Financial Incentives for Industrial Energy Communities Systems Development

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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.