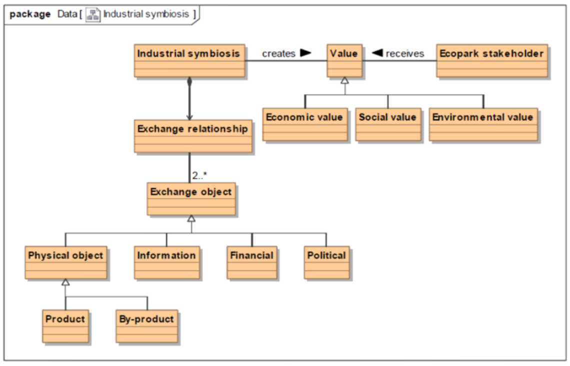

Figure 2 - Industrial Symbiosis model (Hein et al., 2015)

2.4.2 Industrial Parks

Being part of an industrial park, in theory, eases utility and facility management. For such reasons, several global organizations are observing a trend of industries clustering on industrial parks and decided to research the topic (United Nations, 2017). In such locations, logistical access for public utility infrastructure is facilitated, providing advantages for the industries by agglomerating the demand and optimizing resources (Saleman & Jordan, 2014; United Nations, 2017). Researches are probing how such clusters can better operate, prompting further research on how to provide energy to industries in a broad context. Some initiatives are looking over several aspects of it, such as the Nefi initiative in Austria (Nefi, 2018) or the United Nations Industrial Development Organization initiatives across the globe (United Nations, 2017). These types of research are driving investigations to go beyond just physical exchange of goods but to glaze at behavioral science and management systems design (Beloborodko & Rosa, 2015; Hein et al., 2015), in an organization similar to Communities Energy Systems, but with Industries as members. Further, Hein indicates that there is currently no approach for assessing industrial park performance across different economic and regulatory contexts (Hein et al., 2015), reinforcing the need to expand the knowledge of industrial parks to beyond physical goods. As behavioral science studies on the topic still need to advance, many researchers are leaning towards collective behavior modeling.

2.4.3 Industrial park modeling

The literature on the behavioral modeling of energy systems leans over to systems engineering and Agent-based Modeling as it can translate the problem into requirements and further on into a high-level design of the system at study (Hein et al., 2015). This systemic approach explores both classical criteria such as costs and performance but also non-traditional such as resilience and synergy (Hein et al., 2015; van Dam et al., 2013). Researches in energy systems through a systemic approach basically look over how to develop working frameworks that can be applied to several types of systems. Such frameworks serve as a basis for building tech-economic models of the observed system internal elements, recognizing key-elements that must be considered when developing any model (Hein et al., 2015; Romero & Ruiz, 2013; van Dam et al., 2013). By doing so, the exploratory nature of the present approach is reinforced, and the hindrances observed during industrial park operations can be better understood (Hein et al., 2015; Romero & Ruiz, 2014).

Roughly, there are two variants of researches in this field (i) those who develop a conceptual framework focusing on the integration of individual processes (Beloborodko & Rosa, 2015; Cao, Feng, & Wan, 2009; Chertow, 2000; Romero & Ruiz, 2013) and (ii) those that focus on management systems (Koirala et al., 2016; Mendes et al., 2011; Van Der Schoor & Scholtens, 2015; Veneman et al., 2011). The first type aims at optimizing individual results through minimizing loss and reusing goods when possible, or as described by Romero & Ruiz, *"Looking at industrial parks whose goal is to obtain a better overall performance through strategies such as creating a network of material exchanges between companies"* (Romero & Ruiz, 2013). On the second variant, the goal is to develop frameworks that *"are worth exploring for decision-makers looking to gain further insight into their domain"* (Veneman et al., 2011). In this approach, there is a need *"to understand crucial components of ABMs, such as social interactions and the diffusion of knowledge and information"* (Janssen & Ostrom, 2006). With the framework at hand, defining a model becomes naturally, presenting the internal socio-technical networks, which suggests that ABM can be used to predict and analyze agent's behavior, resulting in operational improvement of industrial parks (Janssen & Ostrom, 2006; Romero & Ruiz, 2013; van Dam et al., 2013).

2.4.4 Financial Analysis

The financial aspect of projects and systems is part of the classical criteria for the evaluation of alternatives. In Energy communities, 'Costs' and 'Benefits' are related to the economics of the market as well as other social concepts, resulting in added value (Hein et al., 2015). When dealing with Renewable Energy sources applications, there is still much uncertainty regarding the feasibility of the project, especially on understanding the expected benefits and costs incurred. For this, the well-known Cost-Benefit Analysis has been used in several types of research and provides a suitable method for such evaluation (Mathioulakis, Panaras, & Belessiotis, 2013). A central point when deciding for an economic evaluation methodology is to mind the usefulness of the method to the observed scenario. The CBA method aims for an overall assessment of the project under investigation as it takes into consideration all the costs and benefits parameters from the defined point-of-view, making it a suitable method for CES (Mathioulakis et al., 2013). This gives the CBA method a huge advantage when assessing renewable energy projects as it is flexible enough to be applied in any type of scenario (Boardman et al., 2012).

2.5 General assumptions

The main assumptions in this research are related to the extension of the model. As models are a smaller-scale representation of reality, there are some trade-offs between scale and how generalized the results can be. If a model is of higher complexity and closeness to reality, perhaps it is simpler to already implement the design in reality. On the other hand, limited models may not provide useful results. Therefore, it is for the modeler to determine the best scale of its model to obtain the desired results (Ma & Nakamori, 2009; van Dam et al., 2013; Veneman et al., 2011). In this research, the main assumption is to be data-driven research utilizing real-life data so to bring an extra degree of reality into the results.

Concerning the wider spectrum of renewable energy generation, this research will focus only on wind and solar energy. This choice is justified as both energy sources, in theory, can be applied in any location globally, and no other technology has such a wide field of application. Additionally, other sources of renewable energy such as biofuel, tidal energy, hydroelectricity, or geothermal are very susceptible to availability are many locations, thus making it hard to be considered on this general research. Also, for their peculiar utilization, energy optimizations technology, such as combined heat, hot air, or hot water reuse and technical optimizations as grid balancing and baseload demand, are not considered in this research. The reasoning lies in the fact that this type of technology is much related to productive efficiency and not to community development.

For last, this research adopts a simplistic economic view on choosing between wind and solar energy. It is assumed that noise pollution, available area, and grid connections are solved topics solved when the installation and all costs related to such issues are included on the “installation budget”. This assumption was made for simplicity of calculation, and this research focuses on the economic aspect of renewable energy and not on project management of renewable energy.

Chapter 3 – [Research Approach]

3 Theoretical approach

This section will provide a summary of how the research will approach to answer the research questions. Here the main theories used for answering the problem will be further explained. In section 3.1.2, the decision-making process by industries is briefly explained. Section 3.1.3 will provide the overall theoretical background by presenting the IAD Framework with a brief explanation of the collective action theory, followed by game theory in section 3.1.4 which investigate how people interact with each other and is complemented with Hofstede's Organizational Culture model on section 3.1.5 In Section 3.1.6 details out the Cost-Benefit Analysis and 3.2 summarizing the theoretical approach. Finally, section 3.3 presents the research methodology based on the literature review and theories.

The thesis goal is to understand how elements of a complex socio-technical system interact with each other promoting the diffusion of renewable energy through an economic perspective. As the behavioral aspects of the actors is a central piece to the research question, this poses as elements of a Complex Adaptive System (Cao et al., 2009; Romero & Ruiz, 2014; van Dam et al., 2013). The main characteristic that leverage ABM for this research is the focus on individual agents that can be programmed to interact the same way as real actors while experiencing the same constraints, thus easing the study of Complex Adaptive Systems (van Dam et al., 2013). In an ABM simulation, agents' interactions are inflicted by previous decisions taken and by the environment; ABM commonly assumes decision-makers make adaptive plans based on results created by their previous decisions. By taking in the agent dynamics, it captures the collective action overtime under different variables ranges (Janssen & Ostrom, 2006; Ma & Nakamori, 2009; van Dam et al., 2013).

3.1 Theoretical background

3.1.1 Agent-Based Modeling & Simulation

For the problem presented on how to develop industrial CES, Systems engineering provides a good approach as it is able to translate the problem into requirements and further on into a high-level design (Faulconbridge & Ryan, 2014). By formatting the problem in such a way, the next steps, following a systemic approach, are to develop a conceptual framework and a techno-economic model derived from such a framework (Hein et al., 2015). The resulting model thus is an attempt to understand the problem and how to overcome it. To unravel the complexity of such energy systems, ABM has shown promise as an effective and practical tool as they are considered in the literature as Complex Adaptive Systems (Cao et al., 2009; Romero & Ruiz, 2014; van Dam et al., 2013).

ABM, which is increasingly influential in many fields of social science, can be applied to situations where it is wanted to study macro-level complexities for the interaction of simple systems components which prompts the emergence of complex behavior, on a bottom-up approach (Cao et al., 2009; Ma & Nakamori, 2005). The literature indicates Agent-Based Modeling and Simulation as a good way to deal with such type of problem, as it creates a simplified representation of reality, easing the research while breaking free the constraints imposed by the need to obtain analytical solutions and mathematical formulations (Beloborodko & Rosa, 2015; Cao et al., 2009; Romero & Ruiz, 2014; van Dam et al., 2013). Being a great fit for the proposed problem.

Besides, Modeling provides the ability to add time variable into the studied scheme, allowing to examine different scenarios and understand inputs, variables, and outputs with little effort, enhancing the investigative power (van Dam et al., 2013). Lastly, Agent-Based Modelling characteristics provide good support for business models as it is essentially related to improving the decision-making of socio-technical systems (van Dam et al., 2013).

3.1.2 Industrial decision-making process

When dealing with the decision-making process of industries, they can be classified as composite actors, meaning that the collective of people who act in a decision-making process within an industry can be considered as a unitary actor, owning a much more complex decision process (Keeney & McDaniels, 2008; Scharpf, 1990). Scharpf presents composite actors as

> *"Even though individuals may have considerable difficulty in managing their 'multiple selves', their partners and opponents will generally not hesitate to treat them as unitary actors*" (Scharpf, 1990).

The single actor decision-process, such as a household situation, can quite simple as individuals may decide not based on finance or performance but on preference or ideology, expensing as they please, and the literature considers them as being purely self-regarding, looking only for their payoffs (Bauwens, 2016). Industries face a different reality. As they exist to produce goods or services and deliver a financial result from it constantly, the high management seeks to optimize their productivity by adjusting its internal processes, which are connected and occurring in parallel. Thus, making any change in one process might affect other processes, and consequently, any decision made must have its impact deeply evaluated, increasing the complexity to implement changes (Rajan, 2010). Also, decisions are taken in the majority of cases by a large number of people, either by C-level management, a board of directors, decision board, employees voting, an owning family, or a combination of these (Scharpf, 1988; Sheu, 2019). The larger number of deciding individuals makes a corporate decision be a multi-actor decision process. However, despite spreading the decision to more people, this does not reduce the individual desire of each decision-maker to increase her knowledge and reduce her rationale limitations (DellaVigna, 2009). Within the company's borders, management has the power to adopt many different types of rules over determining what hierarchy structure will be applied, and how decisions will be made (Ostrom, 2005; Storm & Naastepad, 2012).

Additionally, industries must also consider a wide spectrum of variables. Industries need to evaluate its public image, policies, political scenario, national economic, productive capacity, the decision-makers' knowledge, which leads to the development of some sort of analysis. Due to its complexity, no decision is made looking only for a single factor or in a single plane, at least two different points of view are needed to provide reliable information for decision-making. Also, companies have a natural preference to make deals with other companies that share the same corporate values (DellaVigna, 2009; Sheu, 2019). The sum of these variables ultimately assembles a Cost-Benefit Analysis, which reflects on pricing, sales, and culture (Boardman et al., 2012; DellaVigna, 2009; Llop, 2018; Sheu, 2019). As a result, the decision-process of each company ends up following its unique decision-making framework, with a set of decision-rules, styles, and internal policies that guide the industry to fulfill its individual goals and navigate along with other actors (Scharpf, 1988).

Furthermore, industries are influenced by benchmarks and what other peers are doing. Their network might be of influence on their decision to start an activity or join a new group. Network theory argues that every individual follows a collection of social ties, with 'some degree of randomness,' which in the literature is known as a small network. Such connections have a high degree of influence on their decision-models and how decision-makers perceive their options. In practical terms, this means that by default, every industry has a weak connection to other companies they know, which not automatically prompts substantial interactions. These weak connections represent the acquaintances that connect us to other parts of the network, which are too far (Easley & Kleinberg, 2010). Nevertheless, each individual's network also has a strong network, following the homophily principle, of people connecting to similar others. This principle is what creates several interaction triangles, which for companies translates to having a network of partners, suppliers, buyers, other companies on the same group, among others. The strong network provides a richer influence on each other's decisions providing orientation to individuals in a relationship that resembles *friendship* (Easley & Kleinberg, 2010).

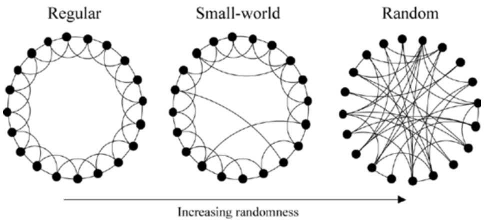

Figure 3 - Small-world network and randomness (Easley & Kleinberg, 2010)

Small networks are presented graphically through *Graphs,* but they can also be mathematically calculated. A very useful small network model for the type of relations enterprises have is the Watts-Strogatz model. This model proposes a circular graph with each node connecting to their neighbor nodes and a probability to rewire and connect nodes across the graph, shortening the paths between nodes (Easley & Kleinberg, 2010). This depicts a very close representation of reality as companies have a connection with their neighbors but may be better related to another company much far away.

3.1.3 Institutional Analysis and Development Framework

The foundation of the problem-at-hand stands on being in a collective setup, where there are different types of actors interacting with each other. Transitioning to renewable energy can be engaged basically in two ways, through a top-down approach or a bottom-up approach. In this thesis context, the top-down approach is perceived as the change is initiated by a government who historically controlled energy production. Such change could occur through the development of a new policy or actions taken by state-controlled companies, which private companies would follow afterward when feasibility is perceived. Oppositely, in the bottom-up approach, the society organizes itself to introduce change (Van Der Schoor & Scholtens, 2015), thus, challenging the presumption that governments always do a better job than users when organizing local resources (Janssen & Ostrom, 2006). As this thesis deals with communities generating electricity through renewable sources, and communities are the result of self-organizing actors, the bottom-up approach is the preferred way. In the literature, this approach is known as Collective Action (Ostrom, 2005). Seeking to deepen the understanding of how a community might act to solve a local problem, Elinor Ostrom developed the Institutional Analysis and Development (IAD) framework for supporting research on bottom-up approach scenarios (Ostrom, 2010).

In a nutshell, the IAD Framework provides a structure with basic elements on how actors interact and develop interpersonal relationships when handling specific group situations. As the framework is composed of several levels of detail granularity, it is capable of providing valuable insights on how to develop conceptual models (Janssen & Ostrom, 2006), delivering the building blocks to develop actors' interactive models (Bamberger, 2010; Ostrom, 2005). Ostrom's work can provide a significant contribution to researches by making explicit the components of a polycentric system with many centers of decision making, independent from each other, refraining from "*one size fits all*" policies (Ostrom, 2010). Looking into the framework components (shown in Figure 4), the central component of the framework is the action arena (action situations). There, actors interact with each other yielding outcomes, which are then assessed by individuals over if it was positive or negative interaction. Depending on the outcome, actors might want to keep the structure as it is or commit to change it if she believes that the outcome was not suitable for her expectations. This can be achieved by the actor changing its strategy or changing the other building blocks in the external variables (Ostrom, 2005). Understanding the external variables can bring out new insights on how actors may behave in the action arena. The external variables are the rules-in-use, community attributes, and the biophysical conditions surrounding the action arena.

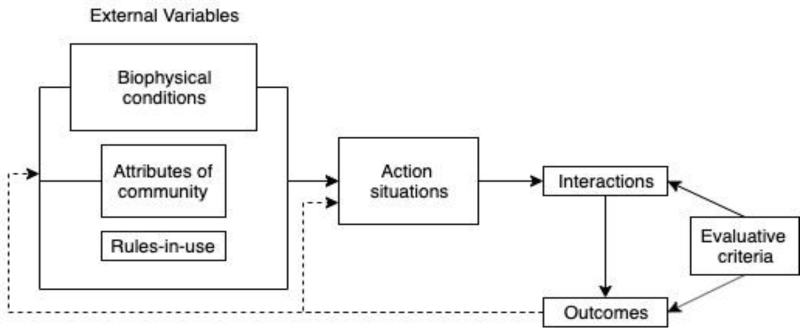

Figure 4 - IAD Framework (Ostrom, 2005)

The term rule has many meanings, but in the context presented in this study, rules should be understood as a set of instructions for creating actor interactions in a particular environment. This description is largely inferred with a regulation sense, as set by an authority power (Ostrom, 2005). However, this does not imply that individuals will only follow the rules if they are enforced. Individuals are expected to voluntarily participate in a situation if they share an understanding that the rules in place are appropriate, constituting some sort of game (Ostrom, 2005; Scharpf, 1990). If the rules are not well understood by the players, they might fatefully develop their interactions into a destructive cycle, eventually reaching failure and even situations where no player wins (Basurto & Ostrom, 2009; Ostrom, 2014). Failure in the Action arena means that the incentives facing individuals in a situation where the rules are insufficient to motivate individuals to produce, allocate, and consume these goods at an optimal level (Ostrom, 2005). Therefore, the set of rules can lead a community for success or failure, prompting the research to understand rules and their effect on an actor's behavior. The stability of rule-ordered communities is very much dependent upon this shared understanding of its value, as there is always a chance for participants to break the rules. Besides, all actors have the freedom to leave the group and new actors to join (Ostrom, 2005), leading to a grasp on community settings, or which are the attributes of the community. As this thesis, is looking over the role of financial incentives in community development, the rule in use observed are the possible financial incentives for renewable energy, which are detailed in section 4.4.

The nature of the community within which the arena occurs is defined on the community attributes. The concept of community has many definitions, but for this thesis, for a community to exist, it depends on having shared values and elements which can characterize the community apart from other groups (Ostrom, 2005). This includes the accepted behavior values, a common understanding of the structure of the action area, the extent to which the community is homogeneous, and how much actors feel part of it. The attributes of the community are often associated with Culture, as culture affects the mental model of participants. Culture evolves, affecting how the actors develop and, consequently, the way participants understand the rules (Ostrom, 2005). A deeper look into the cultural aspect of communities is presented in section 3.1.5, where Hofstede's Organizational Culture model is presented.

The last external variable is biophysical conditions. This concerns what is physically possible and what type of good or service is being dealt with by the community. As with the same set of rules, different outcomes are possible based on the type of good being handled. Understanding biophysical conditions is a question of how is the world affects the possible outcomes? Answering this question goes through understanding what goods the community has. Goods can be classified in several ways, following many different economic theories, but in Ostrom's definition, Goods are classified by two basic attributes: Exclusion and subtractability. Exclusion relates to how difficult it is to restrict access to the goods by any actor and subtractability refers to the extent to which one individual utilizing the good reduces availability for others to consume (Ostrom, 2010). Different types of goods influence how much a set of rules needs to be sophisticated and effective (Ostrom, 2005).

		Substractability / rivalry	
		High	Low
Excludability	High	Private goods *Food, clothing*	Toll goods *Theatre, private clubs*
	Low	Common Pool Resources *Fisheries, forests, atmosphere*	Public goods *National peace, fire protection*

Figure 5 - Typology of goods (Ostrom, 2010)

For this thesis, the considered aspect of biophysical conditions is a simplified observation of the type of good being handled by the community. Electricity is characterized by a particular attribute, such as not having significant variations in consumption by changes in price. In other words, it is not because energy got cheaper that people immediately start to consume more, classifying it as an inelastic good. Nevertheless, there is a limit to this inelasticity. If prices are higher than an individual's budget, she will not be able to afford this good and will stop purchasing it. On the other extreme, despite prices being too low, purchasing electricity still implies some sort of affiliation with the producer (Boardman et al., 2012; Storm & Naastepad, 2012). The model developed follows the above description. The electricity produced by the community is delivered to its members through the general electric grid, with only members having access to the more affordable energy tariff (*high exclusion*). Also, as the production is limited and a member utilizing the produced energy restricts the amount of energy available for others (*high subtractability*). By this description and the typology in Figure 5, the electricity produced by the community is a Private Good (Ostrom, 2010). A characteristic of Private goods is that it requires members to pay for accessing the benefits of such good. In this research, this can be translated as paying to become a member of such a community.

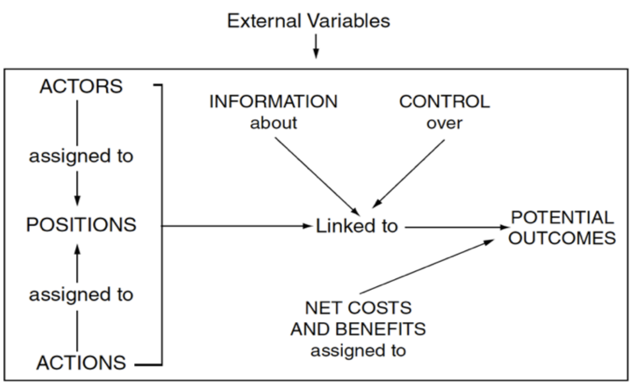

Figure 6 - Internal structure of an Action Situation (Ostrom, 2005)

Another element of the framework with interest for this research is the Action arena as it maps out the actors and actions taken by them at decision nodes being where the actors interact and produce results. The details of the action situation are presented on Decisions taken by individuals consider a larger arrange of inputs, the possible outcomes, and reflection of such outcome on itself. In a nutshell, individual decisions with a group setting are influenced by the social interactions surrounding the decision-maker, pressing the decision-maker to grasp better the game being played (Scharpf, 1990). When entering an action arena, no actor starts ignorant but bears with them previous information, knowledge, and values. Such traits are depicted in the IAD framework as external variables that prompt each actor for a position in the arena. Having a defined position, actors initiate a series of interaction, where each actor gain new information and create new links while assessing net costs and benefits of the potential outcomes of being in such arena (Ostrom, 2010). These interactions in literature are known as a game and are the object of the study of Game theory (Ostrom, 2005; Scharpf, 1990), better depicted in the following chapter. It is important to note that in the action arena, actors may craft their own intragroup rules, in addition to the already societal rules. By doing so, the group enhances governance and control within the community (Ostrom, 2005). Compliance with such a governance system may depend upon the legitimacy of choice made, referencing how the group decides. A group decision is the sum of individual decisions in which results are applied and reflected upon by all members. Decisions taken by individuals consider a larger arrange of inputs, the possible outcomes, and reflection of such outcome on itself. In a nutshell, individual decisions with a group setting are influenced by the social interactions surrounding the decision-maker, pressing the decision-maker to grasp better the game being played (Scharpf, 1990). So, to better understand possible outcomes and how other actors will decide, this research leans towards the literature on game theory.

3.1.4 Game Theory

Game theory is an area of mathematical logic that studies interdependent strategic behavior over conflicts between opponents through a precise analysis of the conflict (Poundstone, 1993; Spaniel, 2011), restricted by the actors bounded rationality and has its focus in understanding the outcomes of such interaction (Scharpf, 1990). A formal definition of a game is a conflict situation where one player selects a choice rationally (in opposition to a random choice) while understanding that the other player will also make rational choices (Scharpf, 1997; Spaniel, 2011). The outcome of the game will be determined by the sum of all choices (Poundstone, 1993; Scharpf, 1997). The study of game theory can provide logic to complex situations, such as the ones in which the IAD Framework is applied, as in the action arena, actors have a distinct position that may be complementing or conflicting. Game theory is a beneficial complement to Ostrom's framework as it provides more tools to understand the action arena (Basurto & Ostrom, 2009).

Much of political and behavioral sciences, such as game theory, can be characterized as an attempt to explain and predict how organizations and individuals will choose (Scharpf, 1988). To facilitate the study and generate valuable results, in the majority of the cases, the scenarios are standardized, which drastically reduces their complexity (Scharpf, 1990). For example, the concern of rules in game theory is much simpler when compared to how collective action theory deals with rules. In game theory, rules are only concerned when defining possible outcomes, while as depicted in the previous chapter, in collective action theory, rules aid in defining the context where the action arena will take place (Ostrom, 2005). Looking further into how game theory structures its problems, this characteristic of reducing complexity can be quite useful to simplify the complex decision process which industries have, where decision-makers face several possible choices on a decision within and outside the organization (Keeney & McDaniels, 2008; Scharpf, 1988, 1990). Scharpf exemplifies this property of game theory by pointing out that several complex environments are dichotomies (parliamentary vs. presidential, unitary vs. collective…) and that these classifications can also be applied to the decision-making in composite actors such as industries (Scharpf, 1997). In his work, Scharpf developed a decision-style framework, presented in Figure 7, wherein one axis is depicted the possible decision-styles a composite actor may have (Unanimous decision, Majority decision or Hierarchical decision) and on the other axis, the type of decision rule (Problem-solving, Bargaining or Confrontation). Scharpf argues that every actor has a preferred way to make a decision, which is a combination of its predominant decision-style and its predominant decision-rule (Scharpf, 1988).

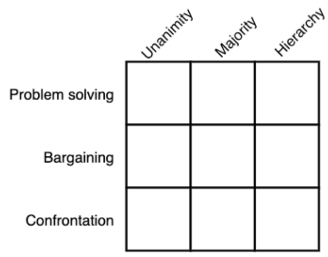

Figure 7 – Decision-style framework (Scharpf, 1988)

Another contribution of game theory besides depicting actors in a game is to explain the interactions itself, portraying the possibilities, and identify if there is an optimal possible outcome. In game theory, defining the type of game helps to analyze different types of problems. Games can either have a clear dominant strategy, such as games with Nash equilibrium or may require more understanding and evaluation by the players to find which strategy is best from them (Spaniel, 2011). Most games in real life do not have a clear strategy dominance, requiring players to evaluate further the possible outcomes (Scharpf, 1997). For the type of problem the IAD Framework deals with, games can be classified as cooperative (were helping each other leads to a welfare-optimization) or non-cooperative games (were acting individually leads to welfare-optimization). A common characteristic in both types of games is the capability to handle negotiations between players to find a welfare-maximizing solution. However, in real life, some games fall in between this dichotomy; they are called mixed-motive games (Scharpf, 1997). Actors caught in such mixed games have motivations to either collaborate or to compete, not being clear which strategy is best. For situations such as dealing with private goods, mixed-motivation games are a better fit for understanding such a scenario, since as the resource is subtractable, there is an incentive for actors not to cooperate and consume more. On the other hand, if they cooperate, there is a higher chance of having resources for a longer time (Ostrom, 2010). In this study, two mixed-motivation games are going to be explored, the battle-of-the-sexes and the assurance game.

Battle-of-the-sexes game

It is a game where each player has a preferred option different than the preferred option of his opposite and must choose between his preference or the other player’s preference, but they prefer to choose the same option than to choose separately. This creates a situation whereby choosing their preferred option will imply a sub-optimal choice for the other player, but choosing distinctively will result in a much worse situation. This situation is presented in Figure 8.

Player 1/Player2	Option 1	Option 2
Option 1	1,2	0,0
Option 2	0,0	2,1

Figure 8 - Battle of the Sexes game (Spaniel, 2011)

An interesting characteristic of the sexes game is that it is not a unique interaction, but a game where the equilibrium comes from repetitive interaction (Spaniel, 2011).

Assurance game

In the assurance game, both players are presented with the option to collaborate in a highly rewarding task directly or to execute a different task independently. If they opt to collaborate, the outcome is significantly higher, as well as the risks of failing, and the collaborative task needs both players' input. If they opt to act independently, the outcome is lower, as well as the risk of failure. This collaborative game does have an equilibrium on individual interactions, but what makes it rare is the fact that history weighs in for each player's decision. Since the chance of a default if the collaboration strategy is selected relies only on how much the other player is trustworthy. The situation is depicted in Figure 9.

Player 1/Player2	Collaboration	No collaboration
Collaboration	10/10	0/3
No collaboration	3/0	3/3

Figure 9 - Assurance game (Spaniel, 2011)

3.1.5 Organizational Culture model

Communities naturally build up particular attributes and regulations which affect how its members behave, being this the attributes of community and rules in use in the IAD framework. Acceptable behavior values, member's homogeneity, population size, composition, and inequality of basic assets are examples of such features (Ostrom, 2005). Such characteristics are also building blocks of a community's culture. A culture is formed by the interaction of individuals' values of members of the same group (Hofstede, 2011). The higher the correlation corresponding to a group member's values, the higher the probability of developing a strong culture (Hofstede, 2011; Ostrom, 2005). As culture sculpt the mental model of actors, understanding a culture is an important step to theorize on how its members may behave. Hofstede defines culture as:

> *"The collective programming of the mind that distinguishes the members of one group or category of people from others"* (Hofstede, 2011)

This definition brings out the idea that members in a community can only identify themselves as members of the community who present similar mindsets. Understanding this will guide each actor to stay or leave the community, as not feeling part of a group pushes individuals to seek other groups (Hofstede, 2011). Hofstede theorizes on some fundamental characteristics, or dimensions, which differ characterize a culture. The differences between cultures are given by different values on such dimensions (Hofstede, 2011). The six dimensions are *Power Distance, Individualism vs. Collectivism, Assertiveness vs. Caring, Uncertainty avoidance, Long-Term Orientation,* and *Indulgence vs. Restraint*. A simplified explanation of each dimension is presented next.

Power Distance

Power Distance is defined as the extent to which the less powerful members of institutions and organizations accept that power is distributed unequally. People in societies exhibiting a large degree of Power Distance accept a hierarchical order in which everybody has a place, with no further justification. In societies with low Power Distance, people strive to equalize the distribution of power and demand justification for inequalities of power.

Individualism vs. Collectivism

Individualism stands for a society in which the ties between individuals are loose: a person is expected to look after himself or herself and his or her immediate family only. Collectivism stands for a society in which people from birth onwards are integrated into strong, cohesive in-groups, which continue to protect them throughout their lifetime in exchange for unquestioning loyalty. The higher the score, the more individualist the country is.

Assertiveness vs. Caring

Assertiveness (or masculinity in the original publication) stands for a society in which social gender roles are distinct: men are supposed to be assertive, tough, and focused on material success; women are supposed to be more caring, tender, and concerned with the quality of life. The Assertiveness side (higher score) of this dimension represents a preference in society for achievement, heroism, assertiveness, and material rewards for success. Its opposite, Caring, stands for a preference for cooperation, modesty, caring for the weak, and quality of life.

Uncertainty avoidance

The fundamental issue here is how a society deals with the fact that the future can never be known: should we try to control the future or just let it happen? Countries exhibiting strong UAI maintain rigid codes of belief and behavior and are intolerant of unorthodox behavior and ideas. Weak UAI societies maintain a more relaxed attitude in which practice counts more than principles.

Long-term orientation

Every society has to maintain some links with its past while dealing with the challenges of the present and the future. Societies prioritize these two existential goals differently. Long Term Orientation stands for a society that fosters virtues oriented towards future rewards, in particular adaptation and perseverance. Short-term orientation stands for a society that fosters virtues related to the past and present, in particular, respect for tradition and fulfilling social obligations.

Indulgence vs. restraint

Indulgence stands for a society that allows relatively free gratification of some desires and feelings, especially those that have to do with leisure and consumption. Its opposite Restraint stands for a society which controls such gratification, and where people feel less able to enjoy their lives.

Hofstede's Culture dimensions theory

Hofstede's dimensions encompass several aspects of culture and can be combined with the other theories presented in this research. Looking over to the IAD framework, the culture dimensions depict the attributes of community, explaining how a member might behave in a group based on its individual believes versus the group collective believe. Also, the dimensions are aligned in explain composed actor's decision-making style as depicted on Scharpf's framework. The combination of the three elements can provide a valid framework for collective actor's decisions to stay or leave a community.

Transposing the dimensions to the IAD Framework and Scharpf's framework requires some interpretation, as the culture dimensions are affiliated with an individual's characteristics, and the frameworks are related to behavior. Among the culture dimensions, there is a slight classification between them that fits first, Scharpf's framework. Some of the dimensions are more associated with how a society is structured and, consequently, to Scharpf's decision-styles while the others are more associated with how individuals interact, ergo with the decision rules. More precisely, *Power Distribution, Individualism vs.*

Collectivism, and Long-term orientation are related to decision-style as a lower value in those dimensions is pertinent to seeking consensus and looking over an overall benefit, thus closer to unanimous decisions. The opposite is also true. High grades on those dimensions lead over to a more structured society where certain individuals have more power and look over to their short-term interests, thus closer to the Hierarchy decision style.

Over the decision rules, the dimensions influencing it are *Assertiveness vs. Caring, Uncertainty avoidance, and Indulgence vs. Restrain*. Those three dimensions are related to how each individual sees itself on the society around it, either through valuing assertiveness and strict traditions or by being uncomfortable with ambiguity or changes. Lower values in Assertiveness and Uncertainty are more related to a confrontation decision rule, as people with high grades on those dimensions are less tolerable thus more prone to confront what conflicts with their beliefs. The individualism dimension is the opposite. Higher values are more related to confrontation for the same principle: The more individualistic the person, the less prone to dialog it is.

Lastly, with this combined Scharpf's framework with the cultural dimensions, this can be applied in the IAD framework as the community attributes. Each community's attributes, or its organizational culture, resides in the way people perceive what goes in their own environment (Hofstede, 2011). This environment may transcend the community level, eventually reaching that any individual's culture is ultimately influenced by the larger collective group it belongs to, the nation it resides. Each country, following its history, customs, and traditions, developed a national identity that can be parameterized following Hofstede's 6-dimensions of culture (Minkov & Hofstede, 2013). Therefore, the formation of community culture is directly related to the national culture, and it is expected that communities in different countries develop different cultures (Hofstede, 2011). Additionally, the association with the cultural dimensions adds generality to the model as if changing the cultural background or national culture will change how actors perceive their peers.

3.1.6 Cost-Benefit Analysis

The economic theories presented in this research are a complement to the IAD framework, providing a focus in the field of the rule in use, providing the economic background needed to detail the rules in the community properly. In the action arena, actors are expected to interact with each other and decide the best option according to their own individual goals. In the economic context of this research, it is lacking a proper tool for measuring what is on the table and which option is best. Having such a tool brings out objectivity to the decision-maker and enhancing the quality of the decision-making process (Keeney & McDaniels, 2008). Taking into consideration, especially the external variables, such as if and which financial incentive is in place, what economic context is presented, and how the community is organized within this context. When comparing different financial projects, a major challenge is to clarify if spending time, effort, and resources on the endeavor will be beneficial or not. Developing such a utility function is a complex task, being part of risk analysis studies and should consider different economic and regulatory contexts (Keeney & McDaniels, 2008). This evaluation can be achieved with utility evaluation techniques such as the Cost-Benefit Analysis. CBA is a project alternative assessment method that quantifies in monetary terms the value of all consequences of an alternative. This method is based on systematic cataloging of impacts as benefits (pros) and costs (cons), valuing in dollars (assigning weights), and then determining the net benefits of the proposal relative to the status quo (Boardman et al., 2012).

As energy projects are built for lasting years, and the costs are spread through the project lifespan, it is important to aggregate the benefits and costs in the same frame, thus, bringing future expenses into their present valuation. This is done by *discounting* their values relative to their Present Values. Dealing with the present values of a project is important as there is an opportunity cost to the resources used in a project. Perhaps using the resources somewhere else will be a better allocation. Secondly, most people prefer to consume now rather than later, making discounting not an inflationary adjustment, although inflation must be taken into account (Boardman et al., 2012; IRENA, 2015). Having costs and benefits at the same timeframe allows the analysis to compare both revenue and costs simply by netting costs from benefits. Doing this for every benefit and every cost of every year on the project timeline gives us the *Net Present Value (NPV) formula*:

$$NPV = \sum_{t=0}^{n} \frac{B - C}{(1+i)^t} \tag{1}$$

Where B is the total benefit for a certain period, C is the total costs for the same period, 'I' is the discount rate for the project, and 't' is the adopted time frame. The basic decision rule for a single alternative project (relative to the status quo) is simple: adopt the project if its NPV is positive. In short, the analyst should recommend proceeding with the proposed project if its present value of benefits minus the present value of costs is positive. A known pitfall when utilizing NPV for evaluating projects is to compare too different projects. The false prerogative lays as the projects may have many different scales. For example, a project might have an NPV of 20 but produce 1 unit while another project might have an NPV of 3 and produce ten units. This lays on the analyst burden to assess how and when projects can be compared, thus not allowing only the Net Present Value as a single calculation. The definition of the best project must come from other complementary analyses (Boardman et al., 2012).

Another popular way to evaluate a project is through its profit margin, or how much profit the project generated. Profit Margin evaluation assesses a relation between the revenue generated by the project and the total costs needed to generate such revenue, displaying easily how much value the project will generate. Through the profit margin, it is easy to compare projects by assessing which one pats better for each money unit applied (Freixas & Rochet, 1999).

$$Profit\ Margin = \frac{Revenue - Costs}{Revenue}\ x\ 100 \tag{2}$$

Lastly, regarding energy projects, another technique to evaluate a project is through the Levelized Cost of Energy (LCOE). The LCOE is the value of how much a productive unit will cost based on the total project cost, similar to a unitary cost, but dealing with total project costs. It is a very useful technique to compare if the total costs of different technologies of unequal life span, project sizes, capital costs, risks, returns, and capacities (US Department of Energy, 2013).

$$LCOE = \frac{\sum_{i=0}^{n} \frac{I + OM}{(1+i)^t}}{\sum_{i=0}^{n} \frac{G}{(1+i)^t}} \tag{3}$$

Where 'I' is the total investment in present value, 'OM' is the present value of the periodic operations and maintenance costs, 'G' is the total generation of energy during the project life span, 'i' is the project discount rate and 't' is the project life span.

Before undertaking a CBA, one needs to consider several issues. In doing so, the CBA method proposes several steps to be followed by an analyst (Boardman et al., 2012). In this thesis, the CBA methodology is being twitched a bit from what textbooks expose. This is due to the nature of the research that already specifies what is the alternative to be evaluated and who is performing the assessment is not a policymaker but an industry comparing a project with its status quo. Therefore, the steps performed in a CBA analysis within this research are:

- *Step 1 – Qualitative Identification of the alternative and its baseline*
- *Step 2 – Quantitative assessment of the impact*
- *Step 3 – Monetization of the impacts*
- *Step 4 – Discount benefits and costs to present value*
- *Step 5 – Compute the Net Present Value of Benefits and Costs*
- *Step 6 – Make a recommendation*

3.2 Theoretical Approach Summary

The theoretical background of the thesis has as its bedrock the IAD Framework. This framework provides the supporting structure to develop the model, with its capacity to describe group interactions clearly and to depict outcomes, providing greater insight to analysts properly. This is achieved by declaring and analyzing the external and internal characteristics of the group being considered.

The group being considered are actors organized within a community for trading electricity, with an enlisting fee for new members. As the traded good is limited to some members, and no one can easily block others from using the electricity, this is classified as a private good and defines the biophysical conditions surrounding the community. This nature of the good influences on how members consume and behave when faced with different behavior. All actors have their specific characteristics, which can vary depending on some factors and summing such characteristics from the attributes of the community. Studying these characteristics is done through social sciences and cultural studies. In this thesis, it was used Hofstede's Organizational Culture theory. Lastly, since this research goal is to understand how certain sets of financial incentives influence communities' formation, these incentives are the rule-in-use utilized on the IAD Framework.

Besides providing the grounds and description of the context surrounding actors and the action arena, the IAD framework also looks inside members' interactions and possible outcomes. However, the framework requires additional theories to fill the voids for creating the proposed model. The central point obtained the framework is the Action Arena, or where the actors involved interact between them. To understand the actors' interactions, Game Theory is used to describe the possible games being played. Here two classical games were identified, the Battle-of-the sexes and the Assurance Game. Such games guide the understanding of the possible outcomes from the action arena and can prompt actors on how to act within the group. This goes through making decisions and assessing the outcomes of individual preferences. To outline how actors preferably make decisions, Scharpf's Decision Style matrix is used. Lastly, it is needed to understand the impact of such financial incentives on the generation and consumption of electricity and, ultimately, how this influences the community. This calls for a proper method of evaluation and criteria definition. The Cost-Benefit Analysis techniques fit in perfectly for this task, as its purpose is to set a common ground for comparing alternatives of different nature.

3.3 Research methodology

This research aims to develop an agent-based model for evaluating how financial incentives influence the generation of renewable energy in Industrial Communities Energy Systems. Developing such a model on an ABM simulation allows for testing the behavior of several factors that influence the development of such projects, aiding the understanding of such phenomenon and supporting the design of the new policy.

For the creation of the model, which will be presented in the next chapter, some phases were followed: The preparation stage collected information and data from several sources so to create knowledge on the topic and develop resilient support for the model. This was done in chapters 2 and 3. In chapter 4, the details of the model are presented, while the specific data utilized on the simulation is exhibited in the chapter. With the introduction of the real-world data, some adjustments were made so to assure the model behaves as expected and simulate reality. Some parameters were made randomly chosen on a data-driven scale, and new connections created based on insights observed as the programming occurred. This was done so to avail the full potential of data. Afterward, the impact of relevant parameters was assessed over a sensitivity analysis to avoid undesired situations as having full runs only with negative outputs. From the output data, graphs and insights can be observed on a results analysis. These results were used to answer the research questions with enough confidence. Figure 10 gives a general overview of the research methodology.

Table 1 - Research questions methodology (the author)

Research question	Approach/theory	Method
What is a definition of the community energy system for industries?	Collective Action / IAD Framework	Literature Review
Which are the potential incentive mechanisms that can be applied to industrial energy communities?	Incentives theory	Literature Review
How industries make decisions?	Game Theory / Organizational culture	CBA Analysis / ABM
How does the interaction between industries influence their decision process to join community energy projects?	IAD Framework / Network Theory	ABM
How can different incentive mechanisms be compared?	Incentives theory	Data Analytics

As a modeling assumption regarding the industries, despite the complexity of the industrial decision-making process, and the many factors which influence the procurement for energy supply, in this research it will be assumed that every actor in the simulation has the will and it is actively seeking to form or join an energy community. As the research goal is to evaluate the emergence of communities, there is no need to model and assess the behavior of actors that do not wish to join an energy community.

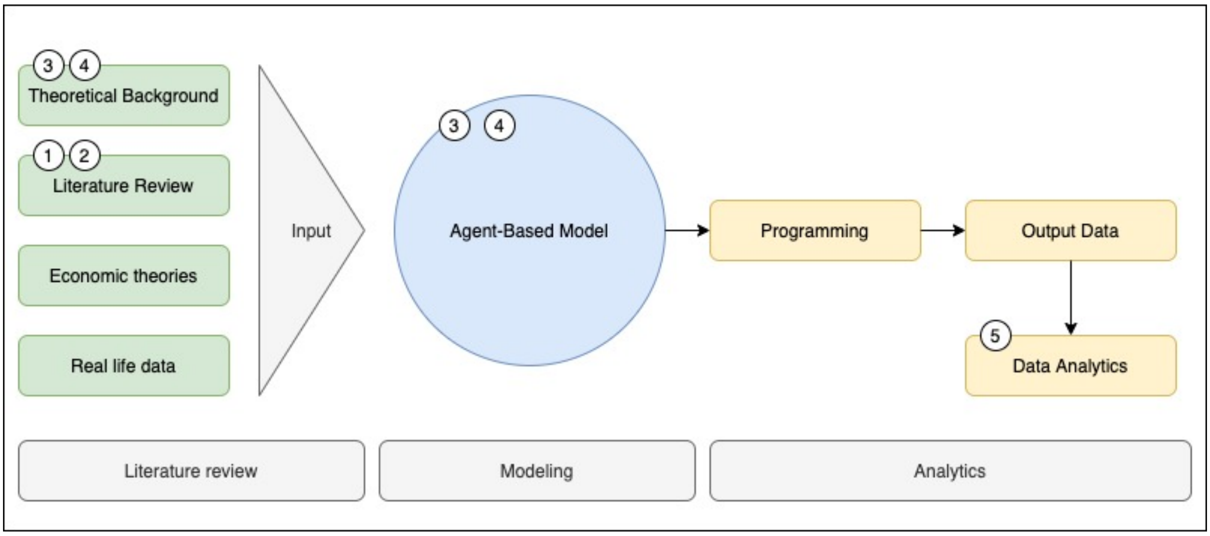

Figure 10 - Research Methodology (the author)

Chapter 4 – [Design of conceptual Model]

4 Design of the Conceptual Model

Having all the theories described, the next chapters layout the conceptual model, firstly the overall design followed by chapter 6, which presents out the real-life data used to run the simulation. In this chapter, the model specifics are presented in section 4.1, followed in section 4.2 by the two types of agent description, section 4.3 presented how renewable energy technology is selected by the communities, and section 4.4 describes the role of financial incentives within the simulation and how it affects it. With the meta elements of the simulation defined and finally, section 4.5 presents out the step by step evolution of the simulation.

4.1 Overview of the Conceptual Model

This conceptual model has the goal of evaluating how financial incentives influence the development of energy communities and their renewable energy generation under different economic and cultural designations. Thus, how many InCES will be created, how many companies will join these communities, how these communities sustain through the time, and what they produce under different financial incentives are key elements to understand how such incentives incentivize renewable energy. Besides what communities produce, the cost of such an incentive to the government is also something to be considered when in the evaluation phase.

The model intends to simulate how different types of financial incentives influence the generation of renewable energy through industrial energy communities using an economic perspective. The model utilizes the IAD Framework as a starting point, with the Action Arena, presented in Figure 11, being the central point of interest. The interaction between actors promotes a dynamism within the simulation, making actors decide to join, leave, or stay in a community. Such a decision is based on their preferences, needs, community economic performance, and culture alignment. The community acts in parallel based on which set of financial incentives rule exists, a national economic context, and follows a defined strategy to fulfill its members' energetic needs. Both actors produce new information and make decisions based on calculations utilizing the CBA technique to find the optimal solution for each industry.

The simulation is designed to happen on a single industrial park, while embracing the concepts of industrial parks and small-world network, through the Watts-Strogatz model, which is a mathematical model over how actors connect within its social network (Easley & Kleinberg, 2010). In practical terms, this means that by default, the grid connection and grid maintenance are considered granted, and, by being part of an industrial park, every industry has a weak connection to other industries in the same park. It is important to notice that this is a "*week*" connection since being neighbors does not automatically prompt substantial interactions. The main interactions happen at the strong network, made of closer neighbors that interact more and influence each other decisions (Easley & Kleinberg, 2010). These stronger connections are relationships that provide orientation to individuals and therefore resemble a type of friendship. With the combination of the weak network with a strong network, a small-world network scenario is defined.

The general economical-physical situation of each industry is that everyone is expanding their activities and yearly have a new power demand that needs to be procured. For supplying this energy demand, industries might purchase grid energy, start to produce renewable energy by themselves, or join an energy community. As producing renewable energy through energy communities is the focus of this study, every industry is willing to evaluate the renewable sources option, and all industries in the park have the potential to become a community member or initiator. Such a proposed evaluation is intertwined with an investment analysis over their energy strategy, and they might conclude that forming a community might be beneficial for them. For doing the investment analysis, industries base their decision on two planes, an economic and a relational plane, following the no single factor decision-making presented on 3.1.2. The economic plane is where each industry gathers the data from their physical location, their new energy demand, and calculate a CBA analysis with the NPV technique to evaluate if developing renewable energy is commercially advantageous. This is tested on three initial evaluations:

- Is buying energy from the grid more expensive than generating RE?
- If I am going to produce renewables, is it better to produce for myself or produce to sell to the grid?
- Forming or joining an energy community yields a better financial result?

Based on the results, each industry might prefer to do business on its own, join an energy community, or start a new community by co-generating with some partners. The first questions are merely financial, while the latter still needs to be evaluated on the relational plane. Here the enthusiastic industry seeks to understand how its peers in the strong network perceive the topic. Actors update their perception of how other industries see renewable energy sources by querying their position on the topic. This process is assumed to be stage-like; only those who found RE financially sound question if others also think the same way. This is a behavior seen in real life as decision-makers tend to talk with their strong connections over topics they have little information to gather more understanding and deliver a better decision (Sheu, 2019).

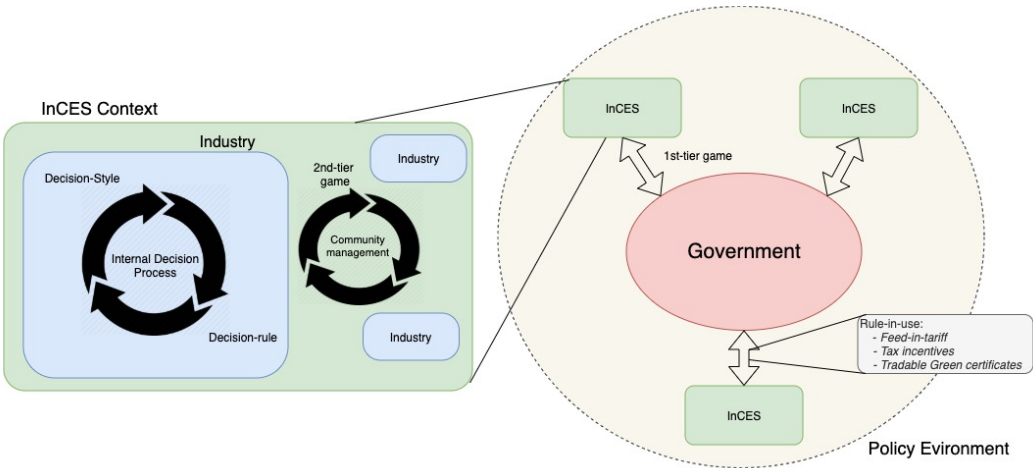

Figure 11 - Proposed Action Arena (the author)

This routine, just like in real life, is set to occur at a certain time interval. The simulation assumes that every year, close to when industries produce their financial reports and update their future planning, every industry performs its energy investment analysis, calculating how much new energy they will need to obtain to keep their expected growth. This yearly evaluation will look over for the best option, but once a member of a community, it is expected that new energy demands will be pushed to the community. Nevertheless, this does not mean an unconditional loyalty from actors, as members may exit the community if it does not see a connection with the group.

If perceived by an industry that renewable energy is advantageous and their strong network also signals the same, the industry will seek out for joining a community, and in case none exists, it will create a new energy community with its partners. This newly formed entity has independent management and has the sole objective to produce sufficient energy to comply with its established goals. Replicating real life, each energy community is susceptible to two types of strategy. They can either provide direct energy to its members or may sell energy to the market and payout dividends. Having this strategy dichotomy aids in evaluating the different nature of financial incentives as it brings more dynamic to the simulation, making it closer to industrial, financial decision-process. Looking over to the communities, in this simulation, all of them are treated like actors, with their internal attributes, decision-process, and a strategy to follow. Not letting down the community side of such actors, communities are faced with a problem on how to produce energy in a way to fulfill its members expectant. In the simulation, members are constantly asked to repeatedly make policy decisions within the constraints of a set of collective-choice rules (Ostrom, 2011). Therefore, the main ruleset is that each member plays out its member role, accordingly, voting on every occasion and having a clear position on the business plan. The combination of the energy demand, strategy, and rule in place, form the exogenous variables of the model, influencing each actors' decision-making in the community action arena.

To further understand the exogenous variables, comprehending the broader, national culture is important. Countries provide different backgrounds for their businesses to flourish, and depending on how an economy is, results can vary enormously. Therefore, to achieve the goal of being a general evaluation, it is required to define some countries to emphasize how culture influences decision making. For selecting the countries for this thesis, the first criteria were to get countries from different geographical regions as physical distance provides a certain level of cultural dissociation (Hofstede, 2011). Next, this research analyzes the results of the six dimensions in search of candidates that had at least two dimensions with a significant separation. The dimensions were calculated through formulas developed by the World Value Survey organization and used data from their sixth wave, the latest dataset available. An example of how cultural differences can influence decision-making is that the Netherlands is significantly different from Japan when considering the *assertiveness vs. Caring dimension*. This translates into an understanding that a Dutch decision-maker will give "soft elements" a higher degree on her decisions when compared to a Japanese decision-maker. In the simulation, these dimensions are combined to form out a decision-style and a decision-rule for each industry, which influences their behavior when each actor compares its preferences with the community attributes. Potentially, a too-large mismatch may lead a member not to identify itself as a community member and leave the community. More details were presented in detail in chapter 3.1.5.

By being a member of a community, every industry starts to play its community member role, which encompasses voting, expending, and receiving energy or dividends from the community. By agglomerating its members' demands into a single demand, the costs of generating renewable energy can be inferior when compared to developing the energy production by itself, since some of the processes can be shared and optimized, reducing the total costs. Nevertheless, only being cheaper to install does eliminate all financial disturbances. As the relationship between a community and its members has an economic root, it is expected from communities to perform economically well. A community that is constantly requesting new investment from its members is in this research perspective, worse seen than one who is delivering its targets. This perception is translated into the model as a loyalty level of its members. If loyalty decrease to an unbearable level, a member might want to leave the community. However, just like joining a community has two factors for the decision to occur, leaving a community is not a single factor decision. For a community to leave, it first has to develop resentment with the community to a certain level and, afterward, assess its economic performance.

For generating the energy per se, each community must present out business plans to its members and show feasibility as, after all, being part of a community is a financial investment by the industries. This feasibility is thus presented over to the community members to approve or reject the business plan. Literature indicates that within some variations, there are two mechanisms available for a large group to decide: Voting or delegating authority to other members (Ostrom, 2005; Scharpf, 1990; Van Der Schoor & Scholtens, 2015). In this thesis, both mechanisms are being applied as the community has delegated powers to generate business plans which are further voted. While developing the business plan, the community is faced with the selection between generating wind or solar energy. This technology choice has some variables to be considered, and more details on how the selection occurs are presented in section 4.3.

Lastly, as the research goal pertains to providing insights that could potentially give support for energy policies, in this model, the government has an interest in comprehending the effects of its policy to promote RE. This is depicted in the simulation through the policy entrepreneur role developed by the communities and how much it costs to put the policy in practice. However, differently than industries and communities, the government is not defined as an actor that interacts with its other peers, but instead, it has the role of the beholder, who evaluates the results obtained from the initial action of promulging what type of incentive is in place. This position is related to the policy-making aspect that this thesis intrinsically has as policy options are being tested, which ultimately concerns the government, who does not need to interact in the action arena.

The communication between communities and the government occurs on every time step where the InCES signalize on a binary input (positive, negative) if, in the past period, they performed better or worse. This indicator is very well suited to provide feedback to a policy analyst on a plural community environment.

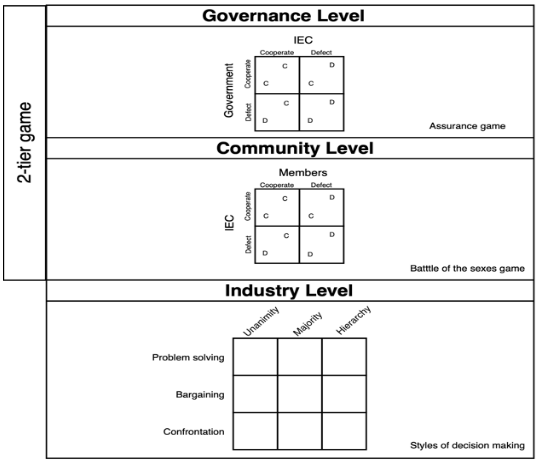

Figure 12 - 2-tier games in Action Arena and Decision style matrix (the author)

At every simulation period, the model produces several indicators, or metrics, that can be collected to provide the needed insight: (1) How much energy was produced, (2) How many communities exist, (3) the number of participants on each community, (4) number of members which exit a community, (5) The Policy entrepreneur signal if the period was better or worse, (6) governmental investment, and lastly, (7) amount invested by the community on renewable energy production. With this collected data at hand, it is possible to evaluate how effective each financial incentive performed in the different countries' contexts. From there, it is possible to compare the three types of incentives and draw conclusions over how each financial incentive is best suited or worse suited for promoting InCES. The general scheme of the model is presented in Figure 13, and more details over each actor and simulation elements are presented in the following sections with their respective theory. The Simulation general scheme leads to investigate how the interaction between different actors occurs.

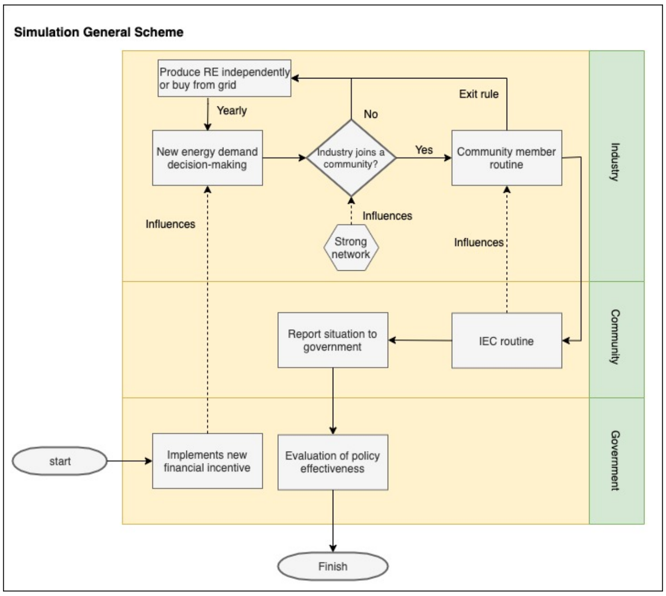

Figure 13 - General scheme of the model (the author)

From Game Theory, this thesis idealizes a 2-tier games action arena, depicted in Figure 13. The first game is between government and communities, while the other is between the community and its members. The 1st-tier game reassembles the assurance game described in section 3.1.4, where both players can perform their business independently and receive a small reward for it, but if they decide to cooperate, the reward is much higher. The 2nd-tier game otherwise resembles the battle-of-the-sexes, once a community and its members might not agree in all situations, but they are better-off acting together than apart.

4.2 Actors descriptions

4.2.1 Industry

Industries are defined as actors affiliated to the Industrial park, which needs to find a solution for its problem on how to procure energy for a new demand it will have as it expands its business. As an enterprise, industries have decision-makers that collectively give the industry a unique decision-style and decision-rules preference. To supply the required energy amount, industries evaluate through a Cost-Benefit Analysis comparing buying energy from their utility company with the costs of implementing a renewable energy production. To evaluate this CBA, the Net Present Value technique is applied. Here, all the information generated on the evaluation culminates in determining an engagement grade for each industry, or in other words, how much prone an industry is to adopt renewable energy for the new energy demand. Possible engagement grades are presented in Table 2.

Table 2 - Engagement grades for industries (the author)

Grade	Description
0	Initial value = not engaged
1	Business as Usual = Buying grid energy is cheaper
2	Producer = Opted to produce energy individually
3	Enthusiast = There is at least one motivated partner to create a community
4	Member = There is a community available
5	Founder = Founder and co-founders of a community

In detail, each engagement grade represents in the model a different stage of progress towards joining or forming a community. The details of each grade are:

- **Grade 1:** Represents that the industry in which a CBA calculation indicates that either buying grid energy is cheaper or the NPV for renewable sources is negative. With this result, the industry concludes that it is not worthy of investing in renewable energy and procures the new energy demand with grid energy.
- **Grade 2:** Indicates an industry that perceives a benefit in generating renewable energy individually. This observation comes as the gird energy option is more expensive, and comparing the RE options, the NPV for producing by itself was higher than the NPV for with a peer. Therefore, a community in this situation will not seek to co-generate energy. Also, the renewable energy produced in such a case is not considered on the total energy produced indicator as it deviates from the objective of studying renewable energy generation by communities.
- **Grade 3:** Having an engagement grade indicates that an industry which finds RE generation better than buying from the grid and also find that co-producing energy is better than doing it alone.
- **Grade 4:** This engagement grade represents an industry with an engagement grade 3 that finds an existing community where its unitary costs of production are cheaper than what that industry has calculated – the industry joins this community.
- **Grade 5:** When an industry reaches this engagement, the grade is becoming a founder of a community. To become a founder, a grade 3 industry checks how its "strong" network perceives renewable generation. If the majority of its *friends* have an enthusiast or member grade, this triggers the industry to become a founder along with all its enthusiast friends on the "strong" network, which are co-founders.

As renewable energy has an economic sense for industries, they expect that investing in the communities provide a financial return. To assess if the return was worthy and influence future decisions, every industry calculates an expected financial return, used for assessing the community's projects, and future evaluations of new energy demands.

Besides, industries also develop a certain loyalty to the community. In the model, loyalty represents the willingness to remain within the community, and a lack of loyalty indicates the will to pursue a different path. The loyalty is inflicted on how much extra burden is applied to the company, either by increasing the financial contribution or if the community starts to behave in ways that go against the industry preferences. The behavior evaluation is divided into the two dimensions of decision style, which evaluates how the industry voted compared to what community members voted, and decision rule which evaluates how my vote was compared to the chosen option. If there occurs a certain number of negative experiences, this triggers a wish to leave the community. When this happens, industries calculate a Return on Investment (ROI) value, or how much profit was made for the total invested. If both values are above the threshold, the industry exists in the community.

4.2.2 Community

The community has a single purpose goal derived from the community strategy of either (1) producing and sell cheap energy for its members or (2) pay dividends to its members. This strategy is determined on the community foundation and was based on how its founder perceived which strategy was best. For doing so, the community develops business plans and presents those plans to be voted on members' meetings, as it is assumed that all members go to every meeting. For a plan to be approved, it needs first to be feasible. This goes through the availability of the community budget. This budget is constituted by founders' investment, sale of the produced energy, financial contribution when new members join or by a requested new investment by members. Here an important aspect comes to play as communities use the LCOE technique to evaluate their performance.

The LCOE is firstly calculated on a project base to assess its feasibility, as a project which has a more expensive tariff than the grid tariff makes no sense. Also, using the average of all project's tariffs, or community premium, provides a good measure to define new joiners down payment.

Nevertheless, approving a project goes through comparing project benefits and costs. The project benefit is the income from selling energy. Renewable energy project costs, on the other hand, is somewhat more complicated. They are a combination of different expenses, which can be split into three categories: Soft Costs, Installation costs, and Hardware costs. Soft costs are all costs not directly related to the physical installation. Installation costs regard to the labor expenses while Hardware costs are related to the equipment purchase (Strupeit, 2016). The advantage of renewable energy projects at an InCES versus an individual installation is that the soft costs are concentrated, unifying activities since one single large project is being done instead of several smaller projects. IRENA, on its 2019 Renewable Generation Costs, breaks down the cost structure for solar energy for several countries. Here it is possible to see the difference in cost composition, but roughly, this cost is around 30% of the total installation cost (IRENA, 2019). This value was used for solar and wind energy installations. In the model, thus, the soft costs are multiplied by a reducer to reflect these savings on soft costs. The defined multiplier is *1 divided by the number of members*, thus reflecting the increased benefit if the community has more members. In other words, the more members a community has, the smaller the weight soft costs will have on the final installation cost.

If at the moment a business plan is drafted, the community budget is lower than what the project will cost; the community may ask its members for new investment to make the project possible. By being the energy producer in this model and behaving like an enterprise, having obligations with its members, the communities can be seen as actors who need to protect their resources. As this model studies financial incentives, it is expected that any new policy should take notice of how the involved actors perceive such a policy. This is the basic reasoning of the policy entrepreneur role. Performing this role provides voice and new insights for a policymaker over the topic, rendering the government some insight on how the community actors perceived the financial incentive policy set in place and what they believe is the best alternative. This is done by the community signalizing to the government beholder if their current period was better or worse than the previous one. The policy entrepreneur role aids in shaping the focus of policymaking by better indicating what the actors experience (Béland & Howlett, 2016; Howlett, McConnell, & Perl, 2015; Khayesi & Amekudzi, 2011). Besides, having the communities to perform such role within the model action arena is appealing, as national governments are "*too far away*" from the citizens to fully understand local needs while local communities are better placed for doing so (Koirala et al., 2016; Van Der Schoor & Scholtens, 2015).

4.3 Renewable Energy Technology Selection

Choosing which type of Renewable Energy Technology will be implemented, between solar, wind, or a mix of both is a task delegated to the communities. The choice is economical, where the source which delivers the best financial result will be the chosen one. This happens in the business plan development phase. Making such a choice takes into consideration some factors. Firstly, the community must consider how much more energy it needs to produce. This amount is the total demand for the project. As presented on the General assumptions section 2.5, only solar and wind energy are being considered as their availability, in theory, is borderless. Three possible alternatives may occur: only solar generation, only wind generation, or a mix between both. The choice over which possible generation alternative to adopting goes over calculating the NPV value of each solution for the specific scenario and choosing the highest NPV value. For simplicity of calculations, wind generation can only happen if the total wind demand is higher than a certain threshold, and in the mixed case, wind energy is calculated at multiples of the threshold value. This was chosen as wind efficiency has a minimum value on how much wind they need to start producing energy and a minimum generator size to be procured (GE Power, 2018). Solar energy, on the other hand, is much modular and easy to expand its generation, not having a minimum threshold. From the economic perspective, literature provides recent installation costs of renewable energy in several countries in a reliable source. Besides installation costs, renewable energy also has Operations and Maintenance costs (OM Costs), which need to be considered on the yearly expenditures.

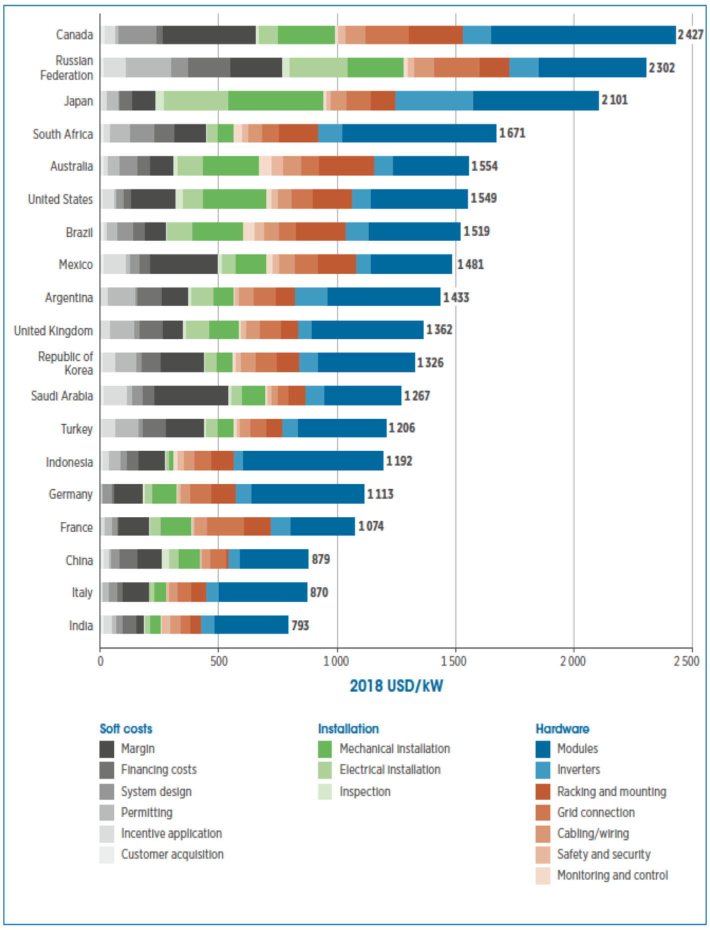

Figure 14 - Cost composition for solar energy generation (IRENA, 2019)

With costs and demands defined, it is possible to calculate several metrics for comparing projects. Among all possible projects calculated by the community, the option presented to members will be the one with the highest NPV. If the margin of such a project is positive, it will be considered a feasible project and put for voting by members in a meeting. If the strategy is to sell energy to members, the evaluation applied will be comparing the project's tariff with the grid tariff following the LCOE technique. On the other hand, if the strategy is to sell energy to the grid since the sale price is fixed by the government, it is not possible to use the LCOE technique. Instead, members compare the project margin with their expected rate of return. For the sake of simplicity, the expected rate of return will vary per industry between 0 and 5% as negative returns are not expected. The upper figure is a defined form of business administration. There, a praxis administrative overhead percentage applied to any product cost is around 6% (Itnal, 1999).

If a company engages on a side business that has a better return than this overhead, this means that the side business is more profitable than the core activity developed by the industry. If the margin is sufficient, members will approve the proposed plan. Otherwise, it will be rejected and recalculated.

4.4 Financial incentives

A central function of any government is to organize society and develop legislation to promote its development. Thus, governments may exercise hierarchical authority over the population by issuing new policies that steer a certain part (or aspect) of the population to a behavior (Palley, 2012; Scharpf, 1990), by issuing new policies, either in the form of regulations or through economic via incentives (Abolhosseini & Heshmati, 2014; DellaVigna, 2009). In a nutshell, regulations are public policies tailored to restrict or organized people behavior while incentives provide a benefit for society to act in a way they would not usually do if not for a benefit (Abolhosseini & Heshmati, 2014; Boardman et al., 2012; Zohlnhöfer & Rüb, 2016). Among the possibilities of governmental incentives, a very efficient and common type is a financial incentive (Nordhaus, 2007; Storm & Naastepad, 2012). In a broad definition, a financial incentive transform an undesired behavior into a financially attractive one (Abolhosseini & Heshmati, 2014; Bolderdijk & Steg, 2015; Furey, 2013; Palley, 2012). Economic benefits are one of the most powerful sources of motivation and have the potential to reinforce certain behaviors, with the implicit assumptions that by paying for behavior will be effective in any circumstances. However, that is not always reality. Financial incentives are not always effective and sometimes might produce the opposite result and restrain the behavior it was set to promote (Abolhosseini & Heshmati, 2014; Bolderdijk & Steg, 2015; Furey, 2013; Palley, 2012). Financial incentives, as described above, are very closely related to the rules in use attribute of the IAD framework. Depending on the type of incentive applied, different behavior is expected, along with different types of actors dealing with what is being incentivized. Policies can be tailored to promote or hinder any specific type of behavior (Abolhosseini & Heshmati, 2014; Ostrom, 2005).

In recent years, with the advent of environmental targets and pollution reduction along with the need to diversify energy matrixes, governments started to promote financial incentives for renewable energy generation (Abolhosseini & Heshmati, 2014). From literature, there are (with few variations), basically three types of financial incentives most widely used by governments to promote renewable energy: *Feed-in-tariffs, Tax Incentives and Tradable Green Certificates* (Abdelaziz et al., 2011; Abolhosseini & Heshmati, 2014; Warbroek & Hoppe, 2017). The details of how each type of mechanism functions to incentivize Renewable Energy were extracted from Abolhosseini & Heshmati publication and are exposed:

Feed-in-Tariffs

Feed-in-tariffs (FIT) is the most common sort of financial incentive. It works through the government guaranteeing the purchase of energy for a fixed price, superior to the grid tariff, for a certain period, thus providing guarantees for the producer that its investment will provide better financial return and, consequently, making it more attractive to invest in RE than fossil fuel. FIT follows a 'pay-as-you-go' scheme where the government expenses based on the amount of energy was produced. If more energy is produced, higher will be governmental expenses, for example. A recurring criticism is that FIT does not generate market competition as it cannot generate a liberalized market. There are three essential provisions needed for a successful FIT contract: unrestricted access to the grid, stable power purchase agreement, and the prices should be calculated on the costs of RE instead of the costs of the existing grid. Finally, the tariff price can be set as a fixed rate, calculated from the generation costs or an added premium to the current grid energy market price. Fixed FIT is simpler to understand and reduces uncertainty, while a premium alternative, in theory, can provide better values (Abolhosseini & Heshmati, 2014).

Tax Incentives

Tax incentives work out as an exemption of some (or all) taxes related to renewable energy generation. This type of policy aims at encouraging renewable energy consumption through applying tax credits or tax deduction on the purchase, installation, generation, and/or consumption of renewable energy, facilitating the penetration of renewable energy deployment into the market. This can work-out as a direct discount when purchasing equipment and installation labor or by lessening other future tax to be paid. A common criticism of this scheme is that it implies directly on tax collection, which can place a heavy burden on fragile economies. However, TAX also makes cash available for taxpayers, allowing them to spend more on other activities, enhancing the economic value of such policy. Looking at the impact on the governmental budget, the application of *Tax incentives* results in a smaller income for the treasury, since this financial incentive is taken by actively renouncing tax collection. TAX as an incentive works by accepting the smaller income at the beginning of the project in exchange for a larger benefit in the future, in a 'pay-now-receive-later' scheme (Abolhosseini & Heshmati, 2014).

Tradable Green Certificates

Tradable green certificates (TGC) are a financial policy that rewards energy producers who generate a specified amount of renewable energy, and by doing so, they receive tradable certificates with a fixed face value for every unit (for example, one certificate = fixed dollars = 1MWh). Such a certificate is dealt with just like stocks and can be traded on the market. TGC being a quantity-based policy, operates in contrast to FIT policy, which is a price-based policy. To increase the number of certificates, a company only needed to increase the amount of energy generated by renewable sources. A criticism of this scheme is that it relies much on the flourishing on a bond-market similar to the Carbon Credit Market. The issue lays that without a proper design on how these certificates can be traded and generate additional profit, TGC can become a marketing stunt without actually generating new renewable energy (Abolhosseini & Heshmati, 2014; Calel, 2011). The literature on this topic suggests that part of the revenues from those bonds could be used to fund subsidies for the production of low-emitter fuels, supporting a concept of combining several schemes to solve the problem (Abolhosseini & Heshmati, 2014). Considering the impact on the governmental budget, TGC has the benefit of being a future expense, as the bond is only paid when of its maturity. This means that the effective payment for TGC by the national treasury only occurs in the future, allowing the government to generate energy first and expense later, creating margins on the treasury in a 'use-now-pay-later' scheme. However, many concerns arise in this model as the tradable market is unclear on how it can support such promotion of energy (Calel, 2011).

Nevertheless, not all countries apply all three types of financial incentives. Some countries have more aggressive environmental goals and provide more compelling incentives, while others focus more on how much revenue can be made for their national budgets (Behrendt, 2015). Also, these incentives can be changed easily by governments if the expected not satisfactory results (Abolhosseini & Heshmati, 2014; Behrendt, 2015). For example, Australia does not have a feed-in-tariff scheme but applies 40% tax deduction on the implementation of new renewable energy development while Brazil applies several small discounts on many different taxes charged, and Japan applies 100% discount on installation taxes for those who manage to get the feed-in-tariff approval (Behrendt, 2015). As the application of a financial incentive is much related to specific government goals, current economic scenario, and cultural aspects, the raw reality is that each country provides a different incentive scheme to generate renewable energy (Abolhosseini & Heshmati, 2014; Behrendt, 2015).

The model is designed to test the three types of financial incentives identified in the literature on six different nations with different economic and cultural backgrounds. Being so, some definitions need to be explicit for each type of incentive. The **feed-in-tariffs model** chosen to be applied to the simulation was for the government to buy energy from the communities for a fixed FIT multiplied by the grid value (FIT Tariff = FIT x Grid tariff) (Abolhosseini & Heshmati, 2014). Considering the model premise that all companies seek to procure energy for their expansion if a community is selling energy to the grid, its members will still need to purchase energy, namely, from the grid. Therefore, the benefit of selling energy to the grid strategy needs to be compared with the benefit of producing energy. Both mathematical formulae are:

$$\begin{aligned} Sell\ Benefit &= Profit - Grid\ Energy \\ Produce\ Benefit &= Grid\ Energy - Production\ Cost \end{aligned} \tag{4}$$

For the selling option to be profitable, it needs to be larger, or at least equal to the benefit of producing:

$$\begin{gathered} Profit - Grid\ Energy \geq Grid\ Energy - Production\ Cost \\ Sale\ Price - Production\ Cost - Grid\ Energy \geq Grid\ Energy - Production\ Cost \\ Sale\ Price\ \geq 2 \times\ Grid\ Energy \end{gathered} \tag{5}$$

Since the Energy amount is the same in all cases, the sale tariff needs to be at least two times higher than the grid tariff. Therefore, to broaden the analysis and to be able to extract insights from the model, more than one value for each incentive is going to be tested in the simulations (van Dam et al., 2013). The definition of those values is depicted for each type of incentive. For FIT, it was selected the multiplier of 2.1, 2.5, and 3. The minimum value stands for being the immediate superior value to the minimum of 2, while for the higher value in the FIT, Literature indicates that considering significant development in renewable energy, with increasing efficiency and reducing costs, FIT payments soon can be considerably reduced or even extinct (Abolhosseini & Heshmati, 2014), and consequently it was chosen a maximum of 1x more the grid tariff.

For **tax-incentives**, the model chosen was of a 20%, 40%, or 60% direct tax discount on the purchase of equipment and installation on all renewable energy (Behrendt, 2015). This translates to a percentage tax discount on the total implementation costs, including purchase, installation, and OM. This model simplifies tax calculation (as taxes vary significantly across nations) and easy the tariff calculations as data available are on productive unitary costs and not on installation costs. Also, a 40% tax incentive is a rounded percentage of the majority of discounts applied in several countries (Behrendt, 2015). The upper and lower values of the tax cut were determined to center out the average rate.

Finally, for **Tradable Green Certificates,** the selected model was the credit rate price. This model is based on the total amount of renewable energy being generated and a predefined rate being paid for such generation. In the model, communities will generate energy and receive a surplus for the issued bonds for that generation. This surplus is added on top of any existing advantage of producing renewable energy. Being this a new topic, the literature is not very supportive of setting a price. Green certificates as a financial product have a very volatile nature, and the amount invest varies substantially by region and project (OECD, 2015; Wind Europe, 2020). Project financing for renewable projects is utilizing such bonds to finance whole projects with private and public funds (World Bank, 2019b). Therefore, finding actual prices for TGC is not a straightforward activity. Ford, Vogstad, and Flynn developed a model and simulated the prices for investments on renewable energy projects based on real-life project investments. Their conclusion was that for the following 20 years, the selling price for installed renewable energy sources should not be lower than $15/MWh and not surpassing $30/MWh (Ford, Vogstad, & Flynn, 2007). These values were observed by the US Environmental Protection Agency, which recorded an average of 18 USD per MWh premium (EPA, 2018), supporting the Ford et al. model. As this research follows the concept of benefit optimization, the values to be tested are going to start at the minimum feasibility value of $15/MWh and be increased by $5/MWh. Being so, TGC is being priced as $15/MWh, $20/MWh, and $25/MWh.

4.5 Simulation Run

Industry

All industries at every step (every year) update their new energy demand and perform the decision-making routine. On such routine, if the industry is not a member of any community, firstly, the industry assesses if renewable energy is advantageous by performing a CBA analysis at Net Present Value. From there, start an engagement grade assessment, by checking if the NPV is positive or negative. A negative NPV indicates that renewables are not feasible, and the industry will continue with business as usual and supplies its energy demand with grid energy. Being the NPV positive, the industry searches over if a community exists and checks the feasibility of joining such a community. Otherwise, the industry will look over its weak network for peers who also have positive NPV for renewable energy. If no community or no industry is available for generating renewable energy, the industry will produce RE individually.

A) [NPV < 1] The industry does not implement RE and continues to consume energy from the grid until the following evaluation period when new energy demand is presented.

B) [NPV > 1] The industry asks if an energy community exists:
- I) If yes
  - 1) A new CBA is made combining the industry and the community energy values:
    - (a) If new NPV < 1, the industry does not join the community and goes to II
    - (b) If new NPV > 1, the industry joins the InCES*
- II) If no, the industry checks if any of its peers on its week network also have an NPV > 1
  - 1) If positive, a new CBA is made using the energy demand of both peers
    - (a) If new NPV < 1, the industry produces energy independently
    - (b) If new NPV > 1, industry becomes the founder and its strong network joins him in creating an InCES*
  - 2) If negative, industry produce energy independently

Notes: * Starts to follow the InCES membership role

Figure 15 - Decision-making routine for industries (the author)

This depicted the situation above and, on the flow-chart below, shows a situation where an industry seeks first to join a community before looking if it is feasible to form one. This situation also reflects reality as it is less bureaucratic and simpler to join an established community than to create one from zero.

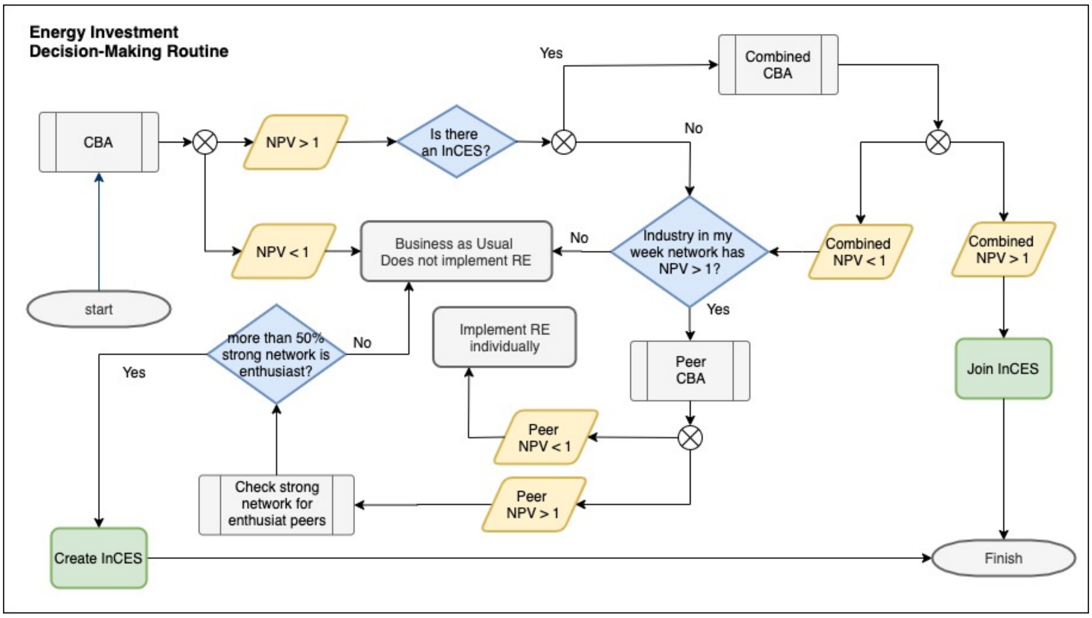

Figure 16 - Energy Investment Decision-Making Routine (the author)

In summary, at the end of every step, all industries will have their situation defined, either being part of a community, purchasing energy from the grid, or producing independently. When an industry joins an InCES, its role changes to become a community member. Members are asked to participate in meetings and exert their role of 'shareholder' by voting over InCES decisions and frequently checking if the actions taken by the InCES are in agreement with their decision-style and decision-rule.

A. Buy-in/payout its membership
B. Check if the community needs additional financial resources
   I. If yes:
      1. Contribute financially
      2. Decrease loyalty
   II. If no:
      1. Increase loyalty
C. Participate in voting meetings organized by the community
   I. Vote on the Business plan
D. Evaluate if InCES business plan actions are aligned with its industry metrics:
   I. If actions are aligned:
      1. Increase loyalty
   II. If actions are not aligned:
      1. Decrease loyalty
E. If loyalty inferior to the threshold:
   I. If profit is higher than the expected ROI:
      1. Leaves the community
   II. If Profit is lower than expected ROI:
      1. Continue in the community

Figure 17 - InCES membership routine of industries (the author)

Moreover, the flowchart for this InCES membership routine is presented next:

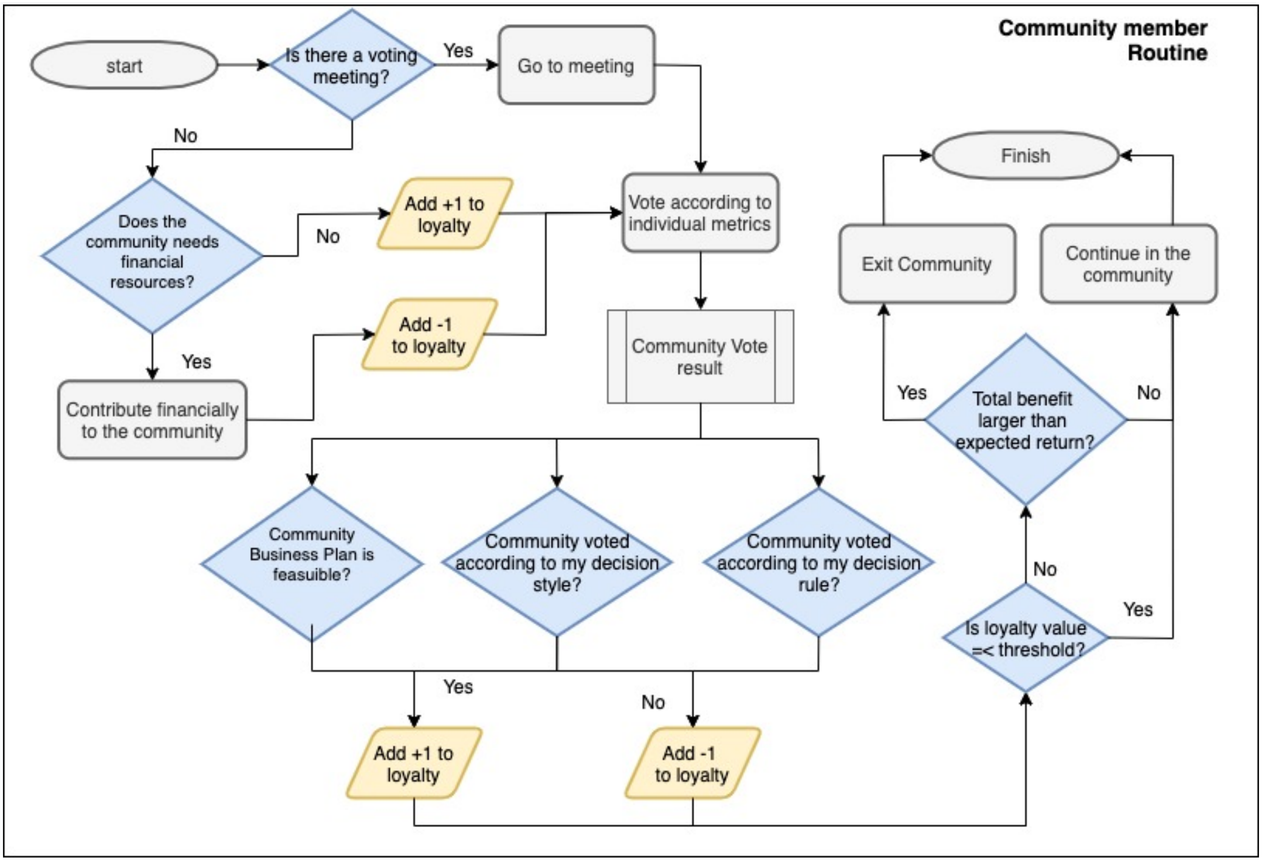

Figure 18 - Community member routine (the author)

Community

When founded, the InCES receives a strategy to provide a certain type of service, either provide cheaper energy to its members or to sell the energy on the market and pay dividends. The defined strategy is then translated into a business plan detailing the steps that the InCES will perform to reach its goals. This business plan, thus, is evaluated using CBA along with the profit margin technique. Also, the business plan is affected by the type of strategy, how much the return rate is expected by members and the amount of budget available. From there, the InCES decides on which technology to use to increase its energy production, and if needed, communities might request more investment from members.

How the community act is one input to members to re-evaluate their position if the community is right for them or not. The alignment between the member believes, and the community actions might lead the member to leave the community. In parallel, the community is always open for new members to join during the energy evaluation window. All new members buy-in their membership by paying out for their energy demand using the calculated Community's energy tariff. On a periodic base, the InCES self-evaluates its profitability (revenue/costs) and if it managed to present feasible plans (Approval or disapproval of business plans in voting). Based on this evaluation, the community can classify its period as good or bad performance, and when reported back, fulfills its policy entrepreneur role.

A. Receive investments from founders/new members
B. Choose technology
C. Organize meetings
D. If there are not enough financial reserves:
    I. Ask new investment for members
E. If there are enough financial reserves:
    I. Elaborate Business plan
        1. If the strategy is producing more energy:
            a. Invest in generating the best feasibility source
        2. If the strategy is selling energy to the grid:
            a. Invest in the most profitable energy source
F. Generate results throughout the year
G. Evaluate obtained results
    I. If community results are positive:
        1. Signal government positively
    II. If community results are negative:
        1. Signal government negatively

Figure 19 - InCES routine (the author)

Furthermore, the flowchart for this InCES routine is presented:

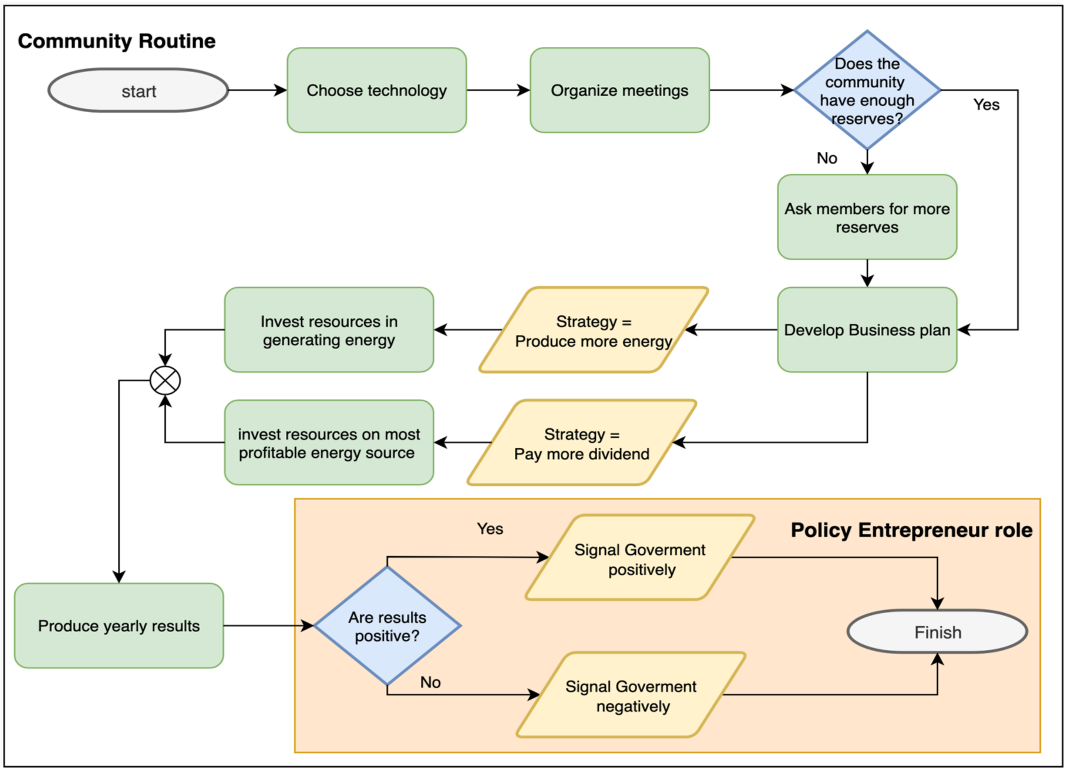

Figure 20 - Community routine (the author)

Government

The role of the government is divided into two aspects: implement an energy policy to incentivize the development of renewable energy and evaluate how such policy affected the community performance. Three types of incentives can be applied: (A) Feed-in-tariffs, (B) Tax incentive, and (C) Tradable certificates. Each simulation will have 1 type only of financial incentive being applied at a time, and the policy will not change during the simulation.

Chapter 5 – [Experimental setup & Data]

5 Experimental setup and Data

This chapter presents the second part of the conceptual model by presenting the data collected for the simulation. Section 5.1 describes the data to be used and its respective sources, while section 5.2 shows the input parameters. All scripts, data frames, analytics, and graphs can be found on the project Github page - https://github.com/rafaelcbfc/InCES_model

5.1 Data and Data sources

As the proposed model in chapter 4 is designed to be capable of being applied in any country scheme, the input data for the simulation should be standardized, generic, and supported by the model requirements. Although the model is a general model, this does not prompt for the use of imaginary data. Au contraire, the data to test the should be real-life data as they promote a higher level of reality. Therefore, this chapter presents the required data, its sources, and its applications. Using real-life data is a double-edged sword. On one side, the model is capable of producing better results, but on the other hand, it attracts attention to comparing the model performance with actual community developments. Without considering the simplifications of the proposed model, such a straightforward comparison may produce diverged observations. A model is a simplified representation of reality, easing the research to focus on specific aspects being studied (van Dam et al., 2013). This means that, despite the utilized data being real data, its application happens in mock countries, or 'country-like' generic nations, unlinking the results with real countries and yet still being able to relate it with their characteristics. In this research, the mock countries were named *Alpha, Beta, Gamma, Delta, Epsilon, and Zeta*.

The first dataset collected was the data from the World Value Survey (Inglehart et al., 2014) that supported the calculation of Hofstede's dimensions. This dataset allows the research to select the six cultural and economically different countries, as discussed in chapter 4. The six selected source countries are *Australia, Brazil, Iran, Japan, the Netherlands, and the United States*. Their Hofstede's six dimensions values are presented in Figure 21. The correspondence between the six selected nations and the fictional countries is presented in Table 3.

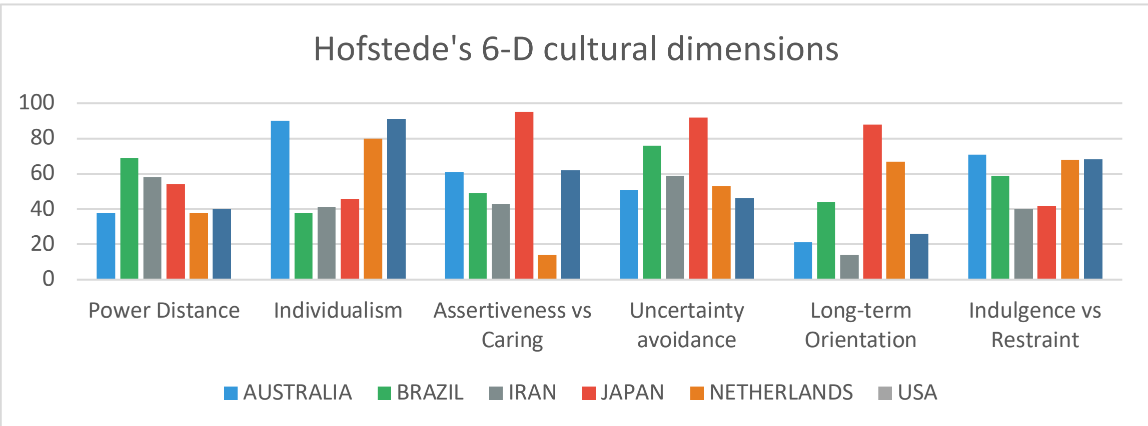

Figure 21 - Cultural dimensions for 6 selected countries (the author; Minkov & Hofstede, 2013)

However, some of the data, such as hours of renewable energy available or grid tariff, may vary widely within the country, making such parameters useless. Thus, it is needed to narrow down the geo-location more into a city or metropolitan area. The choice of such location followed the criteria for the most industrialized city (or metropolitan area) of each country. The following cities will serve as a model for fictional cities of each mock country.

Table 3 - Correspondance between real-life countries and mock countries (the author)

Simulated Country	Real-life representatives	
	Country	Reference city
Alpha	Australia	Sydney
Beta	Brazil	São Paulo
Gamma	Iran	Arak
Delta	Japan	Kyoto
Epsilon	Netherlands	Rotterdam
Zeta	United States	Los Angeles

Following the model design, several parameters are needed to develop the simulation, more specifically:

- Mean grid energy tariff
- Solar installation cost
- Wind installation cost
- Solar operation & maintenance costs
- Government infrastructure discount rate
- Hours of sunshine
- Wind distribution

Some of the data were available on the same single source, such as the International Renewable Energy Agency Power Generation Costs 2018 (IRENA, 2019), which provided the installation costs and Operation & Management Costs for all countries[1,2] on a mean unitary price range in US dollars/kilowatt. Having the costs in this way facilitates to the CBA calculations as unitary costs definitions already consider the total sum of several installation specificities, delivering a value that broadens enough for this exercise, making it was straightforward to calculate how much energy the idealized system could generate and how much that would cost. A downside of using such a method is that mean unitary prices are vague over what is being considered and what should be considered. To deviate such a problem, it was applied to a wide range of values to be chosen. By adopting this solution, the calculations become closer to reality as the differences in unitary prices are explained by soft variables such as better procurement, better suppliers, or more knowledge from project managers, for example. Accordingly to IRENA, these soft-components can vary 30% of the total installation costs (IRENA, 2019), and this characteristic was also applied as a benefit of joining an InCES. In communities, such costs are divided between its members, reducing the overall cost of the project.

Another source that provided several results was the open data website windfinder.com (Windfinder, 2019), which collects and presents statistics over wind collected in several weather stations around the globe. From the page, it was collected the distribution of wind speeds throughout the year on the selected cities and computed the amount of above 7 knots, the starting speed for generating energy (GE Power, 2018). Another data source that could provide data for several locations was the United Nations Database (United Nations, 2019). From the website, it was possible to collect the total yearly hours of sunshine from

[1] Iran's solar generation costs were not available for 2018, so for this research, the value was peered from Saudi Arabia due to geographical vicinity.

[2] The Dutch solar generation cost was also not available at IRENA document and was collected from a VU Amsterdam paper (Paardekooper, 2015)

the selected cities. The last data source that provided more than one entry was a Brazilian ministry of economy report on discount rates for infrastructure projects (Ministério da Economia, 2019). On the document, the ministry presents some other countries discount rates, including the Australian, Dutch, and US rates. The other discount rate was collected from other sources. Iran's (Daneshmand, Jahangard, & Abdollah-Milani, 2018) and Japan's (Leo Dobes, Leung, & Argyrous, 2016) were collected from a research paper on social discounting.

For grid energy tariffs, they were collected from several different sources. Australia (Australian Energy Regulator, 2019), Brazil (Aneel, 2019), and the United States (US Energy Information Agency, 2019) were collected directly from the energy regulator or its statistics branch. The Netherlands' grid tariff came from the European Union Statistics agency (European Union, 2019). Iran's grid tariff came from a World Bank report (World Bank, 2019), and finally, Japan's grid tariff came from a UK Ministerial report on Asian tariffs (UK BEIS, 2019). Finally, those values in currencies different than US dollars were converted to USD using the currency rate of 31-Dec-2018.

5.2 Input parameters & variables

The values utilized in the simulation are presented by country in the following graphs, divided by each data and its value per location.

Grid Tariff

The Grid Tariff represents the most up-to-date mean value of how much a kilo-Watt hour costs for the defined municipality in US dollars. For added dynamics and seeking to mimic better the fluctuation of energy prices, all average tariffs collected for the simulation are randomized 10% up and down, giving a range of 20% around the average. This allows the simulation to reflect the possibility of an industry better to have a better (or worse) deal with its power distribution company, depending on the amount of energy consumed.

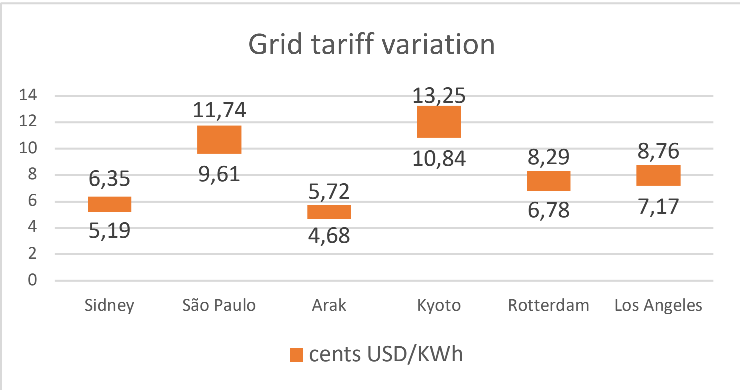

Figure 22 - Grid Tariff amplitude (the author)

Solar Installation costs variation

Solar installation costs represent the observed range of total costs in solar projects in those countries in which IRENA collected information. By dealing with a range and collecting random values, the simulation is augmented with variations between industries that are observed in real life as different companies will generate different projects.

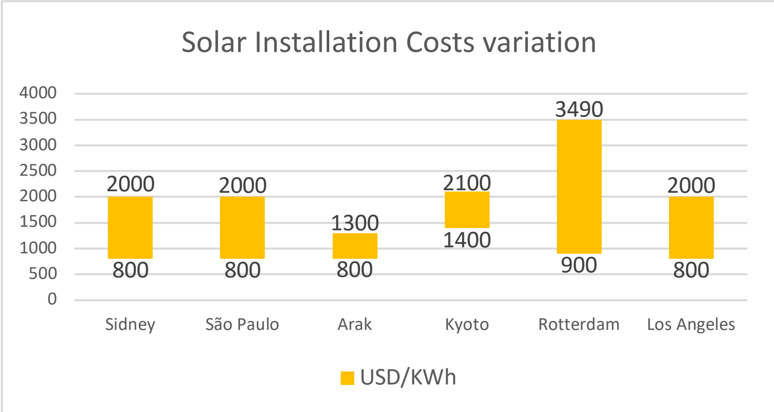

Figure 23 - Solar Installation Costs variation (the author)

Wind Installation costs variation

Wind installation costs represent the observed range of total costs in wind projects in those countries in which IRENA collected information. By dealing with a range and collecting random values, the simulation is augmented with variations between industries that are observed in real life as different companies will generate different projects. The values are presented in the table below.

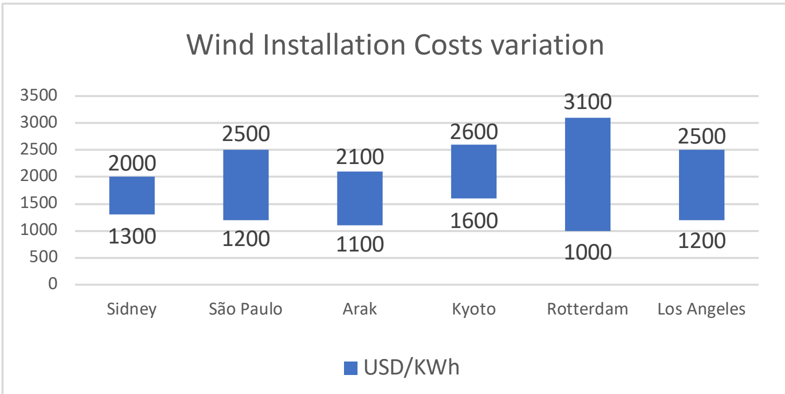

Figure 24 - Wind Installation Costs variation (the author)

Discount rate

The discount rate or social discount rate is the interest rate used in computing values of money through time in projects which are related to social benefits. Determining a precise rate is a very hard task, and it is very susceptible to variations and disagreements. For projects which take longer periods to occur, using a good discount rate is vital for CBA analysis (Boardman et al., 2012). For this reason, in this simulation, the discount rates utilized are the values used by governments to assess their projects and were collected through official governmental documentation.

Figure 25 - Interest rate by country (the author)

Energy production potential

Finally, the last collected simulation value is energy production potential. This value is crucial to determine the amount of available energy, which, in turn, determines the size of the installed generation park and, therefore, the cost of generating renewable energy. It can be observed that Rotterdam leads as the largest wind energy availability, and Los Angeles has the best solar availability. Kyoto lags last on wind availability with Rotterdam in last for solar potential.

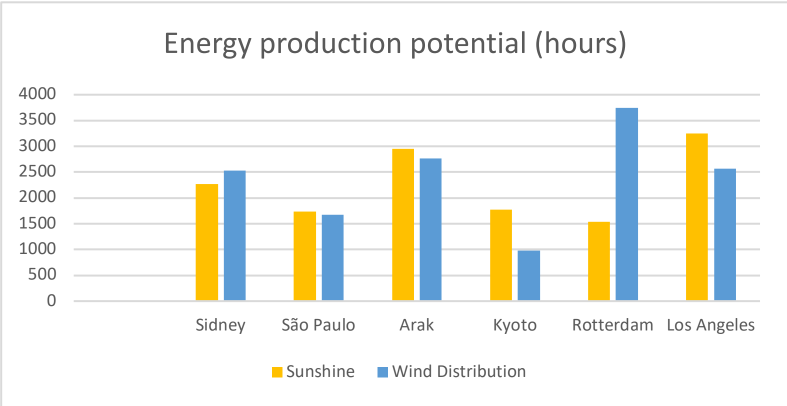

Figure 26 - Energy production potential by energy source (the author)

Hofstede's dimensions distribution

Hofstede's dimensions presented in the chapter Organizational Culture model are the observation of values collected on a global survey, and therefore, every nation has individuals with all types of values for each variable. This leads to transforming the dimensions results in a probabilistic distribution. By doing so, it is possible to translate the result to the model with little hassle and to calculate the decision-style and decision rule distributions as depicted 3.1.5. The distribution of the combined dimensions indicates to which box of Scharpf's decision style and decision rule each industry is characterized. The decision style distribution is composed of the Power Distance, Long Term Orientation, and Individualist variables. In the model, the decision-style is used to determine how each industry perceives the unity of the community and, consequently, adds or subtracts loyalty points. For example, a member with a decision-style of unanimity will prefer to be in a community where the votes are close to unanimity, thus a loyalty point increase if this happens.

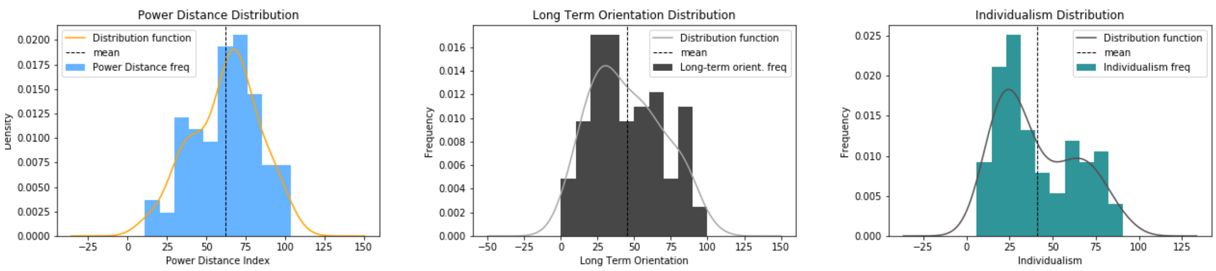

Figure 27 - Hofstede's dimensions distribution for decision-style (the author)

The decision rule distribution is composed of the assertiveness, Uncertainty Avoidance, and Indulgence variables. The decision rule is applied in the model to compare how the member also voted with the community vote. This has to do with the ability to negotiate and deal with differences, as posted by Scharpf. For example, a member with a confrontation decision rule will increase its loyalty if the community voted the same that he did, but it would be unhappy if the community voted differently, decreasing his loyalty points. Among the possibilities, bargaining is a unique type of decision rule that the loyalty threshold is 24 instead of the standard 12. By increasing the threshold, industries with bargaining decision rule have more room for tolerance from different voting, thus better representing such type of individual in real life.

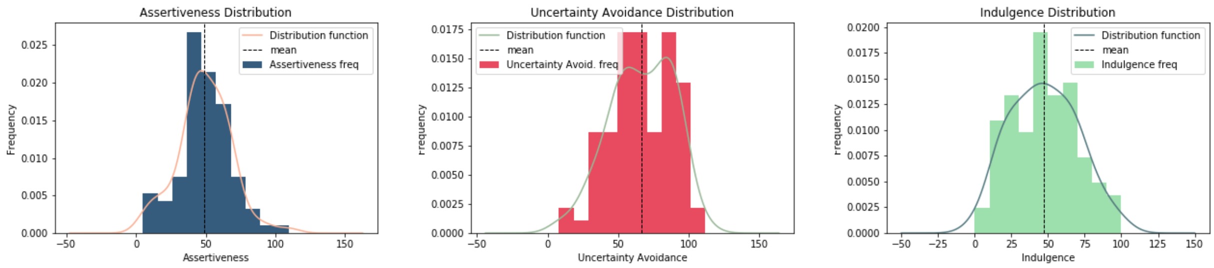

Figure 28 - Hofstede's dimensions distribution for decision rule (the author)

The decision-style and decision rule distribution were calculated by gathering the mean values and standard deviation of each trio of dimensions and normally distributing between 0 and 100. Each industry randomly receives one value for each parameter. For performing the distribution for each country, a mean value and a standard deviation are needed. The mean value was calculated by country, and it is the average of the three dimensions that compose each parameter. All values are presented in Table 4. The standard deviation calculation utilized data from all countries so to provide a better variation and more reliability to the distribution. The standard deviation for the decision style is 39,351 and for the decision rule 36,968.

In the simulation, the industries are randomly allocated with a decision style and a decision rule on each run following the distribution of each country and receiving one of 3 possibilities for each variable, following the Scharpf's Decision-style framework, presented in Figure 7. Decision style options are *Unanimity* (values from 0-33), *Majority* (values from 34-66), and *Hierarchy* (values from 67-100), while the Decision rule options are *Confrontation* (values from 0-33), *Bargaining* (values from 34-66), and *Problem Solving* (values from 67-100).

Table 4 - Average values by country of decision style and decision rule (the author)

Country	Mean values	
	Decision Style	Decision Rule
Alpha	43,33	67,33
Beta	57,33	54,33
Gamma	37,33	47,66
Delta	61,33	77,66
Epsilon	57,66	49
Zeta	44,66	66,33

5.3 Simulation characteristics and settings

Simulation Variables

To run the simulation, some iteration parameters were defined so to generate the results. First, a simulation run planning was defined by varying composition of all variations of iterable data. The first data level to iterate is the defined countries [Alpha, Beta, Gamma, Delta, Epsilon, Zeta], whereby setting corresponding data ranges are updated. Following, each country is investigated under four scenarios, which follow the same pattern and the same units. Such scenarios are the variations being tested by the simulation where one variable is changed (van Dam et al., 2013). As discussed in section 4.4, three values are being tested for each type of financial incentive, which is represented by each type of scenario. **Scenario 0 (S0)** is defined as a *no incentives* scenario, being this the baseline scenario where InCES are formed, but the government has no interference in their business. In **Scenario 1 (S1)**, the feed-in-tariff financial incentive is applied. For FIT, those values are [2.1, 2.5, 3]. **Scenario 2 (S2)** stands for the application of the tax incentive, which is tested with the incentive values of [0.2, 0.4, 0.6], and lastly, in **Scenario 3 (S3)** the Tradable Green Certificates are applied with the values of [0.015, 0.02, 0.025].

Table 5 – Iteration variables for financial incentives (the author)

Scenario	Test variable values			
	Value 1	Value 2	Value 3	Unit
S0 – No incentive	-	-	-	-
S1 – Feed-in-tariff	2,1	2,5	3	Multiplier
S2 – Tax Incentive	0.2	0.4	0.6	Percentage
S3 – Tradabel Green Certificate	0.015	0.02	0.025	USD/KWh

The combination of all possible scenarios results in 60 unique simulation runs. Seeking to avoid statistical issues due to a low number of simulations runs, each unique simulation was repeated for 500 times. This means that each individual combination of a scenario with one of the three values was repeated 500 times.

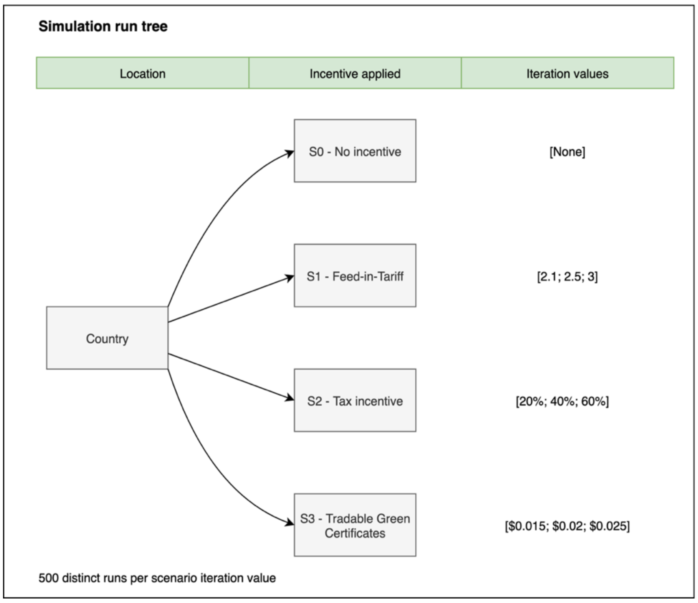

Figure 29 - Simulation run tree (the author)

Parameters to be collected

To answer the research question, some parameters are collected from every simulation run. Their values, combined with the country environment data, are the base of the evaluation of the results chapter.

- Total communities
- Renewable energy generated by communities
- USD invested in Renewable projects
- Industry population in the communities
- Number of industries that exit a community
- Policy entrepreneur indicator
- Governmental expenditure on financial incentive

Table 6 - Simulation run settings (the author)

Characteristic	Value	Unit	Reference
Number of Industries	50	[actors]	(Saleman & Jordan, 2014)
Number of communities	=< 25	[actors]	Based on the number of industries
Renewable energy generation lifespan	20	[years]	(Behrendt, 2015; GE Power, 2018)
Energy demand by industry	200 - 30000	[KWh]	Based on observed grid tariffs brackets
Wind Energy threshold	5000	[KWh]	(GE Power, 2018)
Loyalty Threshold	12 /24	[points]	(DellaVigna, 2009; Hofstede, 2011)

Some last parameters collected from the literature are needed to be explained before presenting the simulation results. Firstly, industries and communities in the simulation are unitary actors or agents in ABMS vocabulary. This means that they have their own script routine, following steps each turn. The number of industries in the industrial park was defined following a World Bank study on industrial parks (Saleman & Jordan, 2014). Over the paper, Industrial parks observed and are considered of small size if they have 25 or fewer industries and large if they have at least 50 industries. As the small-network algorithm works better on larger populations, this research will run its simulations having 50 industries and limiting the maximum number of communities to 25 (as a community needs at least two peers to be created). This decision was made as the literature did not indicate any argument suggesting that different sizes of industrial parks would inflict different outcomes on the proposed parameters. Regarding the timeframe, each turn in the simulation is defined as one year or one tick in ABMS vocabulary. The literature indicates the lifetime for both solar and wind energy generation is of 20 years or 20 ticks (Behrendt, 2015; GE Power, 2018). Therefore, each simulation run will happen in this timeframe of 20 turns. The amount of energy to be procured by every industry is dealt with in Kilowatt-hour, and being the actual value, a pseudo-random number picked from a uniform distribution of 10.000 values between 200KWh and 30.000 KWh. Despite the annual amount of energy demand being a random selection, the range fits in the usual scale of energy demand observed on energy tariffs label at the selected countries. Lastly, the loyalty value is measured in points. The summarized settings applied to the simulation are presented in Table 6.

Finalizing this section, all the parameters utilized in the simulation build are concentrated in Table 7, which presents the parameter, which country it is linked to, and the range it can be chosen.

Table 7 - Simulation parameters (the author)

Parameter	Type	Country	Value	Reference
Grid tariff	Random distribution	Alpha	[5,19 - 6,35]	(Australian Energy Regulator, 2019)
		Beta	[9,61 - 11,74]	(Aneel, 2019)
		Gamma	[4,68 - 5,72]	(World Bank, 2019)
		Delta	[10,84 - 13,25]	(UK BEIS, 2019)
		Epsilon	[6,78 - 8,29]	(European Union, 2019)
		Zeta	[7,17 - 8,76]	(US Energy Information Agency, 2019)
Solar Installation Costs	Random distribution	Alpha	[800 - 2000]	(IRENA, 2019)
		Beta	[800 - 2000]	(IRENA, 2019)
		Gamma	[800 - 1300]	(IRENA, 2019)
		Delta	[1400 - 2100]	(IRENA, 2019)
		Epsilon	[900 - 3490]	(Paardekooper, 2015)
		Zeta	[800 - 2000]	(IRENA, 2019)

Wind Installation Costs	Random distribution	Alpha	[1300 - 2000]	(IRENA, 2019)
		Beta	[1200 - 2500]	(IRENA, 2019)
		Gamma	[1100 - 2100]	(IRENA, 2019)
		Delta	[1600 - 2600]	(IRENA, 2019)
		Epsilon	[1000 - 3100]	(IRENA, 2019)
		Zeta	[1200 - 2500]	(IRENA, 2019)
Solar energy potential	Numeric	Alpha	[2270,2]	(United Nations, 2019)
		Beta	[1732,7]	(United Nations, 2019)
		Gamma	[2951,8]	(United Nations, 2019)
		Delta	[1773,29]	(United Nations, 2019)
		Epsilon	[1542,3]	(United Nations, 2019)
		Zeta	[3254,20]	(United Nations, 2019)
Wind energy potential	Numeric	Alpha	[2525,80]	(Windfinder, 2019)
		Beta	[1673,16]	(Windfinder, 2019)
		Gamma	[2760,86]	(Windfinder, 2019)
		Delta	[979,66]	(Windfinder, 2019)
		Epsilon	[3749,28]	(Windfinder, 2019)
		Zeta	[2562,38]	(Windfinder, 2019)
Discount rate	Numeric	Alpha	[7]	(Ministério da Economia, 2019)
		Beta	[10]	(Ministério da Economia, 2019)
		Gamma	[5,8]	(Daneshmand et al., 2018)
		Delta	[4]	(Leo Dobes et al., 2016)
		Epsilon	[3]	(Ministério da Economia, 2019)
		Zeta	[3]	(Ministério da Economia, 2019)
Decision Style	Numeric	Alpha	[43,33]	(Minkov & Hofstede, 2013)
		Beta	[57,33]	(Minkov & Hofstede, 2013)
		Gamma	[37,33]	(Minkov & Hofstede, 2013)
		Delta	[61,33]	(Minkov & Hofstede, 2013)
		Epsilon	[57,66]	(Minkov & Hofstede, 2013)
		Zeta	[44,66]	(Minkov & Hofstede, 2013)
Decision Style	Numeric	Alpha	[67,33]	(Minkov & Hofstede, 2013)
		Beta	[54,33]	(Minkov & Hofstede, 2013)
		Gamma	[47,66]	(Minkov & Hofstede, 2013)
		Delta	[77,66]	(Minkov & Hofstede, 2013)
		Epsilon	[49]	(Minkov & Hofstede, 2013)
		Zeta	[66,33]	(Minkov & Hofstede, 2013)
Industry Energy	Random choice	-	[200 – 30000]	*From grid tariffs*
Scenario 1 – FIT	Numeric	-	[2,1 ; 2,5 ; 3]	*calculated*
Scenario 2 - TAX	Numeric	-	[0,2 ; 0,4 ; 0,6]	(Behrendt, 2015)
Scenario 3 - TGC	Numeric	-	[0,015; 0,02; 0,025]	(Ford et al., 2007)

The next chapters will present out the results of the simulation runs, with insights in looking to a single country, followed by comparing all six different countries and, finally, an analysis of observed global parameters.

5.4 Model verification

Working with a model in computer code, a question must be answered: did we correctly translate the conceptual model into the code? The verification phase stands for confirming that the researcher has built the *'thing right'* (van Dam et al., 2013). Verification is not an elementary task, especially when dealing with emergent behaviors. Nonetheless, there are some steps to be followed when verifying an ABMS:

- Record and track agent behavior
- Single-agent test
- Interaction test

5.4.1 Record and track agent behavior

The first stage in verifying the simulation model is to take a closer look if the agents are behaving as expected. This is done through recording inputs, outputs, and intermediate steps taken by the agents (van Dam et al., 2013). In this simulation, there are two types of agents, industries, and communities, each one with its own individual activities to perform at each tick. Those activities follow an order to be performed accordingly to the model defined routines in section 4.5. The recording of agent behavior in this research occurred during the simulation development as on each step, values where observed. To check if this function is working properly, Nikolic suggests that the recording of all internal activities should be read as a "conversation" between the agents (van Dam et al., 2013). In other words, each function talks to the others and other agents in the simulation.

The development of the simulation was done on the programming language of Python and followed the concept of object-oriented programming, making all *'agent-activity'* into a building block of the agent role. Such blocks are independent of other activities and performed sequentially. All blocks of functions have expected inputs and outputs[3]. For example, every industry at each tick must have a new energy value to be fulfilled. This on the code was done by creating an energy demand function which sets each individual energy demand to a pseudo-random value. After the implementation of the code section, all industries were instructed to report their current energy demand for the 20 ticks period. With such data, it was possible to assess if new values were being assigned to the industries. The same logic was applied to the other functions, followed by a 'dry-run' to see if the function outputs were as expected. A list of all functions performed on the simulation by which type of agent do it is displayed next.

Industrial Agents Functions

- *Update Neighbors* – Each industry in the first tick creates a list of all neighbors it has, identifying all agents in the simulation. **Confirmed.** The list did not change throughout the simulation.
- *Energy Demand* – Each industry should have a new energy demand value. **Confirmed.** Each tick the numeric value was different.
- *Engagement Grade* – Each agent must update its engagement grade value based on its current engagement grade value and the corresponding CBA calculation. **Confirmed**. Engagement grades changed according to CBA results and not disrespecting their original condition.
- *Create Community* – When an industry has an engagement grade of <u>3-Enthusiast</u>, it will seek its strong-network (identified on *Update Neighbors*) for other industries engagement grade, and if the majority of them are either <u>enthusiasts</u> or <u>members</u>, it will change its own engagement grade to founder and the enthusiast agents in its strong network will also change. Lastly, this creates the initial community member's list. **Confirmed.** This behavior was observed on the engagement report and on the formation of the communities.

[3] https://www.educative.io/blog/object-oriented-programming

- *Return of Investment* – Each industry calculates based on how much it has invested what is the expected return. **Confirmed.** Each industry changed its ROI after investing in the communities.
- *Leave Community* – Each turn, the community checked if their loyalty value was higher than its designated threshold, and if the result was true, check if the return was insignificant. **Confirmed**. Some industries leaving communities were observed.

Community Agents functions

- *Check if the community is active* – Due to limitations in the software, the communities had to be placed at the initialization of the simulation and activated when founders created one. **Confirmed.** Communities start inactive and are activated when industries have the engagement grade of the founder.
- *Set previous tick values to zero* – Each start of tick the community must not have previous ticks values; therefore, the energy demand of members, plan execution, and request for investment is made zero. **Confirmed.** No value was transposed from one tick to another.
- *Energy Demand* – At the beginning of each new tick, the community determines the amount of new energy it must produce for fulfilling its member's energy demand. **Confirmed.** This behavior was observed
- *Initial investment* – In the tick, the community is activated, it must create its starting financial reserves so to create the projects with founders' investment. **Confirmed.** The request for initial investment only occurred at the activation tick.
- *Project Definition* – With the defined energy demand, the community jumps into a series of financial calculations, which returns a projected margin and feasibility. **Confirmed.** Both feasible and unfeasible projects were observed.
- *Community meetings* – Each year, a community meeting must be set for voting the project. **Confirmed.** Both approved and rejected projects were observed.
- *Plan execution* – For approved plans, the community discount the money from the reserves, create the project, and register the new values on its 'books'. **Confirmed.** Values were accumulated on the 'books'.
- *Policy Entrepreneur role* – Based on the economic results and ability to approve a plan, the community reports to the government with a positive or negative value. **Confirmed.** Each tick a new value was recorded.
- *New Members' Fee* – After updating values, the community updates its LCOE value, which is used for calculating new members' fees to join the community. **Confirmed.** LCOE was updated on each tick.
- *Return calculation* – The community calculates how much it is returning financially for each member so they may calculate the return of investment. **Confirmed.** This behavior was observed.
- *Remove members which exit* - After a member decides to leave a community, the community removes it from its list of members. **Confirmed.** The member list got smaller after a member exited.

The last step here is to run a debugger over the code so as to verify if all logic operators are indicated and it there are meaningless scripts. Syder, the python development environment used in this research natively performs debugging as the code is being entered and once more when starting a simulation run.

5.4.2 Single-agent test

After checking the behavior of individual functions, the verification goes to exploring the behavior of a single-agent. Here the objective shifts from assessing the functions performed into observing if the aggregation of all functions delivers expected results. This can be done in two tests, described next.

Theoretical Predictions and Sanity check

The conceptual model describes expected behaviors from the model narrative, providing a general expectation of how the agents will behave (van Dam et al., 2013). For example, a member to approve a feasible that produces cheaper energy than the grid tariff.

- *Simulation setup*
    - 50 industries and 25 inactive communities shall be placed pseudo-randomly on the industrial park grid, not overlapping each other. Some adjustments to the built-in functionality were needed as the number of inactive communities was subtracting the number of industries. **Corrected and confirmed.**
    - Only active communities should perform CBA calculations. It was observed that all communities were performing calculations despite being active or not. A new function was added such inactive communities 'jump its turn' and did not perform any function. **Corrected and confirmed.**
    - Each industry is able to observe all other industries. **Confirmed.**
- *Creating or joining a community*
    - Industries only perform peered-CBA calculations if it is not going for grid energy. **Confirmed.**
    - Industries only create or join a community if its engagement grade is 5 or 4, respectively. **Confirmed.**
    - All new members pay a fee to enter the community. **Confirmed**
- *Project Definition*
    - Projects are only calculated if the community is active. **Confirmed.**
    - *All projects are defined based on CBA evaluations. **Confirmed.***
    - Community generates plans based on their strategy. **Confirmed.**
    - All members attain the annual meeting. **Confirmed.**
- *Community evaluation by members*
    - Industries register community actions that impact their loyalty level. **Confirmed.**
    - The amount provided to members is updated accordingly to the type of strategy. **Confirmed.**
    - Industries only leave if both loyalty and economic planes are unsatisfied. **Confirmed.**

- *Dealing with Null values*
  - All agents with null values do not perform actions. **Confirmed.**
  - No CBA calculation is performed if values are null. **Confirmed.**
  - Agents do not break with null values. **Corrected and Confirmed.** Some CBA calculations resulted in null values that broke the process or the agent performing the activity. Logic gates were added to avoid such a situation.

5.4.3 Interaction & Multi-agent test

The following step regards the interaction testing of agents in a minimal model where the touchpoints between agents are evaluated happening in an environment with the minimal elements of the simulation. Here the objective is not to test the model in totality but to evaluate if the interaction between agents is occurring as expected (van Dam et al., 2013). The existing interaction in the model can be classified into two types: Industry-Industry and Industry-Community.

Industry-Industry interaction

Industries interact with each other in three moments during the simulation, first, during the engagement grade setting, followed by the creation of a community, and lastly, when evaluating if they will continue in the community or not.

- Engagement grade setting
  - Industries are able to perform peered CBA calculations with peers in the weak network. **Confirmed.**
- Creation of a Community
  - Industries can check the engagement grade of their peers in the strong network. **Confirmed.**
  - Industries that are forming a new community can change the engagement grade of their peers from enthusiast to founder. **Confirmed.**
  - Industries do not change the engagement grade of their peers that are not enthusiasts. **Confirmed.**
- Evaluation if the member should continue in the community or not
  - Industries can read other members' votes. **Confirmed.**

Industry-Community interaction

This interaction is the most recurring one as industries become members of the communities. There are some touchpoints between those types of agents before and after becoming members.

- Engagement grade setting
  - Industries are able to identify all communities and their activation status. **Confirmed.**
  - Industries are able to perform peered CBA calculations with active communities. **Confirmed.**
- Creation of a Community

    - Industries can activate communities when changing engagement grade to founder. **Confirmed.**
    - Communities can add new members to their member's list. **Confirmed.**
- Member’s role
    - Industries can vote on the community’s business plan. **Confirmed.**
    - Industries receive a return value from communities. **Confirmed.**
    - Communities can ask and receive new investments from members. **Confirmed.**

5.4.4 Sensitivity Analysis

To verify if the input parameters are coherent with the model, a sensitivity analysis was made. This analysis consists of running a high number of test simulations and examine if by changing the variables, namely, each value of the financial incentive, the output result is very different. If the variation is too significant, the model is sensitive to that variable, and this must be considered and adjusted. A large variation can bias the result and lead to a mistaken conclusion (van Dam et al., 2013). For this analysis, the variables chosen for testing are *the sum of the maximum number of communities* and the *sum of the maximum number of members*. These two variables have a stronger influence on energy production and, thus, a higher impact on the results.

Table 8 - Sensitivity Analysis (the author)

Scenario 1	Value 1	Value2	Value 3	Max variation
Maximum number of communities	25,24	25,57	25,25	1%
Maximum number of members	219,18	229,02	236,48	7%
Scenario 2	Value 1	Value2	Value 3	Max variation
Maximum number of communities	27,08	28,1	27,68	4%
Maximum number of members	254,85	278,96	283,46	10%
Scenario 3	Value 1	Value2	Value 3	Max variation
Maximum number of communities	27,18	26,86	27,58	3%
Maximum number of members	253,46	259,31	276,04	8%

Both values indicate that the model is not sensitive to the proposed variables, reinforcing the choices made. Although the difference in Values 1 and 3 is close to being significant. If value three were chosen higher, this would distort the simulation and harm the results. For some more clarity over the utilized data, a summary of all parameters applied in the simulation is presented in Table 7, where the type of parameter for each country is presented along with all possible values.

Chapter 6 – [Simulation Results]

6 RESULTS

This chapter presents the main results obtained through the execution of the model, as detailed in chapters 4 and 5. Section 6.1 presents out some country-specific insights, focusing on Alpha and Epsilon as they presented particular values. Section 6.2 explores all metrics comparing the different countries, and finally, section 6.3 presents specific insights through the countries and incentives standpoint while evaluating the simulation data.

The hypothesis of financial incentives providing better results when compared to a baseline of no applied incentive can be answered with the datasets produced, which are addressed in this chapter. The fists step into looking at the datasets is to divide the analysis into three segments. (1) Country specific insights, (2) Comparison among countries, and (3) Different types of incentives when aggregating all countries. Besides splitting the analysis, the results were also split by the type of financial incentive applied. The first scenario is a control or baseline situation, called scenario 0. In the control scenario, no incentive was applied. This allows evaluating how each incentive performs when compared to the country standard performance, allowing to assess if any financial incentive depreciates the energetic production. The other scenarios represent each one the introduction of a financial incentive. Scenario 1 represents the application of the Feed-in-Tariff incentive, while Scenario 2 represents the application of Tax incentives, and Scenario 3 depicts the application of the Tradable Green Certificates incentives. Each incentive scenario values are unique, meaning that no simulation run was made with more than one incentive applied at a time.

In this section, the results are presented with the mock countries presented in section 5.1 so to avoid direct comparisons with real-life situations. *Alpha* represents countries with similar Australian characteristics, *Beta* corresponds to Brazilian like characteristics, *Gamma* serves as an example of a country with Iranian characteristics, *Delta* with Japanese characteristics, *Epsilon* has Dutch characteristics and finally, Zeta represents countries with United States characteristics.

6.1 Country individual insights

The exploration of the data from the simulation run starts from a base level by analyzing some country-specific data. This first analysis helps to understand what type of information is provided on the country level, supporting the insights observed on the aggregate level. For presenting such information, Alpha and the Epsilon were chosen as examples as presented very diverging behaviors. A deeper look in the country's comparisons among each other is presented in Section 6.2. The metrics presented in section 4.1 are going to be used in this country evaluation. Namely, Alpha and Epsilon will be evaluated on (i) how much energy was produced, (ii) The average maximum number of active communities, (iii) the average maximum number of members in the communities, (iv) the average number of members which exit a community, (v) the count of policy entrepreneur role, $\pm$ 1 based on how the current period performed against the previous period, (vi) the sum of how much was invested by communities in renewable energy projects, and lastly, (vii) the sum of all governmental expenses with the financial incentive. The seven metrics were collected for all four scenarios following the same procedure.

6.1.1 Country Alpha

Alpha, the mock country with the socio-economic characteristics similar to Australia, is a country worth analyzing more in-depth as it presented some considerable differences in the results between the scenarios. While most of the countries had small variances in between scenarios 1, 2, and 3, in Alpha, the total number of communities, the total number of members, the number of members which exited a community, and the policy entrepreneur indicator varied significantly over each scenario proposed.

Table 9 – Alpha's metrics by scenario (the author)

Alpha	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Total energy production by scenario (MWh)	85.918	56.769	250.332	225.212
Average maximum number of communities	4,07	3,92	4,59	4,62
Average maximum highest number of members	19,76	21,69	42,32	37,60
Average number of members Exit	3,64	3,17	2,26	2,89
Average policy entrepreneur indicator	103,47	21,75	154,36	155,81
Community Investment (USD)	2.187.777	1.568.043	3.822.909	5.994.138
Government Investment (USD)	-	1.472.930	7.782.315	2.625.59
Total Investment (USD)	2.187.777	3.040.974	11.605.225	8.619.728

Going over the values, Scenario 1 - FIT was the lowest in the model running with Alpha data, presenting itself as the worst case for promoting communities. In such a scenario, the average maximum number of communities was 3,92 communities (the maximum possible number is 25), and those communities had an average number of members of 21,69 industries (the maximum possible number is 50), and the average maximum number of members exits was 3,17 members. When compared with other countries, the results in all other scenarios were considerably better. FIT consistently performed worse than the baseline, a clear indication that this scenario is not a favorable one to be applied in Alpha. Looking at the other incentivized scenarios, TGC presented an average maximum number of communities of 4,62, the highest observed for Alpha, while Scenario 2 delivered the highest average maximum number of members of 42,32, and the lowest average number of members exit, 2,26. The unfavorable position of scenario 1 can also be observed in the Policy Entrepreneur indicator. The communities here gave more negative feedbacks to the government resulting in the lowest observed value. All values are presented in Table 9.

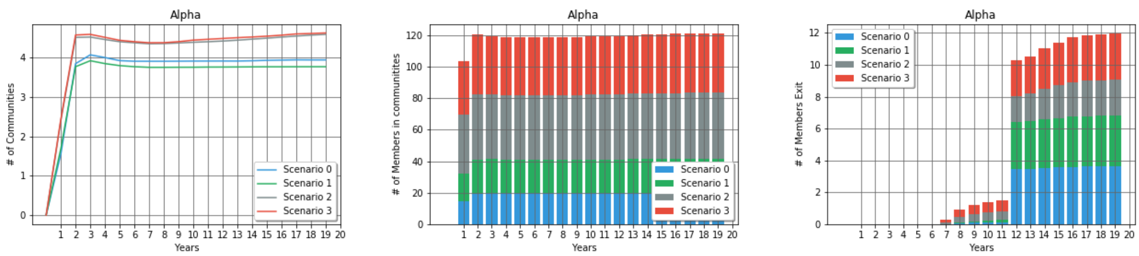

Figure 30 – Alpha's graphs on community-related metrics (the author)

Looking over the total energy produced in Alpha for the 20 years, in scenarios 2 and 3, the most energy was produced (2,41 PWh and 2,17 PWh respectively), while in scenario 1, the communities produced the lowest amount of 0,55 PWh. For comparison, in the Baseline, communities generated 0,82 PWh. However, looking only for energy production is not sufficient to grasp the full comprehension. Considering the invested amount to produce, communities in scenario 1 disbursed the lowest amounts (USD 1,5 million), followed by communities in the baseline (USD 2,1 million). Communities in scenario 2 (USD 3,67 million) and in scenario 3 (USD 5,78 million) were the ones who expensed the most. It is interesting to notice that, when comparing to the baseline, both TAX and TGC produced more energy while demanding less investment by the communities, making it favorable policies to be applied in Alpha.

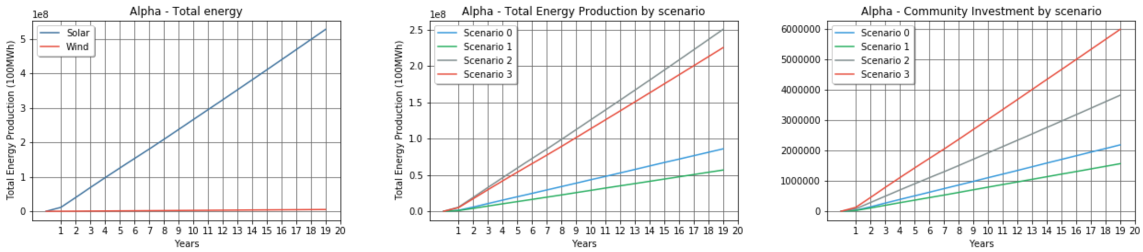

Figure 31 - Energy production by type, per scenario, and invested capital by communities for Alpha (the author)

When assessing how much it cost for the government, the expenses in each scenario followed the same logic. Tax incentives are the scenario with the higher expenditure to Alpha's government (USD 7,78 million, with an average of USD 389.115 per year). On the other side, FIT was the scenario that received less investment from the government (USD 1,47 million, with an average of USD 73.646 per year). Finally, TGC was in between (USD 2,62 million, with an average of USD 131.279 per year).

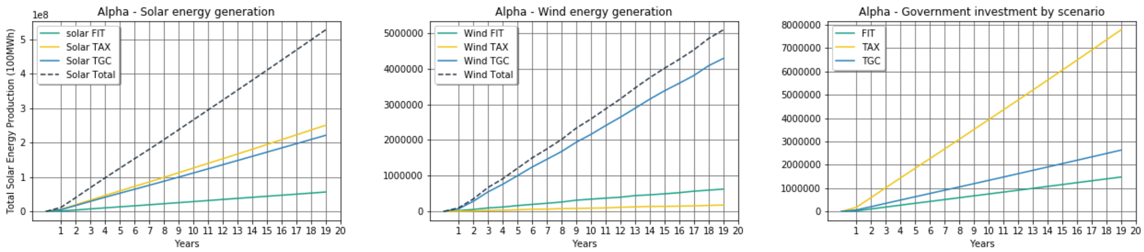

Figure 32 - Energy production and Invested Capital for Alpha by type of incentive (the author)

Finally, looking over the policy indicator, all scenarios presented over a positive response. This indicator would display a positive value if the current period performed better than the last period. In other words, if the community had an approved project in the current period and their revenue was superior to the costs, it sent a positive indicator to the government. Therefore, the higher the indicator is, the more good periods happened to the community. With the application of TAX and TGC, more communities reported positive results, surpassing the baseline. However, in FIT, despite the positive outcome, it had the lowest policy indicators of all. This low value is translated into the communities indicating that FIT was the most disadvantageous financial incentive and hindering them since the indicator was worse than the baseline.

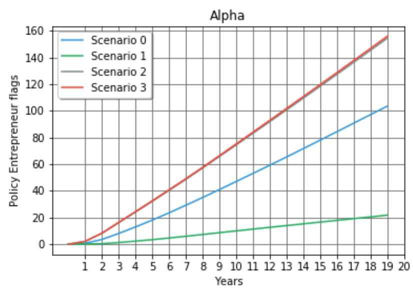

Figure 33 - Policy entrepreneur indicator for Alpha (the author)

To understand the results obtained, the first metric to be observed is energy production. Compared to the baseline, the results from scenario 1 were inferior, while in scenarios 2 and 3, they were considerably better. If the sole goal of implementing a financial incentive is to produce more renewable energy, the Tax incentive is the best option for Alpha. Nevertheless, this research is also interested in the prosperity of the energy communities. Joining the community metrics to the evaluation requires a quick observation of the environment of Alpha. In the city of Alpha, grid energy has a cheap tariff, while its environmental conditions culminate in an average potential for generating renewable energy while the installation costs are high. Such a setting prompts a very fragile environment for developing energy communities as the NPV values become very similar to the option of buying energy from the grid, making the latter somewhat an advantageous option. The number of communities and the number of its members is direct evidence of such observations, as the averages are small compared to the maximum it could be. If grid energy is not as expensive, more industries might prefer to buy from the grid and not join a community. However, the metric that best displays this unwillingness to be part of a community that Alpha's industries present is the number of members exit. In Alpha simulations, the number of members in which exit communities were very high; for example, in the baseline scenario, on average, nearly four members exit the communities while there were merely 20 members.

For understanding this behavior, it is needed to examine Hofstede's values. From the values presented in Figure 21, it can be noticed that countries with socio-economic characteristics similar to Australias have lower values in the *Power Distance*, *Long-Term Orientation,* and *Indulgence* dimension, making the decision-style metric have a low value. This translates into companies from such countries seeking consensus and searching for an overall benefit for society. On the other hand, those companies also have high *Individualism*, average *Assertiveness,* and average *Uncertainty avoidance*. High rates on these dimensions translate into how much each industry values its position when compared to how others behave. For those companies in such countries, a high value in individualism means that they are more prone to confront other opinions (Hofstede, 2011; Scharpf, 1988). These decision values guide industry agents to increase or decrease their loyalty points towards the community based on the voting results.

The number of members who exited a community is explained by the combination of these dimensions and a financial setback. It is interpreted from the values of Alpha that companies from such countries are less prone to handle diversion of opinions and can more easily exit the community if their expected behavior is not observed.

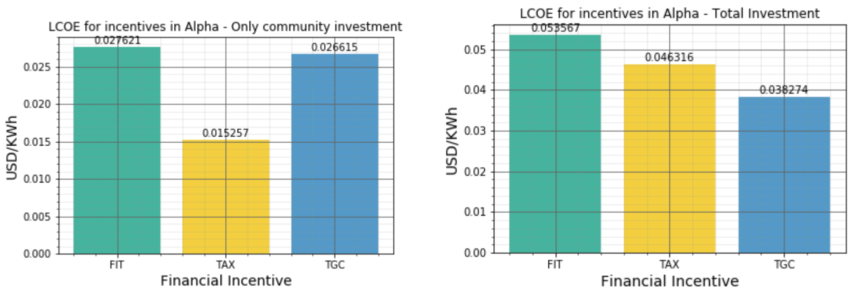

Figure 34 - LCOE for Financial Incentives in Alpha (the author)

Lastly, looking over the economic performance through Alpha's LCOE (Figure 34), it is noticeable that the scenario discrepancy is also observed on the unitary cost of energy. As it will be further explored in section 6.3, the LCOE was calculated with a total investment, meaning the sum of community investment and governmental investment and was also calculated using only the community investment. In a nutshell, the LCOE with total investment allows for a comparison between financial incentives while the LCOE looking only for community investment indicates which incentive is the cheapest for communities. The baseline LCOE is independent and has a value of USD 0,0254/KWh. For the communities, in scenario 2 - Tax incentives, they found the most cost-effective alternative, having an LCOE of USD 0,015/KWh, while in scenario 1 - FIT, the LCOE was most expensive at USD 0,027/KWh. This is an important metric for the policy analyst to observe as the decision-process for joining a community goes over assessing if such an alternative is financially good. However, that analysis alone is not complete if the governmental expenditure is not considered. Looking at the LCOE for total investment, the situation shifts. When considering all expenditures, TGC became the most cost-effective option, while FIT still is the most expensive. The main advantage observed in applying TGC is that the costs to the government are significantly smaller than the costs incurred when applying TAX.

On an overview and in more detail in section 6.2, Alpha performed very well when comparing the incentivized scenarios against the baseline for the costs to communities. Communities performed the worse in scenario 1, producing less energy and with a lower policy entrepreneur indicator, but in scenario 2 and scenario 3, they did produce much more energy than what was produced in the baseline with the addition that the LCOE was lower as well. Comparing to the grid tariff, in all scenarios, the produced energy was cheaper, including the baseline. Examining the incentivized scenarios with the baseline, we have that applying TAX or TGC are better options than not applying any incentive, but a choice between them surpasses the scope of this research. To the eye of the policy analyst, the choice between the two incentives requires a more in-depth evaluation of the current economic situation and budget planning, which this study does not grasp further.

6.1.2 Country Epsilon

Country Epsilon, the mock country with socio-economic characteristics similar to the Netherlands, presented a very different situation than what was observed for Alpha. Epsilon produced plenty of renewable energy with a high level of adherence by community members. Explicating the measured values, the total amount of wind and solar energy produced in all scenarios is on the same scale of magnitude, meaning that both Solar and Wind energy were attractive to production.

Table 10 – Epsilon's metrics by scenario (the author)

Epsilon	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Energy production by scenario	150.993	140.626	258.579	211.597
Average maximum number of communities	4,35	4,38	4,75	4,59
Average maximum highest number of members	31,75	31,29	42,03	47,31
Average number of members Exit	2,33	2,97	1,83	2,00
Community Investment (USD)	6.302.952	6.036.382	8.016.915	8.884.084
Government Investment (USD)	-	2.116.699	11.486.676	3.950.605
Total Investment (USD)	6.302.952	8.153.081	19.503.591	12.834.690

Looking into the community values for the Epsilon, in all incentivized scenarios, communities delivered values higher than what was produced the baseline. The best outcome is observed when TAX was applied, where the average maximum number of communities was of 4,75 out of the 25 possible. In Scenario 2, the smallest number of industries decided to leave the community, and the average of exits was 1,83 members. Nevertheless, it was when TGC was applied that the highest number of members joined a community, with an average high of 47,31 members out of the total 50 industries in the industrial park. In comparison, the worst-case was registered when the FIT was applied in scenario 1. There, an average of 4,38 communities was created, which attracted an average of 31,29 members from which, on average, 2,97 left the community. All values are presented in Table 10.

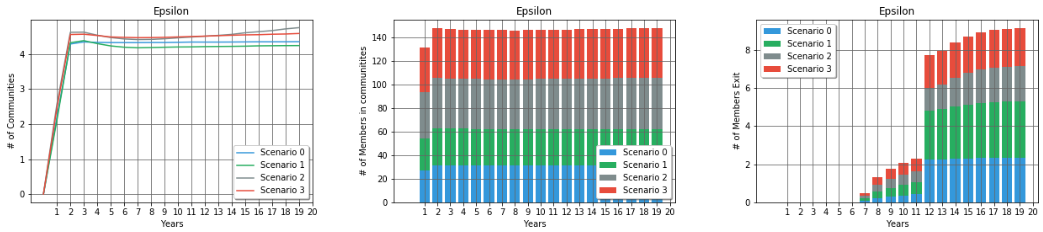

Figure 35 – Epsilon's Graphs on community-related metrics (the author)

Looking over with more details to the total energy produced in the Epsilon, During scenarios 2 and 3 most energy was produced by the communities (2,58 PWh and 2,11 PWh respectively), while in scenario the amount of energy delivered by the communities was even lower than what was produced in the baseline (1,40 PWh and 1,50 PWh respectively). Over the total invested capital by communities in RE Generation, FIT prompted the lowest investment by the communities (USD 6,03 million) value lower than the no incentives scenario (and 6,30 million respectively). Oppositely, TAX required a larger investment from the communities (USD 8,01 million), and TGC was the most demanding one in this metric (USD 8,88 million). It is interesting to notice that in scenario 2, the communities produced more energy while demanding less investment from them.

Evaluating how much governmental expenditure was made, the above logic is still valid. In TAX, the government invested the highest value (USD 11,48 million, with an annual average of USD 574.333). Applying FIT costs less to the government as it was the lowest production amount (USD 2,11 million, with an annual average of USD 105.834), and TGC was in between the other two (USD 3,95 million, with an annual average of USD 197.530).

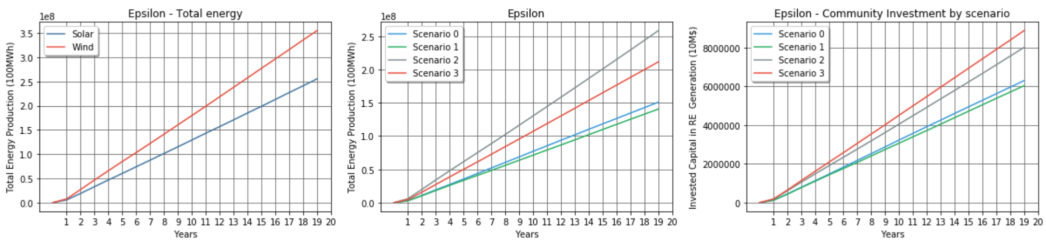

Figure 36 - Energy production by type, per scenario, and invested capital by communities for Epsilon (the author)

Finally, looking over the policy indicator presented in Figure 38, in all scenarios, communities signaled with a positive response over how each community performed when compared to the last term. As expected, due to the higher energy production, communities in scenarios 2 and 3 reported more positive records than in the other scenarios. Communities in scenario 1 indicated that they had a rougher development than any other scenario, including the baseline. This grows the suggestion that FIT may not be the best policy alternative for financially incentivizing InCES. A detailed evaluation of the performance of the financial incentive is presented in section 6.3.

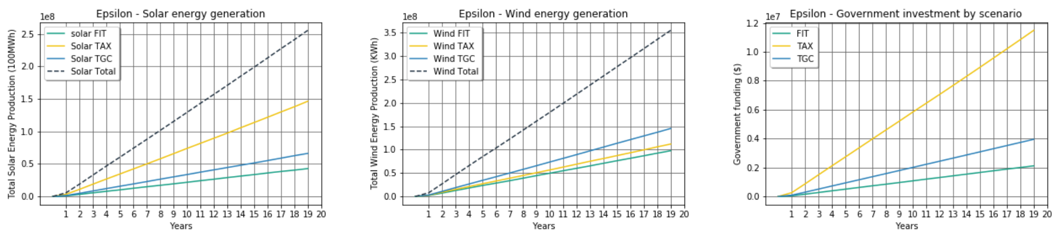

Figure 37 - Energy production and Invested Capita by the government for Epsilon by type of incentive (the author)

Epsilon's case intrigues on how communities handled wind generation. Besides being the only country that produced wind energy on a large amount, with more details in the next section, the amount of wind energy generated was superior to the amount of solar generation, going against the expected behavior. The model design suggested that wind energy production would be smaller than solar energy as the prior is more expensive to install and has an initial threshold to start production. To understand this result, it is needed to observe the parameters behind the decision between choosing energy sources. Communities choose energy sources based on the NPV value of each alternative. The highest NPV value is presented to the community members who vote based on comparing the projected tariff with the grid tariff (in the case of producing energy) or by comparing the project margin against an expected return (in the case of selling energy). The NPV value, in its turn, is defined based on the costs and how much energy can be produced (benefit). In Epsilon's case, not only the wind generation potential is superior to all other locations, but the price of installation has a gap that allows prices to be sufficiently low to incentivize more the production of wind energy.

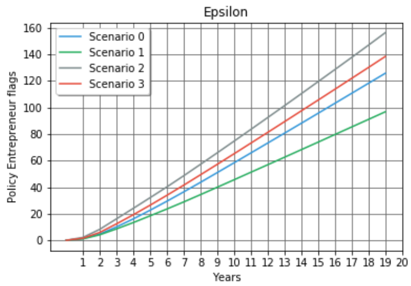

Figure 38 - Policy entrepreneur indicator for Epsilon (the author)

Moreover, Epsilon's grid tariff is not cheap, which turns the option to buy energy from the grid not as advantageous, enhancing support for energy communities. Observing the total investment, another intriguing aspect of Epsilon's case comes to light as the LCOE produced during FIT is the lowest when comparing to TAX and TGC. Looking over the amount of energy produced, with support of Figure 23, Figure 24, and Figure 26, it is possible to explain why Epsilon produced more wind energy than solar energy. While Epsilon sits on a higher wind energy potential when compared to solar energy potential, the installation costs have similar figures, creating a very favorable environment for producing wind energy. This environmental setting provides a large economic advantage for an industry to join and stay within a community. This can be observed in the high number of members in communities and a low number of members who exited a community.

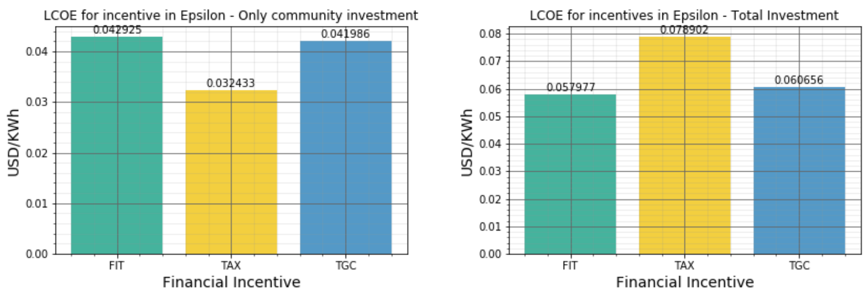

Figure 39 - LCOE for Financial Incentives in Epsilon (the author)

Expanding the understanding of the members which exited a community in Epsilon, the starting point is examining the Hofstede's values, presented in section 5.2. Epsilon has lower values in Power Distance and higher values in Long-term orientation and the indulgence dimension, making the decision-style value higher. This can be translated into Epsilon's companies tending to look more to the long-term plans and can be more restraint over other opinions, despite having an equal society. Therefore, they are less worried about having a unanimous community as long as it follows the agreed plan. If this happens, the industry loyalty points towards the community will increase. On the other hand, Epsilon's society has a high individualism, low assertiveness, and average uncertainty avoidance dimensions. This makes Epsilon's industries more open to being in a community not too much similar to their own beliefs. In sum, Epsilon's companies are more prone to handle diversion of opinions and can easily remain in the community if their expected behavior is not observed.

6.2 Comparing Countries

Continuing the evaluation of the results, the next observations regarding how every country performed when compared to other countries. These comparisons occur over the same metrics presented in the previous chapter. The evaluation goes over the (i) energy production per country, (ii) energy production per scenario, (iii) number of communities, (iv) number of members in the communities, (v) how many members exit the communities, and (vi) the policy entrepreneur indicator. The combination of such values allows assessing how well countries performed when compared to its peers but also introduces the differences between incentives, which will be further explored in the next chapter.

6.2.1 Energy generation

Among the analyzed parameters, perhaps total energy is the most important parameter to follow, as the goal is to incentivize renewable generation through financial incentives. By comparing the sum of all energy generated in the different scenarios, we obtain a reference value for understanding the overall behavior of each country when producing renewable energy. The main behavior observed with this metric is that wind energy was highly underused, with Epsilon being the only country to produce a significant amount of energy through wind source. Epsilon's energy production was very characteristic of the balance between how much was produced in solar and wind at each scenario. Another country that drew attention is Delta, as it led solar energy generation when TAX was applied and was the second-largest producer when TGC was applied. The energy potential values presented in section 5.2, suggested that Epsilon was expected to lead the wind energy generation, which proved to be true, while Delta was to be the least in energy production, since it had a very low renewable energy generation potential, as it was presented in Figure 26.

The observed positive result for Delta (socio-economic characteristics similar to Japan) is not explained by its physical location characteristics, but it can be explained through its costs. As observed in Figure 22, Delta has a higher grid tariff among all nations, and the installation cost range is similar to other countries, as presented in Figure 23 and Figure 24. This creates a scenario where energy communities are able to produce cheaper electricity due to the lower installation costs for renewable energy, and staying outside a community is costlier for industries, making being part of a community attractive. These previous expectations are also challenged by Alpha, which from Figure 26 suggested some large production of renewable generation, which did not show to be true. Lastly, the last main behavior observed was that only when FIT was applied, all countries registered less energy generation than in the baseline.

In total, only three countries produced wind energy, but production was not even. While Epsilon produced approximately 45% of all its generation through wind energy in its most productive scenario, Alpha and Beta (socio-economic characteristics similar to Brazil) produced in much smaller percentages (less than 1% for both cases) comparing to solar generation. In Gamma (socio-economic characteristics similar to Iran), Delta and Zeta (socio-economic characteristics similar to the United States), despite producing only solar energy, they still managed to be top producers, surpassing Alpha and Beta at the baseline and when the incentives were TAX and TGC. It was also in those scenarios that the best values were observed. Alpha, Beta, and Epsilon had their largest energy production with TAX incentives, while Gamma, Delta, and Zeta had their largest production with TGC incentive. Table 11 presents all values in detail, while Figure 40 presents that information through the financial incentives dimensions, and Figure 41 rotates data to present production through the countries' dimensions.

Table 11 – Total energy production by country (the author)

Country	Baseline		FIT		TAX		TGC		Max energy	% to max energy	
	Solar	Wind	Solar	Wind	Solar	Wind	Solar	Wind	(MWh)	Solar	Wind
Alpha	85.050	868	56.146	625	250.155	177	220.924	4.288	250.332 (TAX)	99,93%	0,07%
Beta	170.806	5.037	29.128	792	273.055	1.292	237.903	7.780	274.347 (TAX)	99,53%	0,47%
Gamma	282.925	0	2.125	0	279.400	0	279.893	0	279.893 (TGC)	100,00%	0,00%
Delta	280.558	0	41.496	0	274.963	0	278.310	0	278.310 (TGC)	100,00%	0,00%
Epsilon	48.123	102.869	42.861	97.764	146.487	112.093	66.240	145.357	258.580 (TAX)	56,65%	43,35%
Zeta	286.350	0	1.425	0	277.909	0	280.640	0	280.640 (TGC)	100,00%	0,00%

Comparing to the baseline, Alpha Beta and Epsilon produced more energy in TAX and TGC than what was produced in the baseline in both TAX and TGC. For Gamma, Delta, and Zeta, no scenario produced more energy than the baseline. This result leads to some interesting insights into the incentives. The percentual difference between Scenario 0 and Scenario 3 for Gamma, Delta, and Zeta is small, not surpassing 3%, making this result not significant enough to claim that no incentive is better than having incentive. For comparison, Alpha produces more than 3x more energy in scenario 2 when compared to the baseline.

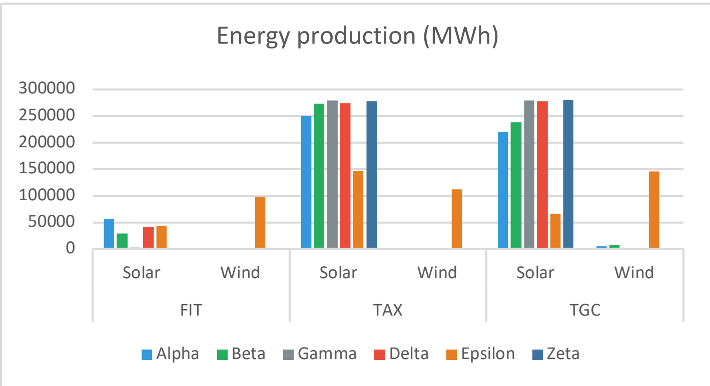

Figure 40 - Energy production by financial incentive, type of generation and country (the author)

Such values raise questions over why so little wind energy was produced. The main explanation comes from the initial threshold to start producing wind energy along with the installation costs. As explained in 4.3, the choice for wind energy goes through producing a minimal of 5 kwh as this is the threshold for installing windmills. In other words, any wind project with less than 5 kwh (projects can vary from 200 – 30.000 kwh) is restrained from existing in the model. Besides, project selection by the communities is evaluated for each technology or a mix between them. On a global average, the solar installation costs are cheaper (USD1532/KW) than wind installation (USD1850/KW). The combination of a threshold for wind generation and cheaper installation costs shows that in the model selecting solar energy projects presented itself as the preferable alternative. This is observed in Alpha, where despite the costs for wind and solar being similar, wind energy only acknowledges for less than 1% of total energy generation. Another interesting observation comes from comparing Beta and Gamma. In both countries, solar generation is marginally superior to wind generation, but the observed results are largely different. This difference is explained by Gamma's installation costs being much cheaper when compared to Beta's installation costs, both for solar and wind. However, Gamma's solar installation is much cheaper than its wind installation costs. Being so, In Gamma, choosing for solar generation projects is a much easier choice, while in Beta opting between solar and wind is a bit more unclear. In sum, wind energy generation is hurt by the threshold limitation and solar cheaper installation costs. This combination leads to an overall minimal wind generation. The only county where wind energy was significant did so for a much higher wind energy potential, compensating the costs and threshold.

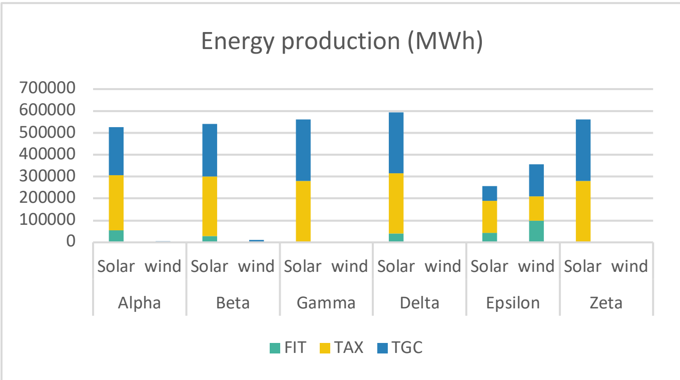

Figure 41 - Energy production by country, type of generation and financial incentive (the author)

Looking only for production results does not allow for a complete understanding if incentivized production is better or not. A country may have produced much energy but have worse results in the other metrics. As this research focuses on understanding renewable energy production in industrial energy communities, it is required to assess other metrics to develop a full understand of how each country performed.

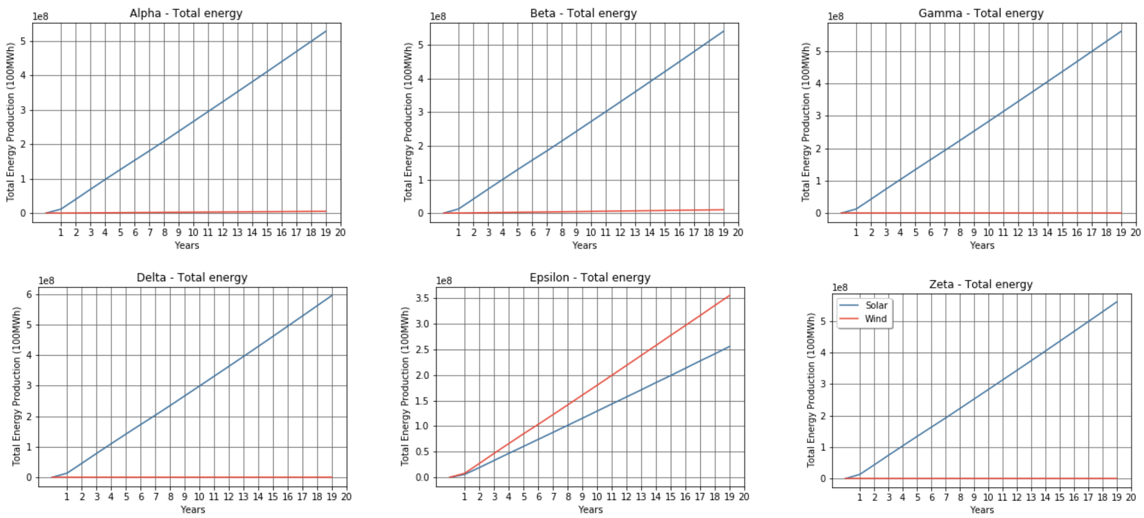

Figure 42 – Total energy produced for all countries (the author)

6.2.2 Communities

The following evaluation regards the total number of formed communities during the simulation run. This is measured by the sum of all active communities for each year on all four scenarios for all countries. In general, data is quite similar, with no significant outliers being observed. The number of communities is relatively constant, with its values increasing rapidly in initial years and varying little after the 5th year, and peak values can be observed starting in the second year. In general, the maximal number of formed communities approximately lies between 4 and 5 communities in all scenarios and all countries. Alpha presented the smallest maximal number of communities (average of 3.92) in Scenario 1, and Epsilon had the highest maximal number of all in Scenario 2 (average 4.75). All values are presented in Table 12.

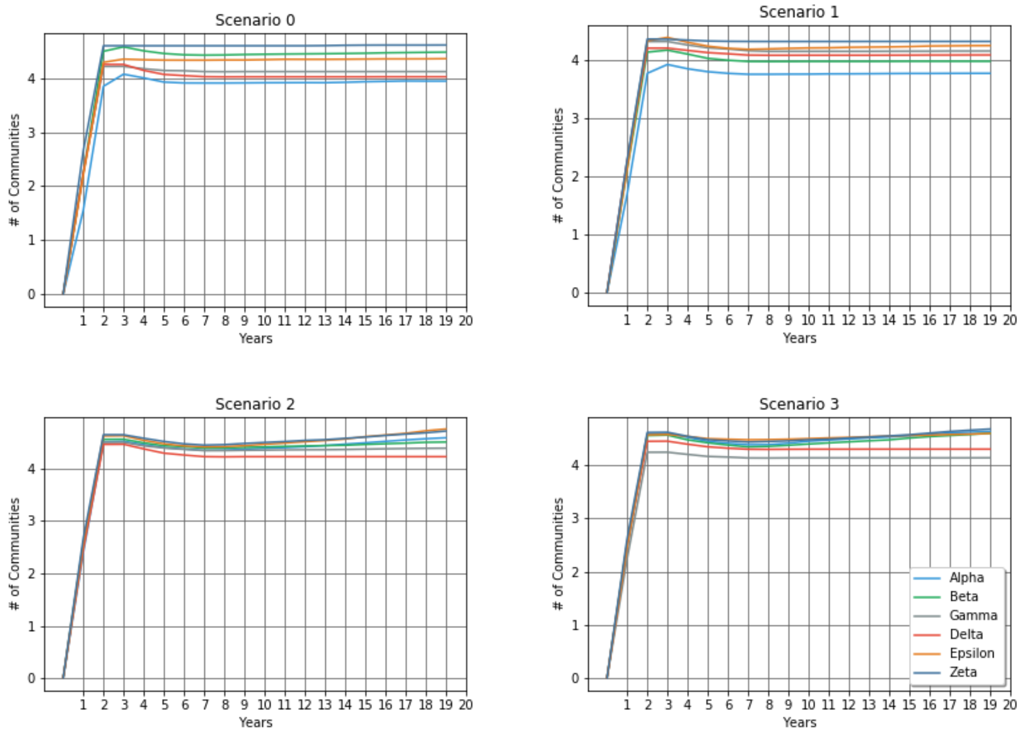

Figure 43 – Average maximum number of communities created in all countries per scenario (the author)

Assessing the number of communities reveals that the model behaved similarly throughout the simulation, and not much difference was observed between nations in this sense. From the smallest to the highest average number of communities, the difference is of 0,83 communities on average, with an average standard deviation of 0,187. The country with the smallest variance between values in scenarios was Gamma with a standard deviation of 0,13, and the country with the most variance between scenarios was Alpha with a standard deviation of 0,359. Also, there is no significant difference observed between the scenarios and the baseline. Scenario 0 values are very close to the values observed in the other scenarios. This results in several communities indicate a clustering degree within the industries population as no scenario produced five or more communities.

Table 12 - Average maximal number of communities per country for each scenario (the author)

Country	Maximal average number of communities				Standard deviation (σ^2)
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	
Alpha	4,07	3,92	4,59	4,62	0,359
Beta	4,57	4,16	4,56	4,59	0,204
Gamma	4,21	4,31	4,50	4,23	0,130
Delta	4,25	4,20	4,46	4,44	0,133
Epsilon	4,35	4,38	4,75	4,59	0,138
Zeta	4,61	4,35	4,71	4,67	0,160
Total	4,34	4,22	4,59	4,52	-

It is interesting to observe that Delta, the highest producer of energy, was only average in the number of communities. Alpha, the smallest producer, had more communities than Delta on Scenario 3 and Scenario 2. Such figures suggest that the total number of communities is not the main factor in determining how much energy production can happen. All simulation runs happened with 50 industries being part of the same industrial park. With this, the total number of communities is limited to 25 as it is required at least two members to form a community. In other words, the range of possible communities falls within 0 and 25 communities. However, looking only for the number of communities does not bring much knowledge. It is possible to have situations with only one community and 50 members or ten communities and 20 members in total. To further develop this analysis, it is needed to combine the number of communities with the number of members in such communities.

6.2.3 Members

Complementing the total number of communities, the total number of members provides a deeper understanding of the situation by explaining how appealing the communities were for the companies in the industrial park. The number of total members is presented in Figure 44 and detailed in Table 13. Following the same trend as the number of communities, the results present uniform values in all scenarios, with little variation in the number of members during the years. It is noticeable that scenario 2 and scenario 3 prevails scenarios 0 and 1 as in the prior, the average sum of all members in all communities in all countries surpassed 250 members (out of maximal 300) while in scenarios 0 and 1 such values stayed below 250 members.

Delta registered the highest number of members in a community in scenario 0 and an average of 47,44 members. Not considering scenario 0, Zeta produced the highest value with 47,36 members within communities in Scenario 1. This is a curious situation as both the highest values happened in the worse performing scenarios. The reasoning why both Delta and Zeta produced most of their energy in Scenario 0 can be explained by the larger number of members within the communities. As more members are part of communities, more energy must be generated by communities, thus explaining the results. The worse performing country again is Alpha. It had the lowest maximum number of members in its communities is all scenarios, with its highest value being 42,32 in scenario 2. Besides the average maximal values of members, it is important to understand how to disperse the values are. The standard deviation between the highest number of members in Alpha is also the largest between the analyzed countries. This means that Alpha is the country that depending on which type of incentive is applied, can have the biggest variation in results. Oppositely, Zeta has the lowest σ^2 value, being the most uniform country. Delta and Gamma, along with Zeta, the largest producers, also have small values of standard deviation. The obtained result is a clear indication that communities are attractive to industries, and the financial incentive increased this attractiveness when looking at all countries as an overall. On average, for the three incentivized scenarios, 78,52% of industries joined a community, while in the baseline, the figure is 69,53%.

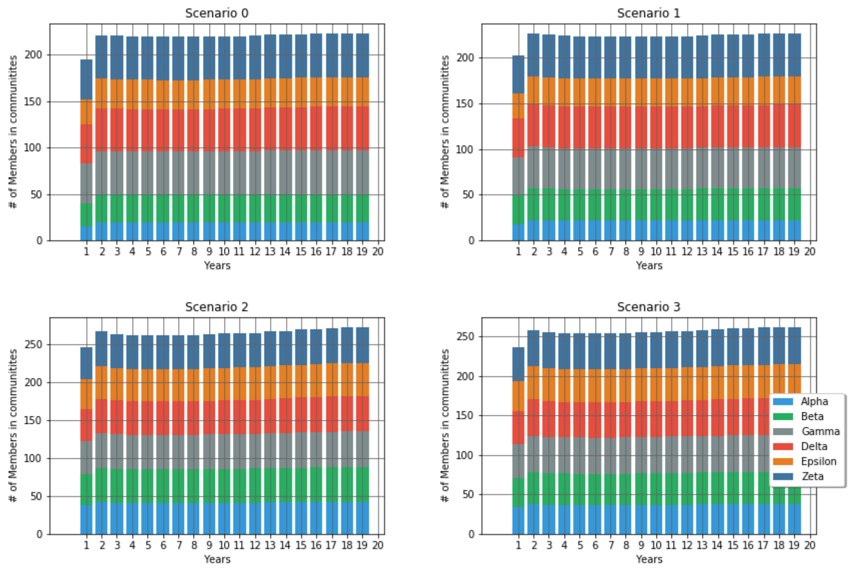

Figure 44 – Number of members in communities in all countries for different scenarios (the author)

The interpretation of the data from table 9 is, for example, in Alpha's scenario 1, on average, the highest number of members achieved in all communities was 21,69 members. For providing perspective, the highest possible number of members is that all communities vary between 2 (minimal number of founders) to 50 (all industries).

Table 13 – Average maximal number of members per country for each scenario (the author)

Country	Average highest number of members				Standard deviation (σ^2)
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	
Alpha	19,76	21,69	42,32	37,60	11,297
Beta	30,14	35,30	46,03	41,24	6,927
Gamma	47,05	45,63	46,84	46,89	0,655
Delta	47,44	46,61	46,63	46,84	0,388
Epsilon	31,75	31,29	42,03	47,31	6,582
Zeta	47,31	47,36	46,80	47,16	0,252
Total	37,24	37,98	45,10	44,50	

6.2.4 Members Exit

As communities are open to join and leave, it was expected that some members would decide to leave. This metric measures how many members did not feel belonging to such a community. In all scenarios and all countries, the number of members who decided to leave a community was considerably smaller than the total amount of members who joined a community. The graphs in Figure 45 show the cumulative number of industries that left their community. The rule for exiting a community is composed of two elements, a negative 12 loyalty level (or 24 for industries with bargaining as their decision-rule) and a mediocre financial return. The loyalty level is affected by the industry perception of how it belongs to the community. This is done on the voting sessions as each industry evaluates how it voted compared to the other member's vote. If the differences are significant, the industry loses a loyalty level, but if the difference is minor, it gains a loyalty level. As the defined threshold was of 12 for most companies, it was expected that the number of companies that decided to exit the community increases in the later years, especially after year 12 (one loss in loyalty point per year for 12 consecutive years). This behavior is observed in the model.

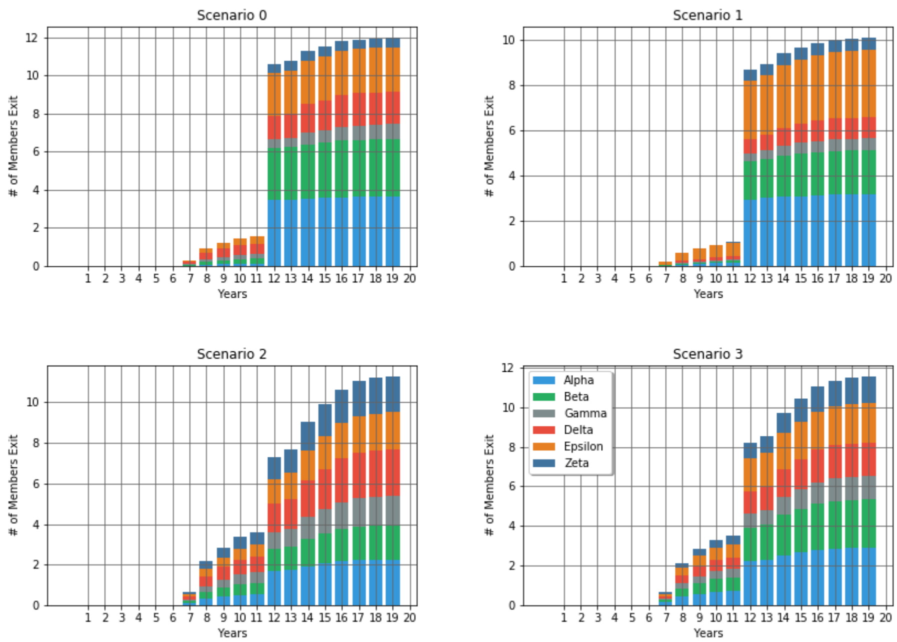

Figure 45 - Number of members that exit communities for different scenarios (the author)

Besides, in alignment with the observation in the total number of members, Alpha is the nation with the highest number of industries which exit a community, being this behavior observed in all scenarios. Both highest and lowest values were produced by Alpha, with the highest in scenario 0 (3,64) and Scenario 1 (3,17) and its lowest in scenario 2 (2,26). Again, the scenario in Alpha is an outlier to other countries. The lowest value was observed in Gamma, who registered in scenario 1, a value of 0,52, being this the lowest value, not considering the baseline. Compared to the baseline, scenarios 1, 2, and 3 presented a better result than the baseline. Scenario 3 was the worst-performing scenario among the incentivized ones. All values are presented in Table 14.

Table 14 – Average number of members who exit a community per country for each scenario (the author)

Country	Average number of members which exit a community				Standard deviation (σ^2)
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	
Alpha	3,64	3,17	2,26	2,89	0,578
Beta	3,02	1,94	1,68	2,45	0,591
Gamma	0,77	0,52	1,46	1,16	0,415
Delta	1,70	0,93	2,27	1,69	0,551
Epsilon	2,33	2,97	1,83	2,00	0,501
Zeta	0,50	0,54	1,76	1,34	0,619
Total	1,99	1,68	1,87	1,92	

In a general view, all countries presented little variations throughout the scenarios. Zeta is the country that varied the most and Gamma, the one which varied the least. The members' exit metric is composed of 2 elements: a decision style/rule evaluation and an economic performance evaluation. The first element appraises the differences between Hofstede's variables within the simulation. A deeper explanation of how the Hofstede's dimensions inflict the metric was presented on 6.1. The Decision Style variable is affected by the evaluation of how each company voted compared with how other companies voted. The decision rule is affected by the voting outcome and if the company chose the same option. From the values presented in Table 4, Gamma has the lower values from all countries, which indicates that most Gamma's companies had Decision Styles of Unanimity and Majority while having more Problem solving and Bargaining decision rules. These characteristics are associated with companies that accept bigger differences, thus explaining why Gamma had the lowest turn-over in communities. Also, from Table 4, it is observed that Alpha and Zeta have similar Decision style and Decision rule values, which would indicate similar performance. Nevertheless, as a result, is the opposite, the explanation for this lay on the economic performance, which is based on the amount of energy produced and how much it cost. The production, as already presented, varied a lot between Alpha and the United States. The costs are presented in the following chapters.

6.2.5 Policy Entrepreneur Indicator

The last metric for comparing countries is the policy entrepreneur role. This metric reports a portrait of how communities perceive the economic incentive, by signaling to the government beholder if the policy is being positive for the community or not. Communities signal either positive or negative, depending on if their business plan voting and business profitability. Every time the community votes a new energy project, if it is approved by the members, it signals positively. If a plan is rejected, the community agent will report negative. Also, the community assesses its profitability. If revenues are higher than costs, the community also signals positively; otherwise, it signals negatively.

The graphs in Figure 46 represent the sum of all reported indicators per country per scenario. Scenarios 2 and 3 produced similar results, having more consistent values across all countries. Scenario 1 otherwise produced a mixed result, with Epsilon and Alpha with a positive indicator, but the other four countries presented negative values. In other words, communities in Epsilon and Alpha experienced positive results for FIT policy, while in the other countries, the experience was negative.

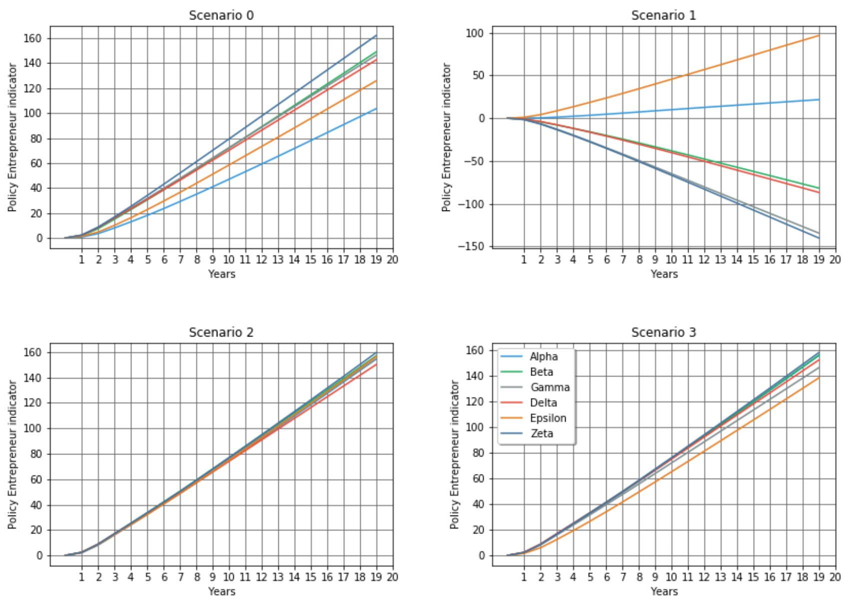

Figure 46 – Evolution of the policy entrepreneur signal by communities for different scenarios (the author)

Comparing scenarios with the baseline, Scenario 1 was the only one to have countries with negative results. All values for scenario 1 are smaller if compared to the baseline. Scenarios 2 and 3 presented better results than the baseline, with scenario 2 being the one with the most positive responses among all scenarios. The detailed values are presented in Table 15. Country-wise, Zeta had the most peculiar results. It holds the highest positive result with an average of 159,45 positive reports in scenario 2, it also holds the lowest results with -140,14 in scenario 1 and is the only country that did not have one value better than the baseline.

Table 15 – Average sum of the policy entrepreneur indicator per country for each scenario (the author)

Country	Average of the sum of policy entrepreneur indicator			
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3
Alpha	103,47	21,75	154,36	155,81
Beta	148,89	-81,72	156,90	156,12
Gamma	146,33	-134,39	154,49	146,40
Delta	142,53	-86,77	150,02	152,40
Epsilon	125,77	96,76	156,33	138,42
Zeta	162,04	-140,14	159,45	158,15
Total	829,03	-324,51	931,55	907,3

6.2.6 Section Summary

In an overall evaluation, it is possible to draw some conclusions from the observations of each country. A distinguished note for Alpha is needed as the country ranked last in almost every metric. It is the country that produced the poorest in energy generation, presented the lowest number of communities, members in communities, and the highest number of members who exit communities during the simulation. However, despite such low performance when compared to other countries, in all metrics, it had at least one scenario with a higher value than the baseline. In sum, Alpha indicates that despite the worse results than in other countries, it still delivered better results than the baseline, indicating that the financial incentives indeed promoted better results. This is also observed in the policy entrepreneur role as Alpha and Epsilon were the only countries to have positive values in all scenarios.

Looking for the energy generated, some surprises arose. Delta is the country that produced the most amount of solar energy, while Epsilon, as expected, was the one that produced the most amount of wind energy. What was not expected was that only Epsilon produced a significant amount of wind energy, with Delta, Gamma, and Zeta producing no wind energy at all. The answer to the above lies in the price of grid energy, energy production potential, installation costs, and the wind threshold set by technology.

Forward-looking the energy production per scenario, it is possible to observe the country's performance per scenario. Scenario 1 was the one with the lowest performance, which is the only scenario where all countries performed worse than the baseline, while scenarios 2 and 3 surpassed the baseline production in at least 8%. Looking for the countries in specific, the best result summing incentivized scenarios were obtained in Epsilon. However, the single highest event was in Zeta for scenario 3. The United States, Delta, and Gamma did not produce in any scenario, more energy than the baseline, but with a minimal difference of less than 3%. Meanwhile, Alpha, Beta, and Epsilon produced more energy in both scenarios 2 and 3 when compared to the baseline.

Regarding the number of communities, it is observed that the number of new communities rises rapidly in the initial years, followed by certain stability in the average number. In general, the average number of communities stays between 4 and 5 for all scenarios except for Alpha that in scenario 1 presented an average of 3.92. The highest value was observed by Epsilon in scenario 2. All countries produced in either scenario 2 or 3 a higher number of communities when compared to scenario 0. This is a good indication that the proposed model was successful in stimulating the creation of more communities. Looking country-wise, the countries produced a similar amount of communities throughout the scenarios. This was measured by the standard deviation, which indicated that Gamma was the one that behaved the most equal. These results for the number of communities indicate a possible maximal clustering degree on the number of communities of 5, as no country in produced more than five communities out of the possible 25. Also, such figures suggest that the total number of communities is not the main factor in determining how much energy production can happen.

The number of members within the communities is a complement to the evaluation of the number of communities. This metric shows the sum of all industries which are part of a community, being 50 the maximum as that is the number of industries in the industrial park. In general, the number of members in a community is relatively uniform, with exceptions for Alpha and scenario 1. Alpha presented the lowest value of all countries in scenario 1. Also, Zeta has the highest average value in scenario 3. The disparity between scenarios was also measured by the standard deviation. Alpha presented a very high σ^2 while Zeta and Delta had the lowest values. Comparing the results of the scenarios with the baseline, only Delta and Gamma had fewer members in the communities in scenarios than the baseline. The obtained results indicate that communities are attractive to industries. An industry joins a community when it perceives that doing so is cheaper than buying energy from the grid. Having a higher average number of members in communities on incentivized scenarios suggests that, overall, the financial incentive increased the attractiveness of communities.

Members exit metric measures how much members feel belonging to the community they are part of. This was measured through the industry's loyalty level, followed by check on the financial return. Each industry appraises the alignment they have with the community they are part of. If they are lined up, the industry loyalty level increases, otherwise it decreases until a threshold when the industry evaluates its financial return at that moment. The loyalty evaluation is tightly related to Hofstede's cultural dimensions as it seeks to replicate the characteristics distribution observed in real life and prompt actions based on the observed differences. The combination of poor loyalty points and miserable financial return leads to the industry to exit the community. Looking to country data, all countries presented a lower turn-over rate than baseline in at least one scenario except for the United States. Alpha was the country with the highest number of members, which exit communities while Gamma was the one with the lowest turn-over. The best scenario in this metric was scenario 1. It presented the lowest values for Gamma, Delta, and the United States. Scenario 3 was the worst-performing scenario.

The last metric is the policy entrepreneur role. This metric reports a portrait of how communities perceive the economic incentive, by signaling to the government beholder if the policy is being positive for the community or not. Communities signal either positive or negative, depending on if their business plan voting and business profitability. Scenarios 2 and 3 produced more consistent values than scenario 1 and the baseline. Both scenarios produced better values than scenario 0, indicating that more communities in more years found their business doing better. Scenario 1, on the other hand, produced a mixed result, being the only one to have negative values. For Epsilon and Alpha, it induced positive values, but for the other four countries, it resulted in negative values. Country-wise, Zeta had the most peculiar results. It holds the highest positive result with an average of 159,45 positive reports in scenario 2, it also holds the lowest results with -140, 14 in scenario 1, and is the only country that did not have one value better than the baseline.

Comparing countries' performance under different scenarios is not a straightforward task as it depends on which point of view is being considered. If we look into the energy generation, Delta and Epsilon were the highest energy producers, with Delta producing the most solar generation while Epsilon produced most of the wind energy. However, in a single specific scenario, Zeta was the highest producer of renewable energy in scenario 3. Nevertheless, when comparing scenarios to the baseline, Gamma, Delta, and Zeta produced less energy in all scenarios. Alternatively, Alpha, Beta, and Epsilon produced, in general, a smaller maximum energy production, but both countries produced significantly more energy than the baseline. If we look through the optics of community, the same logic is applied at the number of members, with Alpha, Beta, and Epsilon has better results than the baseline, despite the best overall values coming from Gamma, Delta, and Zeta. For the number of existing communities, all countries had in at least one scenario a higher number than the baseline.

6.3 Financial outlook insights

The last step in the evaluation of the results is to compare how the incentives performed among each other on the financial outlook. In the previous section, the financial incentives through their specific scenarios were used to assess how each country performed on energy production and community development. In this section a detailed evaluation will be taken on the financial aspect of the incentives, going over (i) How much was invested by the communities to generate energy, (ii) How much was expended by governments, and lastly, (iii) what are the levelized costs of energy production on each scenario. This analysis will assess the unitary total costs to produce energy, which, in combination with the community development from the previous chapter, helps to answer what is the best financial incentive.

6.3.1 Community Investment

The community Investment metric is the measure of how much the communities and its members expensed to build their energy parks. As community investment is expensed by installed production potential, measured in KW, the amount invested regards only the costs of installation of approved projects. In its turn, a project is only approved if it is deemed as feasible after being evaluated following the CBA analysis. Hence, such evaluation is where community investment and governmental investment overlap. With the governmental incentives in place, the cost of the projects decreases, thus increasing the feasibility of the project. Having more incentives from the government makes renewable projects cheaper to install, thus improving project acceptance by community members. Nevertheless, the core investment is still within the community, and they are the direct metric members observe to check the financial return of their investments. Nevertheless, from the literature on financial incentives, if the proposed benefit is not condescending with the population, there is a possibility that the incentive might harm instead of benefit. This aspect of incentives observed in the simulation in Table 11, wherein both scenarios 2 and 3, Alpha, Beta, and Epsilon produced much more energy than in the baseline, and in scenario 1 no country produced more energy than what it produced in scenario 0.

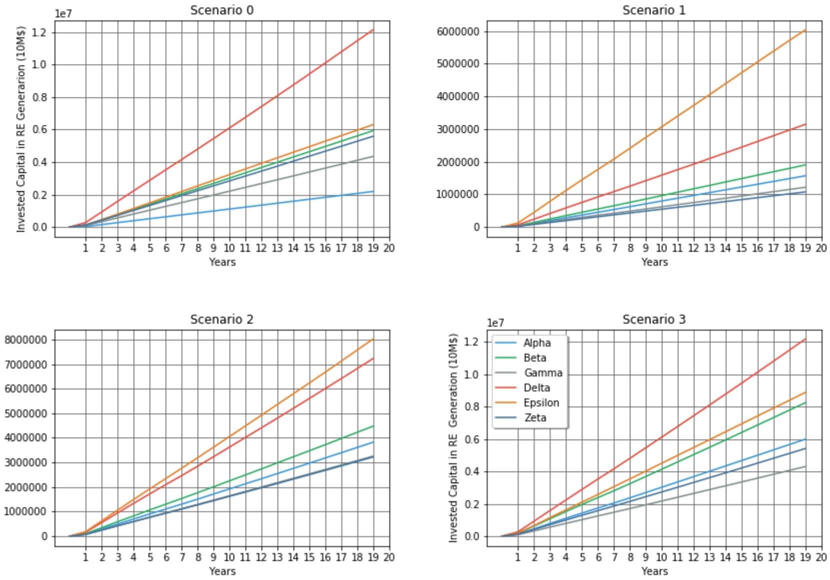

Figure 47 - Total amount invested by communities in renewable generation for different countries in different scenarios (the author)

Looking into the metric data, again, scenario 1 performed below the other scenarios, being the one who prompted the least amount of investments by communities. Scenario 3 was the only one that rendered more investments than the baseline ($45 million and $36 million, respectively). Scenario 2 ($30 million) had more investments than scenario 1 ($14 million) but not more than scenario 0. Evaluating this metric by comparing countries is not going to be performed as it is is not a good comparison metric. The amount of energy potential, grid tariff, and installation costs vary significantly, not supporting a direct comparison. All values are presented in Figure 47 and Table 16.

Table 16 – Invested amount by communities per country (the author)

Country	Invested amount by communities ($ USD)				
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	Total for incentivized scenarios
Alpha	2.187.777	1.568.043	3.822.909	5.994.138	13.572.867
Beta	5.934.257	1.901.446	4.474.898	8.244.186	20.554.787
Gamma	4.347.920	1.215.535	3.257.506	4.302.621	13.123.582
Delta	12.142.851	3.143.526	7.224.916	12.173.650	34.684.943
Epsilon	6.302.952	6.036.382	8.016.915	8.884.084	29.240.333
Zeta	5.585.976	1.074.908	3.222.372	5.416.772	15.300.028
Total	36.501.733	14.939.840	30.019.516	45.015.451	-

So, this metric can only be observed from a scenario perspective. This is possible when comparing scenarios, and the country characteristics are set the same, only varying the financial incentive applied. As it has been consistent through this results analysis, scenario 1 presented itself as the one with the least investments by the communities. This behavior is aligned with the other metrics as scenario 1 was the one that produced the least amount of energy, had the least number of communities, and the least number of members within communities. Oppositely, scenario 3 was the one who received the largest investment in the communities. This brings a large advantage to scenario 2, as this was the most energy-producing one. Costing less and producing more is a trait that benefits the communities. However, this is only part of the financial analysis as the cost of such a policy to the government is required for a policy analyst.

6.3.2 Governmental expenditure on financial incentives

The Governmental investment metric stands for all the expenses made by governments on their financial incentives policies. They represent the subsidies paid on *Feed-in-tariffs,* the amount of renounced tax on the *Tax incentives*, and the bond issue costs by the *Tradable green certificates*. The incentive paid by the government plays a role in the CBA analysis by improving the feasibility. This happens by either improving the benefits (FIT and TGC) or lowering the costs (TAX). Depending on the installation costs and grid energy tariff, renewable generation projects' feasibility has more or less dependency on incentives. If the applied incentive is sufficient for reaching feasibility, it is expected that more projects will be implemented, while if the applied benefits are not sufficient for the project to achieve feasibility, naturally, the amount of energy investment will be low. All values are presented in Figure 48 and Table 17.

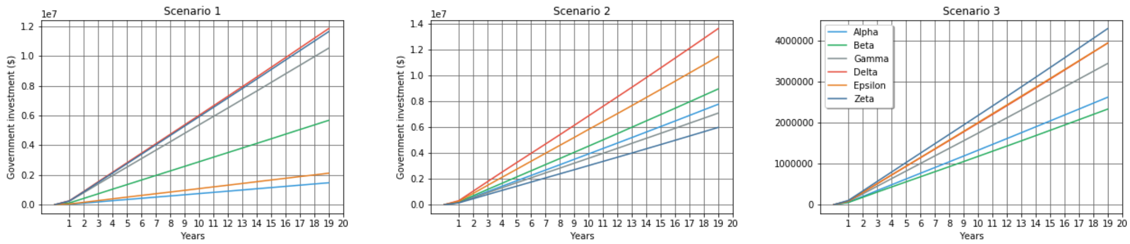

Figure 48 - Total cost in financial incentives by governments for different scenarios (the author)

In 4 out of 6 countries, scenario 3 was the one government invested the least. Oppositely, scenario 2 was the one where governments invested the most in 4 out of 6 countries. Once again, such a position theoretically brings the most advantage to scenario 2's communities as their feasibility increases, but on the other hand, this also means that the policy will cost more for the treasury. For a policy analyst, an effective evaluation of the combined costs is required to determine which financial incentive to apply.

Table 17 - Invested amount by governments per country (the author)

Country	The invested amount by the government ($ USD)				
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	Sum for scenarios
Alpha	-	1.472.930	7.782.315	2.625.59	11.880.836
Beta	-	5.675.626	8.969.286	2.335.781	16.980.694
Gamma	-	10.535.918	7.096.896	3.451.615	21.084.431
Delta	-	11.854.354	13.654.180	3.950.848	29.459.382
Epsilon	-	2.116.699	11.486.676	3.950.605	17.553.981
Zeta	-	11.650.162	5.988.574	4.304.563	21.943.300
Total	-	43.305.692	54.977.929	20.619.004	-

6.3.3 Levelized Cost of Energy of financial incentives

The previous sections alone are not able to explain the whole situation. For a better comparison between financial incentives, an effective technique is to determine the unitary cost, thus comparing the total costs of each incentive and the total amount of energy that was generated with that incentive. This provides a standardized metric capable of comparing different policies, taking a comprehensive view of how effective each incentive was. The total cost of each incentive is considered here as in two strands, firstly as the sum of the community investment and governmental expenditure, providing an overview of the total cost of the policy. The second strand observes the unitary costs only through community investment. This gives out the competitive advantage for companies, enlightening if applying incentives is beneficial for them.

The first step is to evaluate the total investments made by communities and the government, presented in Table 18. For most countries, FIT was the incentive that demanded the least investment. FIT is followed by TGC and TAX, which revealed a costliest financial incentive.

Table 18 - Invested amount by communities and governments per country (the author)

Country	The invested amount by community and government ($ USD)		
	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Alpha	3.040.974	11.605.225	8.619.728
Beta	7.577.073	13.444.184	10.579.968
Gamma	11.751.454	10.354.403	7.754.237
Delta	14.997.880	20.879.096	16.124.498
Epsilon	6.302.952	19.503.591	12.834.690
Zeta	12.725.070	9.210.946	9.721.335
Total	58.245.532	84.997.445	65.634.456

Next, the evaluation proceeds into dividing the total invested amount by the total energy generated in each scenario, previously presented in Table 11, with the result is presented in Table 19. Scenario 3, presented itself as the cheapest scenario on the aggregated unitary cost perspective, having the smallest LCOE in 4 countries. On the combined LCOE, scenario 1 has the worse performance, being much more expensive than the other scenarios. An intriguing outcome is found in Epsilon's value, where FIT presented the lowest LCOE in scenario 1, being the only one to do so.

Table 19 – Levelized Cost of Energy per country and scenario (the author)

Country	Levelized Cost of Energy – Community and Government investment ($USD/KWh)			
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Alpha	0,025	0,054	0,046	0,038
Beta	0,034	0,253	0,049	0,043
Gamma	0,015	5,530	0,037	0,028
Delta	0,043	0,361	0,076	0,058
Epsilon	0,042	0,058	0,075	0,061
Zeta	0,020	8,930	0,033	0,035
Total	0,029	0,214	0,053	0,043

Further, the evaluation proceeds to visualize the data from Table 19 in a bar graph presented in Figure 49. The preeminent observation is the staggering difference between *Feed-in-Tariff* and the other incentives. These values are the result of the puny energy generation, once the amount invested amount is comparable to invested values in other scenarios and other countries. Table 19 present a clear visualization of how each incentive was perceived in each country and provided some patterns that aids in answering which incentive is more effective in generating renewable energy. From such values, it becomes clear that *Tradable Green Certificates* is for most countries the incentive that provides the best cost-benefit, while *Feed-in-tariff* was the costlier for almost every country. However, despite the values being much smaller than the grid tariff for them, they are still more expensive than the baseline. This can lead a policy analyst to conclude that intervening with incentives makes the costs go higher, but this is a fallacy.

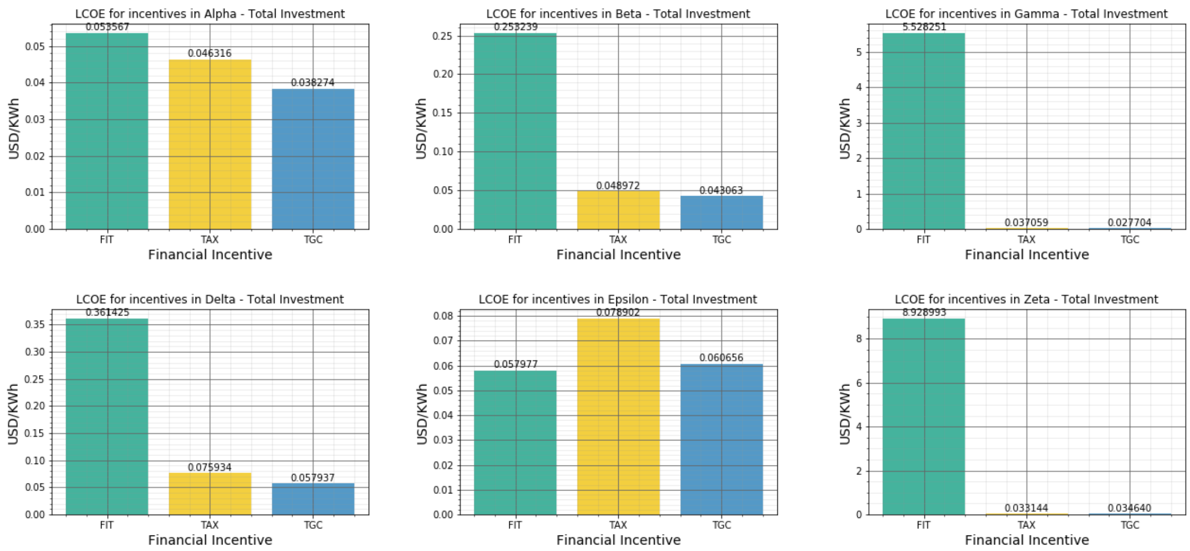

Figure 49 - LCOE for each country and financial incentive with combined community and government investments (the author)

The costs, as previously described, is the combination of governmental investments to the expenses made by communities. Calculating the LCOE with the total investment is a good metric to compare the different incentives and assess which one is suitable for each country. However, to provide a complete view for the policy analyst on the topic, it is important to understand if the application of an incentive increases or decreases the investment made by the communities. With such values, it is possible to address if a policy improved the economic aspect of communities, which is beneficial for society. Providing more liquidity to industries allow them to expense more, reinvesting the value into society through new energy projects, for example (Boardman et al., 2012; Palley, 2012; Storm & Naastepad, 2012). This can be observed in the simulation through the higher amounts of energy generation in scenarios 2 and 3.

Table 20 – Levelized Cost of Energy per country and scenario – Only community investment (the author)

Country	Levelized Cost of Energy – Community investment ($USD/KWh)			
	Scenario 0 (Baseline)	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Alpha	0,025	0,028	0,015	0,027
Beta	0,034	0,064	0,016	0,034
Gamma	0,015	0,572	0,012	0,015
Delta	0,043	0,076	0,026	0,044
Epsilon	0,042	0,043	0,031	0,042
Zeta	0,020	0,754	0,012	0,019
Total	0,029	0,055	0,019	0,030

Looking into the values, a clear pattern emerges of Scenario 1 continuing to be the one with the highest LCOE, but Scenario 2 emerged as the one with the smallest LCOE instead of scenario 3. The logic of this lies in the fact that scenario 2 receives a much higher investment by the government than scenario 3 in the majority of countries. Also, comparing with the baseline, which is community investment only, scenario 2 has lower LCOE in all countries, and scenario 3 is cheaper or ties in 4 out of 6. Table 20 data is presented visually through bar graphs in Figure 50. The most different aspect between Figure 49 and Figure 50 is that the massive difference between FIT and the other incentives is not as large in the latter. Also, the pattern of TGC being the most effective incentive is no longer there, as TAX has lower LCOE.

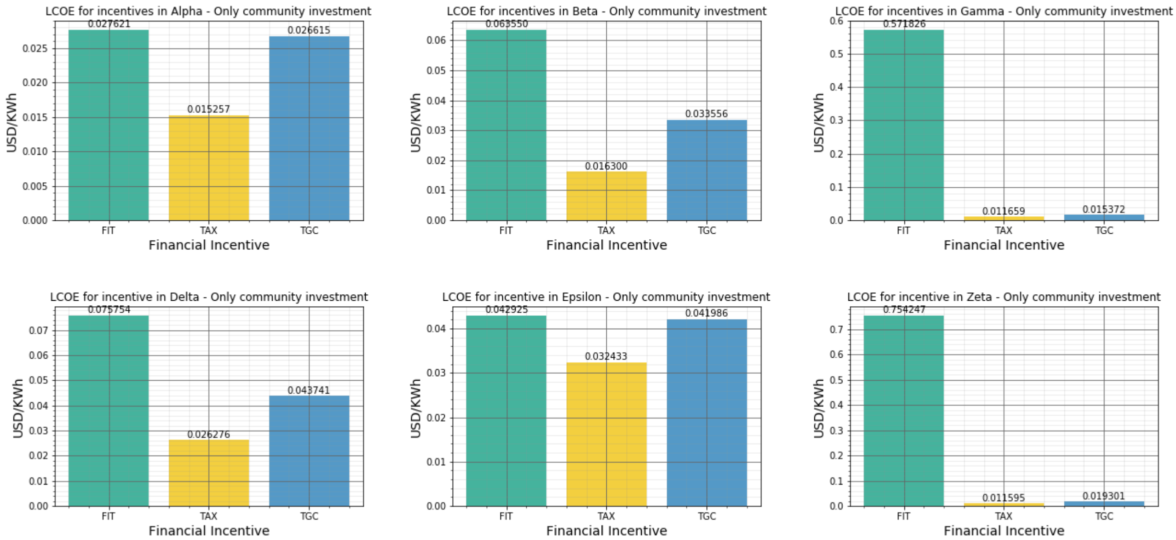

Figure 50 - LCOE for each country and financial incentive having only community investments (the author)

From the LCOE analysis, it is observed that TGC and TAX are the most advantageous policies to be applied as they presented the lowest values, the first considering total investments, and the latter when looking only for community investments. However, as previously exposed, the choice of a policy is not a simple direct task. Such a decision is embedded with other nuances that need to be considered. For example, TGC was cheaper in the overall and the one that received the least governmental investment, but TAX was cheaper for communities and produced more energy. A deeper discussion on this topic is presented in the concluding chapter.

6.3.4 Section Summary

Comparing the different financial incentives applied is the key to understand the economic differences between the applied financial incentives. To perform an economic evaluation of the incentives, it is needed to understand the costs involved and how much production is generated. Therefore, this assessment initiated by understanding how much was expense into generating energy. The costs are split into two tracks, the costs incurred by the communities to build their energy park and the costs expensed by the government through the financial incentive policy.

The community investments aggregate all the expenses incurred by each community member into building their energy parks per country and scenario. Glancing the scenarios, FIT was the one who performed poorly, prompting the least amount invested by the communities. Differently, TGC was the one with more investments, even surpassing the baseline, and TAX was not able to receive more investments than the baseline. Such behavior is consistent with the other metrics observed in section 6.2, as scenario 1 produced the least amount of energy, had the least amount of communities and community members, it is expected that it would demand fewer investments. Oppositely, scenario 3 received the largest investments but was not the most energy-productive. Nevertheless, this is only part of the financial analysis as the cost of such a policy to the government is required for complete policy analysis. Having more incentives from the government makes renewable projects cheaper to install, thus improving project acceptance. Nevertheless, the core investment is still within the community, and they are the direct metric members observe to check the financial return of their investments.

The government investment, on the other hand, stands for all ‘payments’ made by the government through the incentive policy. They happen through subsidies in the case of *Feed-in-tariffs*, renunciation of taxes on the *Tax incentive policy*, and bond issues for the Tradable Green Certificates. This investment by the government has a major role in the CBA Analysis performed by the communities when planning new energy generation constructions. Incentives improve the feasibility of the analysis by either improving the benefits (FIT and TGC) or lowering the costs (TAX). From the scenario viewpoint, scenario 3 was the one that demanded the least investment by the government in 4/6 of the countries. Oppositely, scenario 2 demanded the most. A scenario where communities invest less and governments invest more is the ideal scenario for a community, as it would require less of their own capital, thus increasing the feasibility of the project. Lastly, scenario 1 was also the one with the least investment by the governments. For a policy analyst, an effective evaluation of the combined costs versus the production it generated is required to determine which financial incentive to apply. This was done through the LCOE evaluation.

The LCOE technique, as described on 3.1.6, is an effective technique to determine the unitary cost, thus combining the incurred costs and the total production, providing a standardized metric capable of comparing different policies. The LCOE was calculated following 2 methods, first with the total investment (community plus Government) followed by only with community investments. This was done as it brings different observations. The initial calculation is a good metric to compare the financial incentives as it provides an observation of the global costs per unit produced. The second calculation enlightens the improvement of having an incentive brings to the communities. Both calculations brought diverging results, and no single incentive was the most effective. This definition is more complex than a simple value. Scenario 3 was the incentive that provided the lowest global unitary costs for most countries and tied with the baseline on the LCOE calculated only with community investments. Scenario 2 otherwise presented the lowest LCOE for all countries when calculated only with community investments but was the most expensive for four governments. The largest differences between scenario 2 and the baseline are found in Beta, the United States, and Alpha. The communities in such countries are the ones who most benefited from the implementation of the TAX financial incentive as it significantly decreased the unitary cost of energy production. On the other side, Gamma was the country that had the smallest difference (14%), being the one who least took advantage of the incentive. Lastly, scenario 1 was the worst-performing one, having the most expensive LCOE in all countries when compared to other scenarios, with an exception for Epsilon where FIT was the cheapest LCOE when calculated with the total investment. Observing the LCOE by country, it is interesting to observe the staggering difference between *Feed-in-Tariff* and the other incentives looking at the global investment calculation.

6.3.5 Model Validation

Validating an ABMS can happen in several different ways. The goal is to evaluate if the presented results are comparable to real-life data (van Dam et al., 2013).As InCES is not a complete reality, such comparison should happen with industries producing renewable energy and CES outcomes. The validation can be made through expert validation because the model development occurred based on theoretical backgrounds and real-life data. Here the validation occurs through an expert assessing the model and the values it produced to indicate if this reflects or not reality (van Dam et al., 2013). This thesis' model validation was done by Sina Eslamizadeh, an expert on Industrial development and Luiz Alberto Leite, a Brazilian contractor for renewable energy installation.

Energy production values

The amount of energy produced is the crucial difference between the application of different incentives. Here is where the most significant point of concern comes in play as the values of FIT was much inferior to the other incentives, going against what is observed in real-life, as FIT is the most applied financial incentive in the world. Both experts raised this issue. As discussed in more detail in section 7.3, the possible explanation for this fact is that the simulation did not monitor the behavior of industries outside the communities. So it is plausible that when FIT was applied, industries found more advantageous to produce by themselves than to do so in a community, reducing its attraction power.

Data parameters

Both experts agreed on the parameters used for calculating the CBA values. For the proposed model, the set of parameters is enough to provide the simplified calculations that the model performs. Also, the experts validated the sources of information as reliable and representative of reality. Luiz Alberto mentioned being careful when assessing temporal values such as grid tariffs as they can fluctuate significantly. Sina remarked on the difficulty of finding reliable wind distribution and solar insolation values for adequately developing the simulation.

Model interactions

The model has two types of games being played by three kinds of actors. On one level, communities send information to the government to understand the impacts of the application of the new policy. Here Luiz Alberto raised a concern as this type of interaction is not granted. From his experience with the Brazilian government, a clear communication channel can be quite hard to achieve. For him, the model is possible if the government is seeking this type of feedback, which depends on the current administration. On the other model interaction, members interact within the community deciding the actions it will promote. Both experts validated this interaction.

Literature validation

The last validation of the model is to predict the outcomes theoretically. Being the model data-driven, it was expected that the results would be similar to reality. However, some surprises came across. Only Epsilon, the country with socio-economic characteristics similar to the Netherlands, produced considerable wind energy. Based on real-life observations, Alpha, Beta, and Zeta should also produce significant amounts of renewable energy. Sina also raised concerns over the financial results of Gamma. In his view, the country with similar socio-economical characteristics as Iran should have produced more energy in incentivized scenarios than the baseline. The possible explanation for this behavior may derive from the simplification of economic calculations and the approximation of installation costs. The simplification of the calculations is perhaps the most substantial limitation of the model to reproduce results similar to real-life.

Chapter 7 – [Conclusion]

7 CONCLUSION

This chapter finalizes the evaluation carried in this research by consolidating what was presented and reaching conclusions to answer the research questions. Previous chapters explored the problem of promoting renewable energy in Industrial Communities Energy Systems through the literature surrounding the topic, a proposed model, running a simulation with such environment, and finally analyzing the results obtained from such simulation. In this concluding chapter, a summary of the model is presented on section 7.1, while a summary of the results is presented on section 7.2, section 7.3, a discussion about the results is presented to answer the research questions, and finally, in section 7.4 a reflection about this work execution is presented along with its limitations and future research.

7.1 Summarizing the Model

7.1.1 Problem description and research questions

The motivation of this research was presented in chapter 1 and assisted by the literature review done in chapter 2. It emerges from the lack of understanding of how financial incentives may promote the creation of industrial communities to produces renewable energy. Such communities are better prepared for developing industrial parks as they can navigate through informal relationships and define the strategy for optimizing the physical infrastructure (Saleman & Jordan, 2014). However, the literature on the topic is limited to the research on the production of renewable energy in such communities. Financial incentives, on the other hand, are well studied by policy and economics analysis and present a large potential to be an efficient way to promote renewable energy generation (Abolhosseini & Heshmati, 2014). However, there is a lack of research over applying financial incentives in producing renewable energy in communities. Therefore, the goal of this research is to propose a model and evaluate how financial incentives can promote the generation of renewable energy through Industrial Communities Energy Systems. Furthermore, the hypothesis in this research is that financial incentives scenarios enhance energy production if compared to a base scenario of no incentives and, the main research question which emerges from the above argumentation is:

> *What is the most effective type of financial incentive mechanism for the development of industrial communities for renewable energy generation?*

To answer the main question, this research must also answer some sub-questions, as indicated in section 1.2:

A) *What is a definition of the community energy system for industries?*

B) *Which of potential financial incentive can be applied to industrial energy communities?*

C) *How industries make decisions?*

D) *How does the interaction between industries influence their decision process to join community energy projects?*

E) *What predefined metrics can be used to compare different financial incentives?*

Answering the questions required the development of a model that connects the social and technical aspects of the proposed problem. This was developed in chapter 3, where the literature leads to the Collective Action theory, a bottom-up approach where society organizes itself to introduce change (Ostrom, 2005). Within this field of research, the IAD Framework is a prominent structure to build models upon. In a nutshell, the IAD Framework provides a structure with basic elements on how actors in a polycentric system, interact and develop interpersonal relationships when handling specific group situations (Ostrom, 2005). The IAD Framework excels in providing a structure to design actors' interaction models as it explicit all the components required to detail how a community can organize around resource management. For its characteristics, the Framework is often complemented by Game Theory, a research area on strategic interaction between decision-makers. In such a field, Scharpf developed many pieces of research and theories on Decision-making by composed actors, providing a broader understanding of how actors shall behave. The combination of the IAD Framework and Scharpf's decision-making framework provides the basic tools for designing the model for this research.

Additionally, going into the economic aspect of the model, the CBA analysis method is the central point of data for the decision-making process done by industries and the communities. Such an approach allows comparing projects with distinctive characteristics in a common monetary base through systematically cataloging the impact of benefits (pros) and costs (cons). The method assigns weights to pros and cons to different alternatives, including the status quo, to evaluate each option's monetary value through determining its net benefits (Boardman et al., 2012). With all the above elements at hand, the research methodology, as defined in section 3.3. Moreover, finally, with all elements covered, the model was described in chapter 4, and the data utilized to run the simulation was presented in chapter 5.

7.1.2 Model description

The proposed model follows a 2-tier game being played simultaneously. On the lower level, industries within an industrial park must decide yearly how they are going to procure additional energy for their business. They may either buy it from the grid, in a business-as-usual approach, produce renewable energy by themselves, or join/create an energy community. Such communities thus receive the responsibility to develop new energy projects to provide benefits for its members. Such benefits can be either cheap energy or financial returns from selling such energy to the grid. Choosing between the two is a trait decided at the community foundation. The decision between project alternatives is made through CBA analysis that compares different arrangements, as energy projects can have only the sun as an energy source, only wind or a mix of both. The decision-making mechanism chooses the cheapest project at present value.

In parallel to the upper-level game, the government, a beholder actor, applies on different scenarios a financial incentive policy to encourage renewable energy generation. Such incentives directly impact the CBA calculations made by communities through either increasing the benefits (through *Feed-in-tariffs* or *Tradable Green Certificates*) or by decreasing costs (through *tax exemption*). To assess if the incentive is efficient or not, some metrics are being monitored by a 'bystander' policy analyst. Such metrics are how much energy is generated, how many communities were founded, how many members they had, how many members exit the communities, and a policy indicator. Through these metrics, it is possible to develop a greater evaluation of all benefits and disadvantages of each type of policy applied when compared to a baseline where the government does not apply any incentive.

7.2 Reviewing the results

The results were presented in chapter 6, explaining the first two country individual insights, which covered all the metrics looking only at how a country's government would observe its metrics. The evaluated metrics can be split into two strands, an economy, and a community. The economic one encompasses the amount of energy produced, its costs, and the policy entrepreneur indicator. The community strand, in its turn, embraces the number of communities, its members, and their permanence in the communities. Later, all countries were compared together, providing a deeper understanding of the metrics themselves along with the different scenarios. Lastly, a wider understanding of the financial advantages of each incentive through the LCOE technique, being applied to a scheme where the total investments were considered and another where only the investment made by communities was considered. This section reviews the observations and knowledge generated in the results section for each incentive tested, while the following sections provide the discussion over these results.

7.2.1 Scenario 1 – Feed-in-tariff

Looking into the performance of each scenario, *Feed-in-tariff* was the worse performing incentive. Consistently throughout the evaluation, scenario 1 performed worse than all other scenarios, including the baseline. This claim is corroborated by the metric values. Glancing on the economic strand metrics, FIT was the scenario where energy production was the least in all countries. On average, the amount produced in scenario 1 did not reach 20% of what was produced in scenario 2, the highest producing one. Such poor performance leads to the scenario also being the one who received the smallest investment (by communities and the government), yet, the received investments were proportionally higher. On average, FIT projects received approximately a third of the amount invested in scenario 3. Such unbalance resulted in FIT having the highest LCOEs for all countries. This meager scenario can also be observed through the policy entrepreneur indicator as scenario 1 was the only one that ended with negative values. The only exception is Epsilon. In such a country, the amount of energy produced in scenario 1 was 93% of what was produced on the baseline, being this the best result for FIT. By producing such amount of energy while still receiving the smallest investment in any scenario, resulted in Epsilon having its lowest LCOE for total investment in FIT.

Going to the community strand, scenario 1 also performed poorly. It finished with the smallest average number of communities and members in the communities, presenting values smaller than the baseline for most countries. For the number of members who exit the communities, the result is different. FIT performed better, having the smallest number of members which exited a community. The results on this strand indicate that FIT poorly convinced industries to form or join a community. Assessing the utility of applying FIT, the results indicated that FIT delivered worse outcomes than TAX and TGC. Communities, when FIT was in place, produced less energy, that energy was the least economical option (Highest LCOE), and fewer industries were incited to join or form a community. In general, lines, communities, and industries when the FIT was applied delivered worse results than if no financial incentive was applied. However, having FIT as an incentive prompted the communities to generate cheaper electricity if compared to each country's grid tariff. This by itself presents FIT as a feasible option for being implemented, but the other incentives seem to be more suitable.

7.2.2 Scenario 2 – Tax incentive

While FIT is the worse performing scenario, it is debatable whether *Tax incentives* or *Tradable Green Certificates* presented the best results. Looking initially for TAX results on the economic strand, it was the incentive that outputted the highest amount in energy production, yielding 28% more energy than the baseline and 6% more than TGC. Here a remarkable note is that in scenario 2, Alpha outputted its maximum production, three times more than what was generated in the baseline, is this the largest improvement observed in the simulation. However, going against what was expected, scenario 2 was not the one that received the most investments by communities; this position is held by scenario 3. Even further, scenario 2 investments by communities are 2/3 of what was invested in scenario 3, 18% smaller than what is observed on the baseline, and only more expensive than FIT.

On governmental investments, the picture is the opposite. TAX was the most demanding incentive topping FIT in 27% and more than two times what was invested in TGC. Scenario 2 was the one who received the largest governmental incentive of all in Delta. Therefore, looking into the LCOE, a divergence shows up. The presented concept of LCOE in chapter 3.1.6 explains that such calculation is based on "*the value of how much a productive unit will cost based on the project total cost*" (US Department of Energy, 2013). However, the total costs, as argued on the CBA method, depends on the point of view of who is calculating it. Considering the total costs, including governmental expenditure, leads to TGC presenting the cheapest LCOE, with an exception to Epsilon and Zeta, which has its lowest LCOE for total investment in scenario 1 and scenario 2 respectively. Nevertheless, if the same calculations are done considering only community investments, we have that scenario 2 presents the lowest LCOE, reaching lower values than the baseline in such a situation. Finally, looking over the policy entrepreneur indicator, scenario 2 was the one with the most positive indicators in 4 out of 6 countries.

Considering the community strand, scenario 2 presents the highest average on the number of communities created, surpassing all other scenarios. The same is true to the number of members; on average, the communities in this scenario performed better in attracting members. However, here, the performance was inferior to the community metric, as only Alpha and Beta had their highest number of members in communities in scenario 2 while Zeta presented here its lowest value. Lastly, looking over the number of members which exit a community, scenario 2 was the middle one, not presenting neither the best or worse results and yet, performed better than the baseline.

In sum, scenario 2 produced much better results than the baseline, and scenario 1, is superior to both of them. Regarding scenario 3, superiority is not as clear. TAX was the scenario that produced more energy but was also the most costly one, resulting in the highest LCOE when all investments are considered. If the comparison is made only through the optics of the communities, TAX becomes the cheapest scenario. Part of this behavior comes from the way the incentive works, as Tax incentives are the only type of incentive which reduces the costs of new projects, while the other 2 enhance the benefits. So, by applying tax incentives, the government is sharing part of the investments, thus reducing the load put on the communities.

7.2.3 Scenario 3 – Tradable Green Certificates

Ultimately, the final incentive to be observed is *Tradable Green Certificates*. This incentive is up to appraisal along with *Tax incentives* over which scenario best performed. Starting with the economic strand, scenario 3 was the second-largest energy-producing scenario, on average, outputting 6% less generation than scenario 2 and 20% more energy than the baseline. However, in this scenario, we observed the highest energy production in scenario 3 in Zeta. Also, Gamma and Delta had their highest energy production in this scenario. Apart from the average energy production, TGC was the scenario which received the highest investment by communities and the lowest investment by the government, yielding that scenario 3 to have the smallest LCOE when considering total investments. Still, the investments were not equally split.

The investment made by communities was more than two times the investment made by the governments, displaying a disparity in investments when TGC is applied. Such disparity is associated with the nature of how *Tradable Green Certificates* operates as their increase in benefit for communities is through a single payment made by the government while all actual investment is made by the communities. When observing the LCOE only with community investment, this is more evident as Scenario 3 produced more energy than the baseline, but their costs were proportional, resulting in technically equal LCOE in both scenarios. Lastly, the policy entrepreneur indicator for TGC was not the best but, on average, was very close to scenario 2, indicating a certain parity between the two scenarios on the point of view of the communities.

Going over to the community strand, scenario 3 once again had results very close to the ones in scenario 2 but slightly inferior for the number of communities and the number of members in communities. Regarding the number of members who exit, TGC was the scenario where most members exit a community. A possible explanation for such results could be on the financial return component of the leaving the community decision-process. Since the investment made by communities was superior to others, this might have decreased the financial results of the communities and pushed unsatisfied companies to leave. Despite the not exceptional values observed in scenario 3, the resemblance between the community metrics between TGC and the baseline is notable. As exposed to the economic strand, the LCOE of both scenarios is technically the same, so having similar results on the attracting power of communities is not odd. The largest difference between TGC and the baseline is the amount of energy produced in both scenarios. TGC managed to largely increase the energy production in communities with the smallest investment by the government while maintaining the same level of community development as the no incentive scenario did.

7.3 Discussion

Concluding the thesis, this section discusses the answers to the proposed questions with the base from what was presented, and the conclusions can be drawn from this research. Firstly, the goal was achieved as a model was proposed, and different financial incentives were evaluated on their capabilities of promoting the generation of renewable energy through InCES. From the results, it is possible to conclude that applying financial incentives can promote a better environment for industrial energy communities' development. Therefore, this thesis also proves true the stipulated hypothesis that financial incentives enhance energy production in energy communities. Also, as expected, different types of financial incentives produced different results when applied.

The starting point of this research was to provide some definitions in this new area of research. The first research sub-question was

What is a definition of the community energy system for industries?

The answer to this question influenced the design of the model as it provides context for what an Industrial Community Energy Systems would be. InCES was defined in this research as a community formed by industries whose goal is to either supply cheaper energy to its members or sell the energy to the grid and yielding financial incomes. Nevertheless, to achieve this goal, such communities focus on how its members can cooperate instead of focusing on resource exchanging as Industrial Symbiosis proposes. The attention point of InCES is on the community management of the produced good, following a cooperative-like structure than induces its members to act in organizing themselves (Bauwens, 2014; Koirala et al., 2016; Negro et al., 2012; Van Der Schoor & Scholtens, 2015). Such a model concentrates on the members' inter-relationships to improve community development. Having which type of community this research is dealing, the next step was to understand

Which of potential financial incentive can be applied to industrial energy communities?

Financial incentives, in a broad definition, are able to transform undesired behavior into a financially attractive one (Abolhosseini & Heshmati, 2014). With the appearance of environmental targets and the need to diversify energy matrixes, different types of incentives were implemented by different governments. Consolidating the variety of incentives, the literature reached that basically three types of incentives are applied by governments to promote renewable energy generation, thus can be applied to industrial energy communities (Abdelaziz et al., 2011; Abolhosseini & Heshmati, 2014; Warbroek & Hoppe, 2017). The most common type of incentive is the *Feed-in-tariff*, where the government pays a fixed fee for the energy generated. Another common type of incentive is *Tax incentive,* where a discount in taxes is given for the purchase and installation of renewable energy generation structures. The least common type is the *Tradable Green Certificates*, where a bond-like certificate is issued for a pre-determined amount of energy production. The definition of the financial incentives enters the model as the rule-in-use, directly adjusting the member's behavior. However, it is still unclear how such members make their decisions, and even further, what is the difference in decision-making between industries and households. This lead to the third question

How industries make decisions?

Industries, as composite actors, can be considered as a unitary actor but with a much more complex decision process. While individuals may choose purely based on preference or ideology, only looking to individual factors or simple reasoning, industries must attain to a much more complex decision-process (Keeney & McDaniels, 2008; Scharpf, 1990). As companies, they must attain to several aspects such as its internal policies, economic output, or market trends, sophisticating the process. Due to this complexity, no decision within industries can be made on a single plane, multiple points of view are needed to form a reliable information base. This brings to light a natural preference for composite actors in seeking other companies that share the same values, goals, and ambitions. Industries have a natural tendency to consider their interactions with other peers to form a more solid base of information (DellaVigna, 2009; Sheu, 2019). Thus, the following question to be answered is

How does the interaction between industries influence their decision process to join community energy projects?

As the basis of the model is community development, it is important to understand how other companies influence how industries respond. Industries as businesses are affected by changes in the market and, consequently, by benchmark values and what their peers are doing. This behavior maps out a network of companies in which industries have relations, ultimately influencing their decisions. This process follows the homophily principle, where individuals tend to connect with similar individuals. The result of such interactions is a network of actors that has two types of nodes on it, a weak and a strong network (Easley & Kleinberg, 2010). The week network of those 'acquaintance' companies which do not automatically prompt substantial interactions while the strong network of companies, those that interact with the industry, and provide a richer influence on its decision-process. The decision to join a community follows two planes, an economical and a societal one. The economic plane is where the industry evaluated if joining a community will be financially attractive. Based on this answer, industries than move to observing what their peers are doing. Only it is economically feasible, and other peers perceive the same that industry would join a community. If other peers are not attracted to perform the same action, industries may question if the economic plane is correct or not. Nevertheless, even if its strong network perceives value, if the industry does not see feasibility, it will also not join the community. Finally, this leads to the last sub-question of

What predefined metrics can be used to compare different financial incentives?

To be able to compare different incentive mechanisms, it is needed to apply them to a standard environment. By having the same set of metrics when comparing the incentives, it is possible to interpret the results by incentive change. Otherwise, it would be unclear if different results were due to the incentive or the environment, and, therefore, it is needed to define which elements should be incorporated into the model. Looking back to the decision process of generating RE at the communities, the first step performed by the community is to assess the economic feasibility of the RE technology. This involves gathering economic data such as grid tariff, costs of installation, energy production potential, and the discount rate used to bring the calculated values to Present Value. However, besides this economic feasibility, there is also the need for members to feel part of the community. If members are not satisfied with the outcomes, they may leave. The decision of leaving goes through an individual economic assessment but also a relational assessment that is evaluated using each member's decision-style and decision-rule. Such decision parameters are the convergence of Scharpf's decision-style framework with Hofstede's culture dimensions and delicate distribution of different managerial styles. Such a difference is shared among community members and represents the diversions in ideas that emerge. Adding an extra layer of parameters, and thus, expanding the reach of the results, the proposed model was applied to 6 different countries, which in turn, have different metric values. So in sum, each incentive is applied to different environments forming different scenarios.

In all countries and all scenarios, the LCOE was smaller than the grid tariff. This is a clear indication that with appropriate planning, the adoption of renewable energy generation may be economically competitive with fossil fuel. Nevertheless, this conclusion should be seen only as an indication and not ratification. This model simplifies some of its variables, such as the installation costs, and disconsider other variables such as the technical implementation, which needs to be taken into consideration for an accurate calculation. Therefore, these results should be observed as suggestions and guidance for the initial phases of a policy assessment. However, the results also indicate that having incentivized scenarios may be better than not having an incentive at all, as the baseline was not a superior scenario in any country. A note here is needed for the amount of energy produced by Gamma, Delta, and Zeta. As mentioned in chapter 6.2.1, those countries produced inferior, still quite similar amounts of energy than what was produced in the baseline scenario, thus providing a misleading suggestion that the baseline is preferable. However, the cost of producing a comparable amount of energy in scenario 2 was smaller, making it a superior option over the baseline.

The results also suggest that the total number of communities is not the main factor in determining how much energy can be produced. Having more communities not necessarily leads to more production since the action to choose projects is based on members' voting, where the economic output can lead to more approvals. Still, the relationship between members can lead to disputes restraining agreements. Therefore, situations can occur where smaller communities may have higher demand and be more productive than larger communities. This lower number of communities created is observed on the community metric as the number of communities in the baseline scenario was very similar to the number of communities in incentivized scenarios. Consequently, to evaluate how much energy can be generated in energy communities, this thesis resorts to assessing the financial incentives per se.

Starting with *Feed-in-tariff*, despite being the most popular financial incentive applied in real life, was the worse performing one in the simulation. A possible explanation for this behavior might be on the nature of the incentive. FIT is a ‘pay-as-you-go’ incentive were the government expenses based on how much you produce throughout time. Since the model considers the alternative of industries not joining a community for producing energy themselves, it is possible that the number of industries which considered producing energy outside a community more advantageous was large. In other words, it is possible that an industry which stays outside a community had more advantage than if it had joining one, making FIT a good alternative for producing renewable energy, just not in communities. Alternatively, as discussed in chapter 4.2, to reach feasibility in FIT projects, the incentive to be paid should be more than two times the grid tariff, while the simulation utilized values of 2.1, 2.5, and 3. Perhaps the issue was that feasibility was harder to achieve, and not many industries found it interesting to produce renewable energy, and an even higher FIT could induce more energy production. In any case, the literature indicates that a preeminent difference between energy communities formed by individuals and energy communities formed by industries is that the later has more resources to carry out such projects. On energy communities made of individuals, being in a community enhances the range of alternatives, since being in a group allows them to reduce costs by doing a larger project (Hein et al., 2015; Van Der Schoor & Scholtens, 2015).

Tax incentives and *Tradable Green Certificates*, on the other hand, performed better than the baseline and *Feed-in-tariff*, but between them, the results were quite similar. Both scenarios developed more communities, had more members, fewer of them exiting the communities, produced more energy, and yielded smaller LCOEs than FIT, also demonstrating to be superior scenarios than the baseline. Nevertheless, comparing both scenarios, there is significant uncertainty, to which is superior. With similar results, superiority should be measured by the LCOE value. While considering public and private investments, TGC on the overall is cheaper. Besides, TGC has the potential to create a new bond market, similar to carbon-bonds, adding significant value to this option. These tradings can occur as any other government bonds producing additional revenue for the bond. The literature, as presented on 4.4, suggests that part of the revenues from TGC revenue could be used to fund subsidies for reducing carbon emissions, supporting that the best strategy for this problem is a combination of several schemes. Such a parallel policy requires more research and understanding not to become similar to the Carbon trade market.

Despite the large potential of TGC, having TAX as an incentive is much more advantageous for the communities since the government bears more investments, and the LCOE becomes lower. Applying *Tax incentives* also presents an additional benefit as it makes cash available. Increasing the community liquidity and allowing them to invest even more, also generating a side benefit. In other words, the model shows that the answer to which financial incentive is the most effective goes through determining what the economic preference for the government and policy analyst standpoint is. Should the government bear more costs relieving the community's costs or reduce its investments, making communities invest more? This is a very argumentative question that cannot be simply answered in this research as each government and administration has a different political-economic view of the problem. What this thesis exposes is that both incentives are similar in outputs having differences on approach, not allowing for any automatic rejection of a financial incentive

This results thus, indicates that a policy analyst should not unrestrictedly reject any financial incentives without considering further variables. For example, how much capital a government treasury has can be a huge influence in choosing between a TAX or TGC project. On the first, communities invest less of their capital but increase pressure on national treasury to have enough capital for the project. How much is acceptable here? How much should the project charge in the national budget? Answering these questions requires a much larger debate. Still, this conclusion is aligned with what the IAD Framework brings to light as the external and environmental variables are a key aspect for evaluating the action arena.

And Finally answering the main research question,

Which type of financial mechanisms can incentivize industries to form Energy Communities?

The thesis made clear that the three evaluated financial incentives do promote a better environment to produce renewable energy in InCES, but also, as expected, showed that different types of financial incentives produced different results when applied. Nevertheless, choosing a financial incentive has proven to be a sinuous path. *Tradable Green Certificates* produced good results on the community metrics and also was the cheapest option when considering total investments made by communities and the government. The average values of LCOE indicate that TGC can generate more energy than the baseline at equivalent unitary costs. Besides, there is still the potential outcome of trading such certificates, which were not explored by this thesis. However, on policy evaluation, the analyst's point of view has a strong influence on the assessment. Overlooking governmental investments, *Tax Incentives* was the cheapest option while at the same time considerably reduced the investment costs for communities, producing the best community metrics results. Opting for TAX presents the best scenario for developing communities to produce energy, but the outstanding costs to the government may hinder such policy. Lastly, *Feed-in-tariff* presented the worse results in this research, demonstrating to be an inferior option for developing communities. For most countries, using FIT resulted in high expenses from the government for mediocre energy production. Nevertheless, in Epsilon's context, FIT was the best scenario, having the smallest LCOE. This raised some possible explanations, as the incentive was so good in promoting renewable energy that industries did not see an urge to join a community. Alternatively, the values used in the calculations of FIT indeed were too small and hindered the development of energy communities. So, which option to pick? Just as when performing a CBA analysis, the answer to this question depends on which point of view the analysis is made.

As it was exposed in 4.4, each of the financial incentives applied in this thesis has a different nature on how to promote benefit. FIT and TGC increase the benefit of communities by providing additional capital for the projects. Alternatively, TAX reduces installation costs as the government renounces to collect those taxes. Looking at these differences through a treasury point of view, TAX represents a decrease in revenue at year 0 of any approved project, and its corresponding benefit comes later within the production of energy. In other words, Tax exemptions follow a 'pay-now-receive-later' scheme. FIT is an incentive that requires constant cash outflow with governmental expenses connected to the production in a 'pay-as-you-go' scheme. Finally, TGC creates bonds-like certificates, with a face-value that will only be expensed by the government when of its maturity, in a 'use-now-pay-later' scheme.

Perhaps the most bitter point this conclusion can offer is that answering the main question is much more complicated than originally stipulated. With such different prospects, indicating which financial incentive is the most effective is not elementary. The choice between each type of incentive is much related to the economic and financial situation of each country and the standpoint from the policy analyst assessing this new policy. Poorer or in-debt countries may prefer a bond-type incentive, pushing expenses to the future while more financially equilibrated countries may prefer a 'pay-as-you-go' scheme or even prefer to expense now and collect the benefits in the future. For any of those choices, what this thesis can conclude is that having a financial incentive is a better deal than not having financial incentives. This thesis concludes that no single policy is capable of solving the issue of renewable energy development independently. A broader debate regarding the application of which support policies should be applied is needed for matching the financial incentives observations from this study with the actual fiscal reality.

7.4 Reflections

The last part of this chapter expresses the personal reflection of the author towards the development of this work. Working on this thesis was a superb experience from the stand of promoting the developments of communities through a systems engineering perspective. Exploring the topic through the optics of social and technological branches of works leads to a thought-provoking thesis. This thesis aggregated literature from very distinct areas of study, going through interpersonal relations in game theory, cultural assessments, the decision-making process, economic evaluations of financial incentives, and cost-benefits analysis. All those areas of the literature became a building block of a model that, without the support of the IAD Framework, would not have come together. Lastly, all this knowledge was processed through a Python programmed simulation, which was a very enjoyable part of the thesis.

Nevertheless, despite being a very interesting topic, some aspects of it now are seen as elements that hampered the research. The main element that did so had communities that generated energy for selling to the grid. The motivation of this choice was to bring more reality into the simulation, as communities might choose to do so in real life. However, applying such conditions on the simulation has proven to be of many efforts and little return as it was not clear if the extra complexity it posed for the simulation code brought much difference to the final results. Another element that created difficulties in this thesis was the complexity of the model. This research embraced the idea of being data-driven and as close to reality as possible, which was translated into developing a complex decision-making process within the model, but such an approach posed many issues and questions on how to solve it. The idea resulted in demanding more time and effort to achieve all established conditions laid in the model.

Limitations

Among several simplifications made in this research for completion within the time and scope proposed, how the simulation dealt with cost data is the biggest limitation. All costs applied in the exercise were an approximation of real-life values. For example, the implementation costs are an average range observed by IRENA on countries, but this might not be the reality faced by companies in the specific metropolitan regions we were simulating. Besides, the simulation overlooked grid connection, other technical installation costs, physical scalability issues, and terrain/area acquisition and maintenance. Therefore, the core concept is not to give straight forward answers with precise values, but to provide a comprehensive overview of the behavior of each type of financial incentive for the input parameters. Despite this, the research understands that the reliability of data, having more accurate costs and availability of sun and wind hours, for example, is crucial for the further developments of researches in this field, direct influence on the outcome of the CBA analysis.

Future researches

Among the possibilities of future researches, this study brought to light questions on which internal mechanisms of each financial incentive have a direct influence on energy communities' development. Understanding such structure can aid in a better understanding of how differences between each type of incentive influence the decision-process of new energy projects. Also, there are questions over how governmental treasuries perceive and understand such incentives and what is the effect it does on policy analysts doing CBA analysis. The third research could be in understanding more the nature of the incentives and how they affect the community's financial results in the long term. Does reducing costs or increasing benefits is more favorable for communities in the long run? Another research on financial incentives could be a deeper understanding if *Feed-in-tariff* is such an exceptional incentive that industries prefer to do projects individually than to join a community. Lastly, an important study is to research how a *Tradable Green Certificate* exchange market could operate to avoid the mistakes observed on the Carbon Credit, which helped large corporations to profit much without actually reducing CO2 emissions in the expected levels.

Scientific contribution

This research contributes to the scientific study of the application of financial incentives for the development of Industrial Energy Community Systems. This is done by the development of a generic model that can be applied to country-like scenarios while adjusting the input parameters to develop simulations of any type of evaluation.

References

Abdelaziz, E. A., Saidur, R., & Mekhilef, S. (2011). A review of energy saving strategies in the industrial sector. *Renewable and Sustainable Energy Reviews*, *15*(1), 150–168. https://doi.org/10.1016/j.rser.2010.09.003

Abolhosseini, S., & Heshmati, A. (2014). The main support mechanisms to finance renewable energy development. *Renewable and Sustainable Energy Reviews*, *40*, 876–885. https://doi.org/10.1016/j.rser.2014.08.013

Aneel. (2019). Tarifas elétricas. Retrieved January 5, 2020, from https://www.aneel.gov.br/dados/tarifas

Australian Energy Regulator. (2019). Australian Energy Price. Retrieved January 5, 2020, from https://www.aer.gov.au/

Bamberger, W. (2010). Interpersonal Trust – Attempt of a Definition. Retrieved from http://www.ldv.ei.tum.de/en/research/fidens/interpersonal-trust/

Basurto, X., & Ostrom, E. (2009). Beyond the Tragedy of the Commons. *Economia Delle Fonti de Energia e Dell'ambiente*, *52*.

Bauwens, T. (2014). What Roles for Energy Cooperatives in the Diffusion of Distributed Generation Technologies? *SSRN Electronic Journal*, *7*(0), 1–29. https://doi.org/10.2139/ssrn.2382596

Bauwens, T. (2016). Explaining the diversity of motivations behind community renewable energy. *Energy Policy*, *93*, 278–290. https://doi.org/10.1016/j.enpol.2016.03.017

Behrendt, L. (2015). Taxes and incentives for renewable energy. *KPMG International*, 22. Retrieved from https://assets.kpmg.com/content/dam/kpmg/pdf/2015/09/taxes-and-incentives-2015-web-v2.pdf

Béland, D., & Howlett, M. (2016). The Role and Impact of the Multiple-Streams Approach in Comparative Policy Analysis. *Journal of Comparative Policy Analysis: Research and Practice*, *18*(3), 221–227. https://doi.org/10.1080/13876988.2016.1174410

Beloborodko, A., & Rosa, M. (2015). The Use of Performance Indicators for Analysis of Resource Efficiency Measures. *Energy Procedia*, *72*(November), 337–344. https://doi.org/10.1016/j.egypro.2015.06.049

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (2012). *Cost-Benefit-Analysis: Concepts and Practice*.

Bolderdijk, J. W., & Steg, L. (2015). Promoting sustainable consumption: the risks of using financial incentives. *Handbook of Research on Sustainable Consumption*, 328–342. https://doi.org/10.4337/9781783471270.00033

Calel, R. (2011). Climate change and carbon markets: a panoramic history. *Centre for Climate Change Economics and Policy Work*, (52), 62.

Cao, K., Feng, X., & Wan, H. (2009). Applying agent-based modeling to the evolution of eco-industrial systems. *Ecological Economics*, *68*(11), 2868–2876. https://doi.org/10.1016/j.ecolecon.2009.06.009

Chertow, M. R. (2000). Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment*, *25*(1), 313–337. https://doi.org/10.1146/annurev.energy.25.1.313

CMS. (2016). *Renewable Energy in Iran*. *CMS Cameron McKenna LLP*. London. https://doi.org/58231623v1© Watson Farley & Williams 2016 All

Daneshmand, A., Jahangard, E., & Abdollah-Milani, M. (2018). A time preference measure of the social discount rate for Iran. *Journal of Economic Structures*, *7*(1), 29. https://doi.org/10.1186/s40008-018-0127-x

Darby, M. R. (2016). The Price of Oil and World Inflation and Recession, *72*(4), 738–751.

DellaVigna, S. (2009). Psychology and Economics: Evidence from the Field. *Journal of Economic Literature*, *47*(2), 315–372. https://doi.org/10.1257/jel.47.2.315

Dincer, I. (2000). Renewable Energy and Sustainable Development. *Renewable and Sustainable Energy Reviews*, *4*, 157–175. https://doi.org/10.4018/978-1-4666-0882-5.ch302

Easley, D., & Kleinberg, J. (2010). Networks, Crowd, and Markets - Reasoning over a highly connected world. *Econometric Theory*, *26*(5), b1–b4. https://doi.org/10.1017/s0266466609990685

EIA. (2019). Renewable Energy Explained. Retrieved August 16, 2019, from https://www.eia.gov/energyexplained/?page=renewable_home

El-Katiri, L., & Fattouh, B. (2015). A Brief Political Economy of Energy Subsidies in the Middle East and North Africa. *Oxford Institute for Energy Studies*, (February). https://doi.org/10.1163/9789004336452_005

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects, and their enabling technology. *Renewable and Sustainable Energy Reviews*, *39*, 748–764. https://doi.org/10.1016/j.rser.2014.07.113

Enerdata. (2019). World Energy Production.

EPA. (2018). Green Power Pricing.

EPIA, & AT. Kearney. (2010). Unlocking the Sunbelt Potential of Photovoltaics. *European Photovoltaic Industry Association*, *47*(2), 29–31.

EU. (2018a). A Policy Brief from the Policy Learning Platform on Low-carbon economy Renewable Energy

Communities, (August), 12. Retrieved from https://www.interregeurope.eu/fileadmin/user_upload/plp_uploads/policy_briefs/2018-08-30_Policy_brief_Renewable_Energy_Communities_PB_TO4_final.pdf

EU. (2018b). *Report on the functioning of the European carbon market*. Brussels. Retrieved from https://ec.europa.eu/clima/sites/clima/files/ets/docs/com_2018_842_final_en.pdf

European Union. (2019). European energy statistics. Retrieved January 5, 2020, from https://ec.europa.eu/eurostat/data/database

Farah, P. D., & Rossi, P. (2015). Energy: Policy, Legal and Social-Economic Issues Under the Dimensions of Sustainability and Security.

Farris, A. (2016). Wind Power's Intermittency Problem. Retrieved November 9, 2019, from http://www.energybc.ca/intermittency.html

Fattouh, B. (2016). Adjustment in the Oil Market: Structural, Cyclical, or Both? *Oxford Institute for Energy Studies*, (May). Retrieved from www.goldmansachs.com/our-

Faulconbridge, I., & Ryan, M. (2014). *Systems Engineering Practice*. Canberra.

Ford, A., Vogstad, K., & Flynn, H. (2007). Simulating price patterns for tradable green certificates to promote electricity generation from wind. *Energy Policy*, *35*(1), 91–111. https://doi.org/10.1016/j.enpol.2005.10.014

Freixas, X., & Rochet, J.-C. (1999). *Microeconomics of Banking* (4th ed.). Boston: Massachusetts Institute of Technology. https://doi.org/10.1016/S0925-5214(98)00058-1

Furey, K. (2013). A reading on money and money creation. *Forum for Social Economics*, *42*(1), 38–58. https://doi.org/10.1080/07360932.2013.770775

GE Power. (2018). *The Digital Energy Transformation*. *General Electric*. Retrieved from https://www.ge.com/power/digital-transformation-in-energy-industry

Hein, A. M., Jankovic, M., Farel, R., & Yannou, B. (2015). A Conceptual Framework for Eco-Industrial Parks. *Volume 4: 20th Design for Manufacturing and the Life Cycle Conference; 9th International Conference on Micro- and Nanosystems*, (August), V004T05A024. https://doi.org/10.1115/DETC2015-46322

Hofstede, G. (2011). Dimensionalizing Cultures: The Hofstede Model in Context. *Online Readings in Psychology and Culture*, *2*(1), 1–26. https://doi.org/10.9707/2307-0919.1014

Howlett, M., McConnell, A., & Perl, A. (2015). Streams and stages: Reconciling Kingdon and policy process theory. *European Journal of Political Research*, *54*(3), 419–434. https://doi.org/10.1111/1475-6765.12064

Inglehart, R., Haerpfer, C., Moreno, A., Welzel, C., Kizilova, K., Diez-Medrano, J., … Puranen, E. P. & B. (2014). *World Values Survey: Round Six - Country-Pooled Datafile*. Madrid. Retrieved from version: http://www.worldvaluessurvey.org/WVSDocumentationWV6.jsp.

International Energy Agency. (2019). Energy security. Retrieved August 23, 2019, from https://www.iea.org/topics/energysecurity/

IRENA. (2015). SMART GRIDS AND RENEWABLES A COST-BENEFIT ANALYSIS GUIDE FOR DEVELOPING COUNTRIES. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_PST_Smart_Grids_CBA_Guide_2015.pdf

IRENA. (2018). *Global Energy Transformation: A Roadmap to 2050*. *International Renewable Energy Agency*. Abu Dhabi. https://doi.org/Doi 10.1002/(Sici)1097-0029(19990915)46:6<398::Aid-Jemt8>3.0.Co;2-H

IRENA. (2019). *Renewable Power Generation Costs in 2018*. *International Renewable Energy Agency*. https://doi.org/10.1007/SpringerReference_7300

Itnal, P. G. (1999). *Practicals in Cost Accounts*. Atlantic Publisher. Retrieved from https://books.google.nl/books?id=OxzV_r_PB9IC&pg=PA307&lpg=PA307&dq=overhead+of+6%25&source=bl&ots=J2cduoTIO3&sig=ACfU3U0XcZi0UNcEaK4ZMhghKkrJ2ZP-gg&hl=en&sa=X&ved=2ahUKEwiJnvj4kLPnAhURJFAKHRjuCc4Q6AEwDnoECAkQAQ#v=onepage&q=overhead of 6%25&f=false

Janssen, M. A., & Ostrom, E. (2006). Empirically Based, Agent-based models. *Ecology and Society*, *11*(2). https://doi.org/10.5751/es-01861-110237

Keeney, R. L., & McDaniels, T. L. (2008). Value-Focused Thinking about Strategic Decisions at BC Hydro. *Interfaces*, *22*(6), 94–109. https://doi.org/10.1287/inte.22.6.94

Khayesi, M., & Amekudzi, A. A. (2011). Kingdon's multiple streams model and automobile dependence reversal path: The case of Curitiba, Brazil. *Journal of Transport Geography*, *19*(6), 1547–1552. https://doi.org/10.1016/j.jtrangeo.2011.06.012

Kilian, L. (2008). The Economic Effects of Energy Price Shocks. *Journal of Economic Literature*, *46*(4), 871–909. https://doi.org/10.2469/dig.v39.n3.33

Kingdon, J. W. (2013). *Agendas, Alternatives, and Public Policy. Pearson* (Vol. 2). https://doi.org/10.2307/2150882

Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, *56*(February 2018), 722–744. https://doi.org/10.1016/j.rser.2015.11.080

Leemans, R., & Vellinga, P. (2017). The scientific motivation of the internationally agreed 'well below 2 °C' climate protection target: a historical perspective. *Current*

Opinion in Environmental Sustainability, *26–27*(December), 134–142. https://doi.org/10.1016/j.cosust.2017.07.010

Leo Dobes, J., Leung, O., & Argyrous, G. (2016). *Social Cost-Benefit Analysis in Australia and New Zealand: The State of Current Practice and What Needs to be Done*.

Llop, M. (2018). Measuring the influence of energy prices in the price formation mechanism. *Energy Policy*, *117*(March), 39–48. https://doi.org/10.1016/j.enpol.2018.02.040

Ma, T., & Nakamori, Y. (2005). Agent-based modeling on technological innovation as an evolutionary process. *European Journal of Operational Research*, *166*(3), 741–755. https://doi.org/10.1016/j.ejor.2004.01.055

Ma, T., & Nakamori, Y. (2009). Modeling technological change in energy systems - From optimization to agent-based modeling. *Energy*, *34*(7), 873–879. https://doi.org/10.1016/j.energy.2009.03.005

Mathioulakis, E., Panaras, G., & Belessiotis, V. (2013). Cost-benefit analysis of renewable energy systems under uncertainties, (October 2013), 09002. https://doi.org/10.1051/metrology/201309002

Mendes, G., Ioakimidis, C., & Ferrão, P. (2011). On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. *Renewable and Sustainable Energy Reviews*, *15*(9), 4836–4854. https://doi.org/10.1016/j.rser.2011.07.067

Ministério da Economia. (2019). *Social discount rate estimative for infrastructure project in Brazil*. Brasília.

Minkov, M., & Hofstede, G. (2013). *Value Survey Module Manual*.

Nasa. (2019). Global Climate Change: Vital Signs of the planet.

Nefi. (2018). *New Energy for Industries - Innovation folder*. *Nefi*.

Negro, S. O., Alkemade, F., & Hekkert, M. P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews*, *16*(6), 3836–3846. https://doi.org/10.1016/j.rser.2012.03.043

Nordhaus, W. D. (2007). A Review of the Stern Review on the Economics of Climate Change. *Journal of Economic Literature*, *XLV*(September), 686–702.

OECD. (2015). Policy Perspectives: Green Bonds - Mobilising the debt capital markets for a low-carbon transition. *OECD Publishing*, (OECD/Bloomberg Philanthropies). Retrieved from http://www.oecd.org/environment/cc/Green bonds PP [f3] [lr].pdf

Ostrom, E. (2005). *Understanding Institutional Diversity*. *Public Choice* (Vol. 132). https://doi.org/10.1007/s11127-007-9157-x

Ostrom, E. (2010). Beyond Markets and States : Polycentric Governance of Complex Economic Systems. *American Economic Review*, *100*(June), 408–444. https://doi.org/10.1080/19186444.2010.11658229

Ostrom, E. (2011). *Background on the Institutional Analysis and Development Framework p sj_394 7..28*. https://doi.org/10.1111/j.1541-0072.2010.00394.x

Ostrom, E. (2014). A Polycentric Approach for Coping with Climate Change. *Annals of Economics and Finance*, 97–134.

Paardekooper, M. (2015). *Economic Feasibility of Solar Panels in Amsterdam Assessing and validating the potential of roof top solar panels in the city of Amsterdam*.

Palley, T. (2012). *From Financial Crisis to Stagnation* (First). New York: Cambridge University Press.

Poundstone, W. (1993). *Prisoner's Dilemma* (1st Editio). New York: Anchor Books.

Rajan, R. G. (2010). *Fault lines*.

Romero, E., & Ruiz, M. C. (2013). Framework for Applying a Complex Adaptive System Approach to Model the Operation of Eco-Industrial Parks. *Journal of Industrial Ecology*, *17*(5), 731–741. https://doi.org/10.1111/jiec.12032

Romero, E., & Ruiz, M. C. (2014). Proposal of an agent-based analytical model to convert industrial areas in industrial eco-systems. *Science of the Total Environment*, *468–469*, 394–405. https://doi.org/10.1016/j.scitotenv.2013.08.049

Saleman, Y., & Jordan, L. (2014). The Implementation of Industrial Parks: Some Lessons Learned in India. *The World Bank Policy Research*, *6*(1). https://doi.org/10.1142/S1793993315500052

Scharpf, F. W. (1988). Decision Rules, Decision Styles, and Policy Choices. *Max-Planck-Institut Für Gesellschaftsforschung*.

Scharpf, F. W. (1990). Games Real Actors Could Play: The Problem of Connectedness. *Max-Planck-Institut Für Gesellschaftsforschung*.

Scharpf, F. W. (1997). *Games real actors play: Actor-centered institutionalism in policy research*. *Westview Press*. https://doi.org/10.4324/9780429500275

Sheu, D. (2019). How Companies Decide. Retrieved August 8, 2019, from https://www.linkedin.com/pulse/how-companies-decide-danny-sheu-1c/

Spaniel, W. (2011). Game Theory 101: The complete Textbook, *1st*.

Staudt, A. (2011). Climate Risk: Yet Another Reason to Choose Renewable Energy. Retrieved September 20, 2007, from https://www.renewableenergyworld.com/articles/2011/04/yet-another-reason-to-choose-renewable-energy.html

Storm, S., & Naastepad, C. W. . (2012). *Macroeconomic* *beyond the Nairu* (First). Cambridge: Harvard University Press.

Strupeit, L. (2016). Streamlining photovoltaic deployment: The role of local governments in reducing soft costs. *Energy Procedia*, *88*, 450–454. https://doi.org/10.1016/j.egypro.2016.06.023

Szulecki, K., & Kusznir, J. (2018). Energy security and energy transition – securitization in the electricity sector. In *Energy Security in Europe: Divergent Perceptions and Policy Challenges* (Vol. 1, p. 351). Oslo. https://doi.org/10.1007/978-3-319-64964-1

Toke, D., & Vezirgiannidou, S. E. (2013). The relationship between climate change and energy security: Key issues and conclusions. *Environmental Politics*, *22*(4), 537–552. https://doi.org/10.1080/09644016.2013.806631

UK BEIS. (2019). *Industrial electricity prices in the IEA*. London. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/834368/table_531.xlsx

United Nations. (2015). Convention on Climate Change: Climate Agreement of Paris., 1–25. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

United Nations. (2017). Handbook for eco-industrial parks, 95. https://doi.org/10.1016/j.ijantimicag.2004.03.023\rS0924857904001888 [pii]

United Nations. (2019). UNdata. Retrieved January 5, 2020, from http://data.un.org/Default.aspx

US Department of Energy. (2013). *Levelized Cost of Energy (LCOE)*.

US Department of Energy. (2015). Assessment of Energy Technologies and Research Opportunities. *Quadrennial Technology Review*. Retrieved from https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter1.pdf

US Energy Information Agency. (2019). Electricity Data. Retrieved January 5, 2020, from https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_06_a

van Dam, K. H., Nikolic, I., & Lukszo, Z. (2013). *Complex Adaptive Systems*. *Agent-Based Modelling of Socia-Technical Systems*. https://doi.org/10.1007/978-94-007-4933-7

Van Der Schoor, T., & Scholtens, B. (2015). Power to the people: Local community initiatives and the transition to sustainable energy. *Renewable and Sustainable Energy Reviews*, *43*, 666–675. https://doi.org/10.1016/j.rser.2014.10.089

Veneman, J. G., Oey, M. A., Kortmann, L. J., Brazier, F. M., & De Vries, L. J. (2011). A review of agent-based models for forecasting the deployment of distributed generation in energy systems. *Proceedings of the 2011 - Grand Challenges in Modeling and Simulation Conference, GCMS 2011*, 16–21.

Wade, R. (1987). The management of CPR - coll action as an alternative. *Cambridge Journal of Economics*, (11), 95–106.

Warbroek, B., & Hoppe, T. (2017). Modes of governing and policy of local and regional governments supporting local low-carbon energy initiatives; exploring the cases of the dutch regions of Overijssel and Fryslân. *Sustainability (Switzerland)*, *9*(1), 1–36. https://doi.org/10.3390/su9010075

Wheeler, E., & Desai, M. (2016). Iran's Renewable Energy Potential. Retrieved August 4, 2019, from https://www.mei.edu/publications/irans-renewable-energy-potential

Wind Europe. (2020). Financing and investment trends, 48.

Windfinder. (2019). Windfinder.com. Retrieved January 5, 2020, from https://www.windfinder.com/?utm_source=windfinder.com&utm_medium=web&utm_campaign=redirect#10/34.7850/135.4395

World Bank. (2019). *Economy Profile of Iran, Islamic Rep. Doing Business 2020 Indicators*.

Yergin, D. (2006). Ensuring Energy Security. *Foreign Affairs*, *85*(2), 69–82. https://doi.org/10.2307/20031912

Zohlnhöfer, R., & Rüb, F. W. (2016). *Decision-Making under Ambiguity and Time Constraints*.

[Appendixes]

Appendix A

Financial Incentives for Industrial Energy Communities Systems Development

Rafael C. B. F. Costa*, Amineh Ghorbani[a], Rolf Künneke[a], and Sina Eslamizadeh[a]

[a] *Technology, Policy and Management, TU Delft, Delft, Netherlands*

Financial Incentives for Industrial Energy Communities Systems Development

The development of energy communities across the globe is a landmark for the development of decentralized generation, supporting the transition to renewable energy sources. However, energy communities focus on households with little attention to industries or towards the development of Industrial Community Energy Systems. A central issue is the lack of understanding of how different types of financial incentives influence the development of renewable energy in such communities, as researches and policies focus only on energy production. To solve this problem, this study evaluated the impact of financial incentives in Industrial Energy Community Systems through economic and community metrics to compare how each policy performed under different environments. In doing so, this research developed a social-technical model which was analyzed through an Agent-Based Modeling Simulation to understand how the elements of such a complex system interact with the diffusion of renewable energy through an economic perspective. This research contributes to supporting the development of policy analysis on promoting renewable energy by comparing the effects of applying different types of incentives on a simulated environment.

Keywords: InCES; financial incentives; agent-based modeling

1. Introduction

Industries are a major contributor to economic development, but they are largely dependent on energy and its availability at the grid. Most national energy matrixes are fossil fuels based, being reliable, easy to stock, and distribute energy sources [1]–[7]. Yet, they are also high pollutant and depletable [8], imposing an Energy Security of Supply (ESS) issue [6], directly affects people's lives and the economy [9]. Alternatively, Renewable Energy (RE) sources are gaining traction as a feasible substitute for fossil fuel [10], contributing to a more reliable energy system [6], [11]. Nevertheless, the adoption of such energy sources is still slow, since generating RE energy requires a more sophisticated management system, which is especially challenging for the industrial sector [1], [5], [10], [12], [13]. There are still many questions on how to transition to RE without disrupting reliability while still providing economic feasibility [14]–[17].

In countries leading RE generation, decentralized-small scaled projects, following the bottom-up approach, act as key-drivers for their transition [5], [18]. The development of such projects mostly occurs through local energy communities, as they are better placed for understanding the local needs [10], [11], [18]–[23]. Yet, transitioning to RE is not simple and it is needed to develop a suitable energy policy, planning, and implementation scheme [6], [24]. Examining the policy aspect, a tool largely utilized by governments to promote expected behavior is the financial incentives, as they make the desired actions financially attractive [25]. But such an advantage not always reached and implementing a new policy may culminate in negative results [25]–[28].

Seeking to develop a larger understanding of the effect of utilizing financial incentives, policy analysts are recurring to modeling and simulation techniques as they lay a structure to test scenarios within a simplified environment. Among modeling techniques, Agent-Based Modeling and Simulation presents itself as an advantageous alternative, since it creates an adaptable and simplified representation of reality, allowing for the modeler to adjust parameters and reproduce the research [21], [29]–[33].

Therefore, there is a gap in understanding how financial incentives may promote the creation of industrial communities to produces renewable energy. The hypothesis in this research is that financial incentives scenarios enhance energy production in energy communities if compared to a base scenario of no incentives. To answer the proposed problem, this research will seek to (i) define an industrial energy community system, (ii) what are the incentives mechanisms that can be applied in such communities, (iii) evaluate how industries make their decisions (iv) and how the interaction between industries influence such decisions, and finally (v) indicates a model on how different incentives mechanisms can be compared. This work intends to fill in this research gap by suggesting a model on the formation of Industrial Community Energy Systems (InCES). For that, some scenarios were created based on real-world data while utilizing a behavioral approach, where each actor takes decisions as the simulation advances. Ultimately, this can provide insights into the establishment of these initiatives and aid to design better energy policies.

The structure of this report continues with a literature review in chapter 2. followed by the theoretical approach in chapter 3. In chapter 4, the model is detailed connecting all elements presented in the thesis and describing the storytelling of the simulation. Chapter 5 expands the simulation understanding by describing the experimental setup and presenting the real-life data collected. Chapter 6 displays the results from the simulation and finally, in chapter 7 the conclusion is reached with a summarization of the thesis.

2. Literature Review

Industrial sector energy consumption

To date, the industrial sector has been the largest consumer of energy globally, yet the slowest to transition to Renewable Energy [15], [17], [34]. In 2015, only 14% of all consumed energy by the industrial sector came from a renewable source [2], demonstrating a large potential for improvement.

Insert Figure 1 - Industrial energy consumption [34]

Yet, with most national energy matrixes relying on fossil fuel, achieving a diversity of energy sources is a hard task. In 2018, the main energy sources globally were all fossil-fuel-based, with Oil as the most used source of energy, followed by Coal, and Gas [7]. These sources, being depletable and highly pollutant [8], bring insecurity to national energy systems on how to provide energy in the future. Lastly, energy matrixes based on fossil fuels also require a long chain of production and distribution, increasing more insecurity to the system [11], [12], [18].

Renewable Energy and Decentralized generation

RE technologies can help reduce air pollution while ensuring reliable and cost-efficient energy, providing significant dividends for energy security, being an important mark for future energy grids [2], [35]. But, RE sources are much dependable on geopolitical variables, limiting their geographical applicability [1], [36]. For example, hydroelectric energy can only be implemented in locations with large rivers. Also, wind and solar energy burden the issue of intermittency [11], [37], as they have long unproductive hours, requiring more sophisticated management [5], [10]. On the other hand, both technologies have very little geographical limitations and in theory, they can be applied in any geographical location [5], [38].

Energy production has historically been a centralized process. Yet, Decentralized Energy Generation (DG) a concept of splitting generation into smaller geographically distributed energy producers is gaining traction [11]. DG not only provides a higher degree of flexibility but by having producers and consumers closer together, transportation and infrastructure costs are reduced [11], [19], [39].

Energy Community

A prominent example of DG is Energy Communities. They encompass local energy generation initiatives through a collective organized structure that enhances its members' awareness, promotes their engagement, and provides reliable cleaner energy [5], [10], [11], [18]. Such communities are usually organized for either 1) supply cheap(er) energy to its members or 2) sell to the market and yield financial income [10].

The motivations to join an energy community are intricate on individual self-regard and variate from ideological believes to financial return, as they expand their members' investment into larger and more profitable projects [5], [10], [19]. Besides an increase in scale, energy communities are also well suited to reduce project costs, since soft costs such as planning, designing, Operation & Maintenance, and permit acquisition can be unified and optimized [10], [40], [41].

Despite the benefits of community-owned infrastructure, this approach is still underappreciated in many countries and mainly focused on individual or households communities, with few studies on industrial energy community [1], [5], [10], [11], [18], [19], [23], [42]–[44]

Industrial Energy Communities

The existing literature on industrial energy communities is primarily focused on the physical exchange of energy and optimizing resources through Industrial Symbiosis (IS), which aims at understanding how industries can deliver value while having the environment as a stakeholder [40], [45].

Insert Figure 2 - Industrial Symbiosis model [40]

Across the globe, industries are clustering on Industrial Parks, where in theory, utility and facility management are made simpler, through simplified logistical infrastructure and providing advantages by agglomerating the demand while optimizing resources [46]. Yet, only a small fraction of those parks follows IS principles [40].

Even though IS is an emerging phenomenon, the focus is on resource management and member's inter-relationships are not a considered aspect of IS [40], [45]. Such positioning is driving new research to glaze at behavioral science and systems design [29], [40].

General assumptions

The main assumption in this research is to limit the wider spectrum of renewable energy generation, focusing only on wind and solar energy, adopting a simplistic economic view on choosing between the two technologies. Therefore, technical aspects such as noise pollution, available area, and grid connections are considered a solved topic when installation costs are calculated.

3. Theoretical approach

Industrial decision-making process

When dealing with the decision-making process of industries, they can be classified as composite actors [47]. Scharpf presents composite actors as

> *"Even though individuals may have considerable difficulty in managing their 'multiple selves', their partners and opponents will generally not hesitate to treat them as unitary actors*" [47].

In a single actor decision-process, such as a household, it may simply decide not based on finance or performance but on preference or ideology, expensing as they please in a purely self-regarding way[19]. Oppositely, as industries must deliver a financial result seeking to optimize their productivity [48]. Additionally, industries must also consider a wider spectrum of variables. Due to its complexity, no decision is made looking only for a single factor or in a single plane, at least two different points of view are needed to provide reliable information for decision-making [49], [50]. As a result, the decision-process of each company ends up following its unique decision-making framework [51].

Furthermore, industries are influenced its peers. Network theory argues that every individual follows a collection of social ties known as a small-world network. In practical terms, this means that every industry has a greater number of companies they know in s weak-network, with little interactions and a strong network of companies which provides a richer influence [52].

Figure 3 - Small-world network and randomness [52]

A very useful small-world network model for the type of relations enterprises have is the Watts-Strogatz model. This model proposes that each node is connected to its neighbor nodes but may rewire to nodes across the graph, shortening the paths between them [52]. This depicts a very close representation of reality as companies have a connection with their neighbors but maybe better related to another company much far away.

Institutional Analysis and Development Framework

Transitioning to renewable energy can be engaged basically in two ways. Through a top-down approach or a bottom-up approach. In this thesis context, the bottom-up approach, where society organizes itself to introduce change [18], is the preferred way. In the literature, this is known as Collective Action [53]. Elinor Ostrom developed the Nobel-winning Institutional Analysis and Development (IAD) framework for supporting research on bottom-up approach scenarios [20] and it is the bedrock theory of this research. In a nutshell, the IAD Framework provides a structure with basic elements on how actors interact and develop interpersonal relationships when handling specific group situations [54]. The framework is much capable of providing valuable insights on how to develop conceptual models. Its central component is the action arena, where actors interact with each other yielding outcomes. But for interaction to happen, the actors are influenced by external variables, the rules-in-use, community attributes, and the biophysical conditions which surround the action arena [53].

Figure 2 - IAD Framework [53]

In short, for a community to exist, members must share the community values and elements which can characterize the group apart from others [53]. These attributes of the community are often associated with Culture [53]. Individuals are expected to participate in a situation if they understand the external variables and believe that the rules in place are appropriate [47], [53]. The community stability is dependent upon this shared understanding of its value. As this thesis, is looking over the role of financial incentives in community development, the rule in use observed are the possible financial incentives for renewable energy, which are detailed later on.

Figure 5 - Internal structure of an Action Situation [53]

The Action arena maps out the actors and their actions. Having a defined position, from its external variables and knowledge, actors initiate a series of interactions, where they gain new information and create new links while assessing net costs and benefits of the potential outcomes of being in such an arena [20]. These interactions in literature are known as a game and are the object of the study of Game theory [47], [53], A group decision is the sum of individual decisions in which results are applied and reflected upon by all members, pressing the decision-maker to grasp better the game is played [47]. So, to better understand possible outcomes and how other actors will decide, this research leans towards the literature on game theory.

Game Theory

Game theory is an area of mathematical logic that studies conflict situations where one player makes a rational decision knowing that the other party will also do it [55]–[57]. The game theory is characterized as an attempt to explain and predict how organizations and individuals will choose to be a beneficial complement to Ostrom's framework [51], [58].

In Games, the scenarios are usually standardized, drastically reducing their complexity [47]. Scharpf exemplifies this property by pointing out several complex environments as dichotomies, e.g. parliamentary vs presidential governments. This logic can also be applied to the decision-making process in composite actors [56]. From this rationale, Scharpf argues that every actor has a preferred way to make a decision which is a combination of its predominant decision-style and its predominant decision-rule, presented on his decision-style framework [51].

Figure 6 - Styles of Decision Making [51]

In this study, two mixed-motivation games, where players may want to cooperate or not, are going to be explored.

Battle-of-the-sexes game

Each player has its preferred option and must choose between his option or its opponent, yet, both players prefer to choose the same option than to be separate, implying in a sub-optimal choice for one of the players. Equilibrium comes from repetitive interaction [57].

Figure 7 - Battle of the Sexes game [57]

Assurance game

Both players may collaborate towards a highly rewarding and risky task or to execute independently a certain but less rewarding task. Since there is a chance of default in the collaboration strategy, trustworthiness is a key element.

Figure 8 - Assurance game [57]

Organizational Culture model

Communities naturally build up particular attributes and regulations which affect how its members perceive as acceptable behavior Such characteristics are also building blocks of a community's culture [53], [59]. Hofstede defines culture as:

> "*The collective programming of the mind that distinguishes the members of one group or category of people from others"* [59]

Understanding this guides each actor to stay or leave the community, as not feeling part of a group pushes individuals to seek other groups [59]. Hofstede theorizes on some fundamental dimensions, which differ one culture from another [59]. The 6 dimensions are

Power Distance

It is defined as the extent to which the less powerful members of institutions and organizations accept that power is distributed unequally.

Individualism vs Collectivism

Individualism stands for a society in which the ties between individuals are loose: a person is expected to look after himself or herself and his or her immediate family only. Collectivism stands for a society in which people from birth onwards are integrated into strong, cohesive groups.

Assertiveness vs Caring

Assertiveness represents a preference in society for achievement, heroism, and material rewards for success. Its opposite, Caring, stands for a preference for cooperation, modesty, and quality of life.

Uncertainty avoidance

Strong Uncertainty Avoidance Cultures maintain rigid codes of belief and behavior and are intolerant of unorthodox behavior and ideas. Weak societies in this dimension maintain a more relaxed attitude in which practice counts more than principles.

Long-term orientation

Stands for a society that fosters virtues oriented towards future rewards, while Short-term orientation stands for fostering virtues related to tradition and fulfilling social obligations.

Indulgence vs restraint

Indulgence stands for a society that allows relatively free gratification, especially those that have to do with leisure and consumption. Its opposite Restraint stands for a society that controls such gratification.

Looking over to the IAD framework, the cultural dimensions depict the attributes of the community. Also, the dimensions support composed actor's decision-making style and rule. The combination of these elements can provide a valid framework for collective actor's decisions to stay or leave a community. *Power Distribution, Individualism vs Collectivism, and Long-term orientation* are related to decision-style as these dimensions are pertinent over seeking consensus. Decision rules, in its turn, is closer to *Assertiveness vs Caring, Uncertainty avoidance, and Indulgence vs Restrain*. Those 3 dimensions are related to how each individual sees itself in the society around it.

Financial Incentives

In a broad definition, a financial incentive is a type of policy that transforms an undesired public behavior into a financially attractive one [25], [26], [60]. Money is one of the most powerful sources of motivation with the potential to reinforce behavior, which may not happen [25]–[28]. In recent years, with the advent of environmental targets, governments started to promote financial incentives for renewable energy generation [26]. Three types of financial incentives, with some variation, are widely used to promote renewable energy generation: *Feed-in-tariffs, Tax Incentives, and Tradable Green Certificates* [23], [26], [34].

Feed-in-Tariffs (FIT)

It is the most common sort of financial incentive. It works through a guarantee in purchasing energy production for a superior price than a grid tariff, making it more attractive. FIT follows a ‘pay-as-you-go’ scheme where the government expenses based on the amount of energy was produced [26].

Tax Incentives (TAX)

it works out as an exemption of taxes related to renewable energy installation and equipment. The results in a smaller governmental revenue, as it is actively renouncing to collect taxes in exchange for an expected greater societal benefit in the future, in a ‘pay-now-receive-later’ scheme [26].

Tradable Green Certificates (TGC)

For the generation of a specified amount of renewable sources electricity, a tradable bond with a fixed face value is emitted (e.g. 1 certificate = fixed dollars = 1MWh). Being the effective payment for TGC only occurring in the future, governments can generate energy first and expense later, in a ‘use-now-pay-later’ scheme [26], [61]

Cost-Benefit Analysis (CBA)

When comparing different financial projects, a major challenge is to clarify if spending time, effort, and resources will be beneficial. This evaluation can be achieved with Cost-Benefit Analysis, a project alternative assessment method that quantifies in monetary terms the value of all consequences of an alternative. This method is based on systematic determining the monetary net benefits of different proposals [60].

In energy projects, the expenses and revenues are spread through the venture timespan. Therefore, to be able to compare alternatives, the future values must be *discounted* to their today value through the Net Present Value (NPV) technique [60], [62].

Formula (1) – NPV formula

Where B is the total benefit for a certain period, C is the total costs for the same period, ‘I’ is the discount rate for the project and ‘t’ is the adopted time frame. The basic decision rule when dealing with NPV calculations is to adopt a project if NPV is positive. But when assessing several alternatives, more acceptance criteria are needed. Another popular way to evaluate a project is through its profit margin. It assesses a relation between the revenue generated by the project and the total costs needed to generate such revenue.

Formula (2) – Profit Margin formula

Lastly, project alternatives can be evaluated through their Levelized Cost of Energy (LCOE). The LCOE is the value of how much a productive unit will cost based on the project total cost [63].

Formula (3) – LCOE formula

Where 'I' is the total investment in present value, 'OM' is the present value of the periodic operations and maintenance costs, 'G' is the total generation of energy during the project life span, 'i' is the project discount rate and 't' is the project life span.

Finally, with all project calculations alternatives, the CBA method proposes some steps to be followed [60]. The steps performed in a CBA analysis within this research are:

- *Step 1 – Qualitative Identification of the alternative and its baseline*
- *Step 2 – Quantitative assessment of the impact*
- *Step 3 – Monetization of the impacts*
- *Step 4 – Discount benefits and costs to present value*
- *Step 5 – Compute the Net Present Value of Benefits and Costs*
- *Step 6 – Make a recommendation*

4. Design of the Conceptual Model

Overview of the Conceptual Model

The model intends to simulate how different types of financial incentives influence the generation of renewable energy through industrial energy communities using an economic perspective. In such a model, the interaction between actors promotes a dynamism within the simulation making actors decide to join, leave, or stay in a community. The communities act based on which set of financial incentives rule exists, following a defined strategy to fulfill its members' energetic needs. Both actors make decisions based on calculations utilizing the CBA method to find the optimal solution. The model details a single industrial park, meaning that the grid connection and grid maintenance are considered granted. Also, being in an industrial park, every industry has a weak connection to all industries and a strong network with some of the members. To achieve the ambition of being a general evaluation, this model will be tested among different sets of economic and cultural backgrounds through 6 countries and gathering its culture 6-dimensions, using data from the World Value Survey [59].

Yearly, all industries have a new power demand that needs to be procured. For supplying so, they might purchase grid energy, start producing renewable energy by themselves, or join an energy community. Also, every industry is willing to evaluate renewable sources option and all industries in the park have the potential to become a community initiator. For doing its investment analysis, industries base their decision on two planes, an economic and a relational plane. The economic plane is where the CBA analysis with the NPV technique is calculated. This is tested on three initial evaluations

- Is buying energy from the grid more expensive than generating RE?
- Is it better to produce for me or sell to the grid?
- Forming or joining an energy community yields a better financial result?

The first questions are merely financial, while the latter still needs to be evaluated on the relational plane. Here the industry seeks to understand how its peers in the strong network perceive the topic.

Figure 9 - Proposed Action Arena

By being a member of a community, every industry starts to play its community member role, expecting that the community will perform economically well. Otherwise, it might want to leave the community.

The communities on its turn generate business plans which are voted by its members and if approved, construct the new energy generation. The progress here is monitored by the government which is a beholder in the simulation. It collects from the communities: (1) How many communities exist yearly, (2) the number of participants on each community, (3) the total amount of energy produced, (4) governmental investments, (5) amount invested by the community and lastly (6) number of members which exit a community. With this collected data at hand, it is possible to evaluate how effective each financial incentive performed in each country context.

Figure 10 - 2-tier games in Action Arena and Decision style matrix

The general scheme of the model is presented in figure 11

Figure 11 - General scheme of the model

Lastly, this thesis idealizes a 2-tier games action arena, depicted in Figure 10. First, the assurance game between government and communities while the other is the battle-of-the-sexes between the community and its members.

Actors descriptions

Industry

To supply its needed energy, industries evaluate the possible energy sources through a Cost-Benefit Analysis, using the Net Present Value technique. The evolution of this evaluation determines an engagement level for each industry, representing a different stage of progress towards joining or forming a community. Possible engagement levels are presented in Table 1.

Table 1 - Engagement level for industries

Besides, industries also develop a certain loyalty or the willingness to remain within the community. The behavior evaluation is divided into the decision style and decision rule. If a certain number of negative experiences happen, a wish to leave the community is triggered. When this happens, industries calculate a Return on Investment value. If both values are above the threshold, the industry exists in the community.

Community

The community develops business plans, based on its defined strategy and presents those plans to be voted on members' meetings, and all members go to every meeting. For a plan to be approved, it needs first to be the feasible and available budget is needed.

But approving a project goes through comparing project benefits and costs. The project benefit is the income from selling energy. Renewable energy project costs, on the other hand, is somewhat more complicated. The advantage of renewable energy projects at an InCES versus an individual installation is that the part of the costs is concentrated, unifying activities and reducing members' expenses.

Renewable Energy Technology Selection

Choosing which type of Renewable Energy Technology will be implemented, between solar, wind, or a mix of both is a task delegated to the communities. The choice is economical, where the source which delivers the best financial result will be the chosen one and occurs in the business plan development. As wind efficiency requires a minimum amount of wind [39], wind generation operates with a threshold in the model.

Figure 12 - Cost composition for solar energy generation [41]

Having the total costs and demand defined, the communities calculate the feasibility. Since all projects have the same timeline and all costs are in present value, the project that will be presented to members is the one with the highest NPV. If the project margin is positive, the project is considered feasible. Depending on the community strategy, members evaluate the project by comparing its LCOE with the grid tariff or their expected rate of return. For simplicity, the rate of return varies per industry between 0 and 5%.

Financial incentives role

Not all countries apply all 3 types of financial incentives. Each nation develops its approach to the problem utilizing different financial incentives and some variations depending on its political-economic context [64]. As the model is designed to test different types of financial incentives and different economic and cultural backgrounds, this research will apply 3 different values for each incentive.

The **feed-in-tariffs model** chosen is to simply multiply the grid tariff with a fixed FIT rate (FIT Tariff = FIT x Grid tariff). For FIT to be feasible, the rate needs to be at least >2, being this evidenced mathematically. The FIT rates in the model are thus, 2.1, 2.5 and 3

Formulae (4) – FIT minimum value calculation

For **tax-incentives**, the model chosen was of a 20%, 40%, or 60% direct tax discount on the installation costs of both renewable energy. A 40% discount is a rounded average of the majority of tax incentives across the globe [64].

lastly, for **Tradable Green Certificates** the selected model is to pay a fixed value for a certain amount of energy produced. The literature indicates that the price should be set above USD$15/MWh [65]. Being so, TGC is being priced as $0.015/KWh, $0.02/KWh, and $0.025/KWh.

5. Simulation Run

Industry

All industries at every step (year) update their new energy demand and perform the decision-making routine. If it is not engaged in a community, it assesses if renewable energy is advantageous by performing a CBA. A negative NPV indicates that the industry will continue with buying from grid energy. If NPV is positive, the industry searches over for a community and checks the feasibility of joining it. Otherwise, the industry looks over its peers with a positive NPV. If no one is available for generating RE, the industry will produce its energy.

Figure 14 - Energy Investment Decision-Making Routine

At the end of every step, all industries will have their situation defined, either being part of a community, purchasing energy from the grid, or producing independently. When an industry joins a community, its role changes. Members are asked to participate in meetings, vote over decisions, and check if the actions taken are in agreement with their decision-style and decision-rule.

Figure 15 - Community member routine (the author)

Community

When founded, a community receives a strategy to either provide cheap energy to its members or pay dividends by selling energy to the grid. This is the base for business plans which are to be developed and evaluated using CBA. The evaluation checks on the 3 technological possibilities described in the previous section. Based on the feasibility of the proposals, the community might execute more or fewer projects, influencing its yearly results.

Figure 16 - Community routine (the author)

Government

The role of the government is divided into two aspects: implement an energy policy and evaluate how such policy affected the community performance. Each simulation will have 1 type only of financial incentive being applied at a time and the policy will not change during the simulation.

6. Experimental setup & Data

Data and Data sources

For the modularity design of the model and its data-driven nature, the input data for the simulation should be standardized, generic, and supported by the model requirements. Using real-life data to promote a higher level of reality. Since this model has simplifications to real-life attributes, a straightforward comparison between the simulation results and real-life results is a pitfall [32]. To prevent this trap, the application of the real data collected is applied to ‘country-like’ generic nations of *Alpha, Beta, Gamma, Delta, Epsilon, and Zeta*.

The first dataset collected was the data from the World Value Survey [66] that supported the calculation of Hofstede’s dimension. The six selected source countries are *Australia, Brazil, Iran, Japan, the Netherlands, and the United States*. Their correspondence fictional countries follow *Alpha-Australia, Beta-Brazil, Gamma-Iran, Delta-Japan, Epsilon-Netherlands, and Zeta-USA*.

Figure 17 - Cultural dimensions for 6 selected countries (the author; Minkov & Hofstede, 2013)

However, some of the data may vary widely within the country, requiring magnifying the location into metropolitan areas. It was chosen the most industrialized cities of each country

- City of Alpha - Sidney, Australia
- City of Beta - São Paulo, Brazil
- City of Gamma - Arak, Iran
- City of Delta - Kyoto, Japan
- City of Epsilon -Rotterdam, Netherlands
- City of Zeta - Los Angeles, USA

Following the model design, several parameters are needed to develop the simulation, more specifically:

- Mean grid energy tariff
- Solar installation cost
- Wind installation cost
- Solar operation & maintenance costs
- Government infrastructure discount rate
- Hours of sunshine
- Wind distribution

Those data were collected from different official sources, such as the International Renewable Energy Agency Power Generation Costs 2018 [41] which provided the installation costs and Operation & Management on an average unitary price range in US dollars/kilowatt. For the nature values, it was used the open data website windfinder.com and the United Nations. A Brazilian ministry of the economy report provided several infrastructure discount rates of many of the countries and the lacking one came from published researches [68] [69]. For grid energy tariffs, they were collected from several different sources. Australia [70], Brazil [71], and the United States [72] were collected directly from their energy regulator. The Netherlands' grid tariff came from the European Union Statistics agency [73]. Iran's grid tariff came from a World Bank report [74] and finally, Japan's grid tariff came from a UK Ministerial report on Asian tariffs [75]. Finally, those values in currencies different than US dollars were converted to USD using the currency rate of 31-Dec-2018.

Input parameters & variables

The values utilized in the simulation are presented by country in the following graphs, divided by each data and its value per location.

Grid Tariff

The Grid Tariff represents the mean value of how much a kilo-Watt hour costs for the defined municipality in US dollars. Bringing more reality, as tariffs may vary according to consumption, a range of 20% was added around the average.

Figure 18 - Grid Tariff amplitude

Solar Installation costs variation

Solar installation costs represent the observed range of total costs in solar projects in those countries reported by IRENA.

Figure 19 - Solar Installation Costs variation

Wind Installation costs variation

Wind installation costs represent the observed range of total costs in wind projects in those countries reported by IRENA.

Figure 20 - Wind Installation Costs variation

Discount rate

The discount rates utilized are governments reported rates used to calculate the Present Value of public interest projects.

Figure 21 - Interest rate by country

Energy production potential

The last collected simulation value is energy production potential for solar and wind energy.

Figure 22 - Energy production potential by energy source

Hofstede's dimensions distribution

Hofstede's dimensions being a dispersed parameter with an average value, can be mathematically calculated. Each dimension can be translated into probabilistic distributions. Combining those parameters allows the decision-style and decision-rule to also be probabilistic distributions, indicating on which 'box' each company is classified.

Figure 23 - Hofstede's dimensions distribution for decision-style

The probabilistic distribution in the simulation is a value array where one is assigned to each industry at the beginning of the simulation. This array is calculated using the mean value of the decision-style distribution along with its standard deviation and a normalization of the values on a scale from 0 to 100.

Figure 24 - Hofstede's dimensions distribution for decision rule

Decision style alternatives are *Unanimity* (values from 0-33), *Majority* (values from 34-66), and *Hierarchy* (values from 67-100). Decision rule options are *Confrontation* (values from 0-33), *Bargaining* (values from 34-66), and *Problem Solving* (values from 67-100).

Table 2 - Average values by country of decision style and decision rule

Simulation Variables

The simulation run planning is defined based on all variable data. The first data level to iterate is the countries, which bring along their respective parameters. Following, the type of financial incentive is defined in 4 different scenarios. **Scenario 0** is defined as a no incentives, **Scenario 1**, has the feed-in-tariff incentive, **Scenario 2** has the tax-incentive, and **Scenario 3** the Tradable Green Certificates. The last level is to vary each scenario based on the assigned values

Table 3 – Variables for financial incentives

The combination of all possible scenarios led to 60 unique simulation runs. Seeking to avoid statistical issues due to a low number of simulations runs, each unique simulation was repeated for 500 times with the total numbers of ticks set to 20 as this is the defined simulation period.

Figure 25 - Simulation run tree

Parameters to be collected

To answer the research question, some parameters are collected from every simulation run. Their values combined with the country environment data are the base of the evaluation of the results chapter.

- Total communities
- Renewable energy generated by communities
- USD invested in Renewable projects
- Industry population in the communities
- Number of industries that exit a community
- Policy entrepreneur indicator

Sensitivity Analysis

The sensitivity analysis consists of running a high number of test simulations and examine if by changing the variables namely, each value of the financial incentive, the output result is very different. A large variation can bias the result and lead to a mistaken conclusion [32]. For this analysis, the variables chosen for testing are the sum of the maximum number of communities and the sum of the maximum number of members. These two variables have a higher influence on energy production and thus, a higher impact on the results.

Table 4 - Sensitivity Analysis (the author)

Both values indicate that the model is not sensitive to the proposed variables, reinforcing the choices made. Although, the difference in Values 1 and 3 is close to being significant. If value 3 was chosen higher, this would distort the simulation and harm the results.

Simulation characteristics and settings

Some last parameters are needed to be explained before presenting the simulation results. The number of industries in the industrial park was defined following the World Bank study on industrial parks [46]. As the small-network algorithm works better on larger populations, this research will run its simulations having 50 industries. This decision was made as the literature did not indicate any argument suggesting that different sizes of industrial parks would inflict different outcomes on the proposed parameters. Regarding the timespan of a simulation run, it was defined as 20 years (20 ticks) as this is the reported lifetime of solar and wind energy in the literature [39], [64]. And finally, the amount of energy to be procured by every industry is a random number picked from a uniform distribution of 10.000 values between 200KWh and 30MWh. This range fits in the usual scale of energy demand observed on energy tariffs label at the selected countries.

Table 5 - Simulation run settings (the author)

7. RESULTS

Countries collective insights

Evaluating the simulation results, some parameters are observed by the government beholder. Namely, (i) energy production per country, (ii) energy production per scenario, (iii) number of communities, (iv) number of members in the communities, (v) how many members exit the communities, and (vi) the policy entrepreneur role. The combination of such values allows assessing the differences between incentives, which will be further explored in the financial outlook insights.

Energy generation

As the goal is to incentivize renewable generation in industrial energy communities through financial incentives, this is perhaps the most important metric.

Table 6 – Total energy production by country on incentivized scenarios

Some interesting results came along this metric. Only 3 countries produced wind energy, but Epsilon was the only one to produced in a significant measure. Also, Delta as the highest producer was a surprise as the generation potential is the lowest among all countries. Epsilon was expected to be the leading country in wind energy, which prove to be true and Zeta to be leading in solar, which was not true.

Figure 26 – Total energy produced for all countries

Energy production per scenario

Exploring the energy production further by breaking the values per scenario, from the 3 incentivized ones, the best producing scenario was scenario 3, with Scenario 3 also performing well. Both scenarios followed similar portraits, differing little on the amount generated by country.

Figure 27 - Total amount of renewable generation for different scenarios

Gamma, Delta, and Zeta face a little issue as in no incentivized scenario they produced more than the baseline. Still, the difference does not surpass 3%, indicating that this can be considered an acceptable variation. In scenario 1, production followed a very different picture. Producing less energy, than the baseline and other incentivized scenarios.

Table 7 - Energy production by country and scenario (the author)

This observation leads to the question of if financial incentives are useful for promoting the increase of renewable energy generation in communities. For Gamma, Delta and Zeta, having an incentive did not spark an increase in production while for Alpha, Beta, and Epsilon incentivized production was much higher. Looking only for production results does not allow for a complete understanding if incentivized production is better or not. This requires assessing the other metrics to understand how each country performed.

Communities

This measure counts the sum of all active communities for each year on all four scenarios for all countries. In general, data is quite similar with no significant outliers being observed. In general, the maximal number of formed communities approximately lays between 4 and 5 communities in all scenarios and all countries. Alpha presented the smallest maximal number of communities and Epsilon had the highest maximal number.

Figure 28 – Average maximum number of communities created in all countries per scenario

Assessing the number of communities reveals that the model behaved similarly throughout the simulation and not much difference was observed between nations in this sense. Also, there is no significant difference observed between the scenarios and the baseline. This can be interpreted as a clustering degree within the industrial population or perhaps financial incentives do not promote a significant increase in the number of communities.

Table 8 - Average maximal number of communities per country for each scenario

A possibility is that the communities in the simulation attracted more members instead of prompting industries to form more communities. To further develop this analysis, it is needed to combine the number of communities with the number of members in such communities.

Members

The total number of members provides a deeper understanding of the situation by explaining how appealing the communities were for the companies in the industrial park. Following the same trend as the number of communities, the results present uniform values in all scenarios, with little variation in the number of members during the years. The result is a clear indication that communities are attractive to industries and the financial incentive increased this attractiveness when looking at all countries as an overall.

Figure 29 – Number of members in communities in all countries for different scenarios

For providing perspective, the highest possible number of members is all communities vary between 2 (minimal number of founders) to 50 (all industries).

Table 9 – Average maximal number of members per country for each scenario

Members Exit

This metric measures how many members did not feel belonging to such a community. In all scenarios and all countries, the number of members who decided to leave a community was considerably smaller than the total amount of members who joined a community. As the defined threshold was set to 12, it was expected that the number of companies that decided to exit the community increases in the later years, especially after year 12. This behavior is observed in the model.

Figure 30 - Number of members that exit communities for different scenarios (the author)

Compared to the baseline, scenarios 1, 2, and 3 presented a better result. Scenario 3 was the worst-performing scenario among the incentivized ones.

Table 10 – Average number of members who exit a community per country for each scenario (the author)

Policy Entrepreneur Indicator

The last metric for comparing countries is the policy entrepreneur role. This metric reports a portrait of how communities perceive the economic incentive, by signaling to the government beholder if the policy is being positive for the community or not. Communities signal either positive or negative, depending on if their business plan voting and business profitability. Scenarios 2 and 3 produced similar results, having more consistent values across all countries. Scenario 1 otherwise produced a mixed result, with

Epsilon and Alpha with a positive indicator, but the other 4 countries presented negative values. In other words, communities in Epsilon and Alpha experienced positive results for FIT policy while in the other countries the experience was negative.

Figure 31 – Evolution of the policy entrepreneur signal by communities for different scenarios

Comparing scenarios with the baseline, Scenario 1 not only was alone with negative results, but all values are smaller if compared to the baseline. Scenarios 2 and 3 presented better results than the baseline, with scenario 2 being the one with the most positive responses among all scenarios. Country-wise, Zeta had the most peculiar results. It holds the highest positive result with an average of 159,45 positive reports in scenario 2, it also holds the lowest results with -140,14 in scenario 1 and is the only country that did not have one value better than the baseline.

Table 11 – Average sum of the policy entrepreneur indicator per country for each scenario (the author)

Financial outlook insights

In this section, a detailed evaluation will be taken on the financial aspect of the incentives looking over the community investment, government investment, and LCOE.

Community Investment

The community Investment metric is the measure of how much the communities and its members expensed to build their energy parks. It is connected to the governmental investment as one goes up, the other goes down. Having cheaper project costs for communities increases the approval outlook. Looking into the metric data, again scenario 1 performed below the other scenarios, being the one who prompted the least amount of investments by communities. Scenario 3 was the only one that rendered more investments than the baseline. Scenario 2 had more investments than scenario 1 but not more than scenario 0.

Figure 32 - Total amount invested by communities in renewable generation for different countries in different scenarios

Table 12 – Invested amount by communities per country

Governmental expenditure on financial incentives

It represents the subsidies paid on *Feed-in-tariffs,* the amount renounced on the *Tax incentives* and the bond issue costs by the *Tradable green certificates*. The incentive improving the feasibility of projects by either improving the benefits (FIT and TGC) or lowering the costs (TAX).

Figure 33 - Total cost in financial incentives by governments for different scenarios

Looking from a scenario perspective, in 4 out of 6 countries scenario 3 was the one government invested the least. Oppositely, scenario 2 was the one where governments invested the most in 4 out of 6 countries.

Table 13 - Invested amount by governments per country

Levelized Cost of Energy of financial incentives

For a better comparison between financial incentives, an effective technique is to determine the unitary cost, thus comparing the total costs of each incentive and the total amount of energy that was generated with that incentive. The total cost of each incentive is considered here as in two strands, (i) sum of total investment and (ii) seeing only with community investment.

For most countries, FIT was the incentive that demanded the least investment. Exceptions are Gamma and Zeta. FIT is followed by TGC and TAX, which revealed to be the costliest financial incentive.

Table 14 - Invested amount by communities and governments per country

Looking over the LCOE, scenario 3, presented itself as having the smallest LCOE in 4 countries. Combining all LCOE, scenario 1 has the worse performance, being much more expensive than the other scenarios. The country with the lowest LCOE was Gamma on Scenario 3 and the one with the highest was Zeta on scenario 1. An intriguing value was observed in Epsilon where FIT presented the lowest LCOE, being the only country to have so.

Table 15 – Levelized Cost of Energy per country and scenario

Each incentive was perceived differently in each country and provides some patterns that aid in answering which incentive is more effective to generate renewable energy. Yet, a preeminent observation is a staggering difference between *Feed-in-Tariff* and the other incentives in Beta, Gamma, Delta, and the Zeta.

Figure 34 - LCOE for each country and financial incentive with combined community and government investments

Looking into the values of community investments only, a clear pattern emerges of Scenario 1 continuing to be the one with the highest LCOE, but Scenario 2 emerged as the one with the smallest LCOE instead of scenario 3. The logic of this lays in the fact that scenario 2 receives a much higher investment by the government than scenario 3. Also, comparing with the baseline, scenario 2 has a lower LCOE than the baseline in all countries.

Table 16 – Levelized Cost of Energy per country and scenario – An only community investment

From the LCOE analysis, it is observed that TGC and TAX are the most advantageous policies to be applied as they presented the lowest values, the first considering total investments, and the latter when looking only for community investments. But as previously exposed, the choice of a policy is not a simple direct task, such decision is embedded with other nuances that need to be considered. For example, TGC was cheaper in the overall and the one that received the least governmental investment, but TAX was cheaper for communities and produced more energy. A deeper discussion on this topic is presented in the concluding chapter.

Figure 35 - LCOE for each country and financial incentive having only community investments

8. CONCLUSION

Concluding the research, from what was presented previously, several conclusions can be drawn. From the results, it is possible to conclude that applying financial incentives can promote a better environment for industrial energy communities' development. Therefore, this research also proves true the stipulated hypothesis that financial incentives enhance energy production in energy communities. Also, as expected, different types of financial incentives produced different results when applied.

In all countries and all scenarios, the LCOE was smaller than the grid tariff. This is a clear indication that with appropriate planning, the adoption of renewable energy generation may be economically competitive with fossil fuel. Yet, this conclusion should be seen only as an indication and not ratification.

This model simplifies some of its variables, which need to be taken into consideration for an accurate calculation. Therefore, these results should be observed as suggestions and guidance for the initial phases of a policy assessment. Yet, the results also indicate that having incentivized scenarios may be better than not having an incentive at all, as the baseline was not a superior scenario in any country.

The results also suggest that the total number of communities is not the main factor in determining how much energy can be produced. Having more communities not necessarily leads to more production since the action to choose projects is based on members' voting, where the economical output has a large effect.

Considering the financial aspect and starting with *Feed-in-tariff*, despite being the most popular financial incentive applied in real life was the worse performing one in the simulation. A possible explanation for this behavior might be on the nature of the incentive. FIT is a 'pay-as-you-go' incentive were the government expenses based on how much you produce throughout time. It is possible that being outside a community was more advantageous than joining one, making FIT a good alternative for producing renewable energy, just not in communities.

Tax incentives and *Tradable Green Certificates*, on the other hand, performed better than the baseline and *Feed-in-tariff*, but between them, the results were quite similar. Both scenarios developed more communities, had more members, fewer of them exiting the communities, produced more energy, and yielded smaller LCOEs than FIT, also demonstrating to be superior scenarios than the baseline. But comparing both scenarios there is significant uncertainty, to which is superior. While considering public and private investments, TGC on the overall is cheaper. Also, there is an unexplored potential on the parallel bond-market that TGC may create. Nevertheless, having TAX as an incentive is more advantageous for the communities now, as the government bears more investments in reducing their investment. Applying *Tax incentives* also presents an additional benefit of increasing community liquidity, allowing them to invest more.

In other words, the model shows that the answer to which financial incentive is the most effective goes through determining what is the economical standpoint. Should the government bear more costs relieving the community's costs or reduce its investments making communities invest more? This is a very argumentative question that cannot be simply answered in this research. What this study exposes is that both incentives have similar outputs with different approaches. Still, this conclusion is aligned with what the IAD Framework brings to light as the external and environmental variables are a key aspect for evaluating the action arena. And Finally answering the main research question,

Which type of financial mechanisms can incentivize industries to form Energy Communities?

The thesis made clear that financial incentives do promote a better environment to produce renewable energy in InCES, but also, showed that different types of financial incentives produced different results when applied. Yet, answering the main question of which option is the most effective has proven to be a sinuous path as each type of incentive vary in nature and the potential outcome is much related to the economic outlook. Each of the financial incentives applied in this research has a different nature on how to promote benefit. FIT and TGC increase the benefit of communities by providing additional capital for the projects. Alternatively, TAX reduces installation costs as the government renounces to collect those taxes. Tax exemptions follow a 'pay-now-receive-later’ scheme, while FIT requires constantly cash outflow in a ‘pay-as-you-go’ scheme, and Finally, TGC creates bonds-like certificates in a ‘use-now-pay-later’ scheme.

Perhaps the most bitter point this conclusion can offer is that answering the main question is much more complicated than originally stipulated, indicating which financial incentive is the most effective is not elementary. Poorer or in-debt countries may prefer a bond-type incentive, pushing expenses to the future while more financially equilibrated countries may prefer a ‘pay-as-you-go’ scheme or even prefer to expense now and collect the benefits in the future. For any of those choices, what this research can conclude is that having a financial incentive is a better deal than not having financial incentives. This study concludes that no single policy is capable of solving the issue of renewable energy development independently. A broader debate regarding the application of which support policies should be applied is needed for matching the financial incentives observations from this study with the actual fiscal reality.

Appendix B

Gmail **Rafael Castelo Branco F. Costa <rafaelcbfc@gmail.com>**

Request for permission to use VSM 2013 manual

2 messages

Rafael Castelo Branco F. Costa <rafaelcbfc@gmail.com> Sat, Nov 16, 2019 at 2:34 PM
To: rights@geerthofstede.nl

Dear, Prof Hofstede,

My name is Rafael Costa and I am a Master student from TU Delft.

Firstly, thank you for your research, it is really inspiring. Secondly, I am doing my thesis over Industrial Energy Communities and I plan to use your 6 dimensions as theoretical background along with game theory to model how industries in different countries make decisions.

The purpose of this e-mail is to request permission to use parts of the VSM 2013 manual as I will perform some calculations with the formulas presented on it.

Thank you very much,

Rafael Costa

---

rights@geerthofstede.com <rights@geerthofstede.com> Tue, Dec 17, 2019 at 12:28 PM
To: "Rafael Castelo Branco F. Costa" <rafaelcbfc@gmail.com>

Dear Rafael,

Apologies for the belated reply to your message. Professor Geert Hofstede is always pleased to hear that younger generations are building further upon his work and yes, of course, for academic purposes you are free to use the VSM. Please do read the manual carefully in order to obtain valid results. You can find them on www.geerthofstede.com.

Wishing you much success with your studies, also on behalf of Geert Hofstede, who is an alumnus of TU Delft.

With kind regards, Met vriendelijke groet,

GEERT HOFSTEDE B.V.

Loes Husain-Cornelissen

Rights Manager

Lindelaan 54

6711 MV Ede

The Netherlands

Phone: +31 640730598

[Quoted text hidden]