Resisting The Iron Law of Oligarchy: case of community energy system

Master Thesis

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Challenge the future

Resisting The Iron Law of Oligarchy: case of community energy system

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Preface

This thesis report is written as part of the Master Program in Systems Engineering, Policy Analysis and Management at the Faculty of Technology Policy and Management. It marks the final step in completing this study at the TU Delft.

The goal of the research is to study the dynamic of community energy system that able to analyse under what condition the oligarchy could happen and its effect on health and fairness in the community. The research has interested me since it combines social sciences, and technological aspect in modelling and simulation study.

I would like to thank you for all the graduation committee, especially for my first supervisor Amineh Ghorbani, for the inputs and feedback during the process.

Estria Asi Putri
Delft, August 2017

Summary

The iron law of oligarchy claims that the complex organisation will always end up in an oligarchy, no matter it was constituted originally. In that sense, the oligarchy should also happen in the Community Energy System (CES) as a complex self-govern common-pool resource system. This thesis is specifically concerned with the emergence of oligarchy in the CES and the effect of the iron law of oligarchy on the health and the fairness in the CES.

Due to the dynamic nature of CES, the modelling and simulation approach was used as the main method. As a consequence, the main deliverable of this thesis was the conceptual and simulation model that enables the analysis of the emergence of oligarchy and its effect on the health and the fairness. Here, the Agent-Based Model and Simulation (ABM&S) is used as the modelling approach.

This thesis was structured into three main parts, (1) the desk research, (2) the model conceptualisation, and (3) the model simulation. The desk research was conducted to provide the input for the conceptual model. The desk research consisted of the literature review, the exploration of theoretical background, and the exploration of CES's case studies.

The model conceptualisation translated the empirical and theoretical concept found in desk research into a formal model. The conceptual model was structured in the IAD framework due to the dynamic nature of the institution in self-govern common pool resource system. Then, those concepts were formalised into Agent-Based Model (ABM) implemented in NetLogo. After that, the model was simulated, and the data analysis was performed to extract the insight from the simulation result.

The result from the data analysis suggested that the iron law of oligarchy occurs in the CES to a different extent depending on the community attribute and the heterogeneity of the population in the community. Also, the result revealed that the strong presence of the oligarchy situation has a positive effect on the health and the fairness in the community.

The leader under the high oligarchy situation was noticeable as the group of highly active members, instead of the autocrat. This fact made their presence paramount to the health and the fairness of the community. In the case where the autocrat leader emerged, the members lost their trust to the community, and more contenders appeared. As a consequence, less stable leadership happened and the community lost the unity, the active participation, and the legitimate outcome and process.

As a result, this thesis has the scientific and societal contribution. It was scientifically relevant because it was an attempt to produce an essential tool-kit to gain a better insight of the dynamic of the CES. The use of ABM as the method also contributed to the growth of the family of ABM. Moreover, the model can give the policy makers the insight needed to create or manage the CES better.

Nevertheless, several improvements can be made as the future works. Scope-wise, the system description can be broadened to involve more case studies not only in the Netherland. Moreover, the model can be elaborated more to involve more technical characteristics, such as several tariff options, the fluctuation of electricity price, or the distribution of electricity generated. Also, this model can be improved by adding more dynamic and complexity in the possible emergence of the institution.

From the data analysis part, the more advanced descriptive data analysis can be a valuable feature in the future, for example using PRIM to get the significant factors. Also, the use of a database of community energy system as a reference case could be used to validate the model and more face validation with the expert is encouraged as the future work.

Contents

1
Introduction

This chapter aims to give an introduction to this project. Firstly, it will describe the background of this thesis project, which includes the identified knowledge gaps, and the objective of this project. Based on that, the research questions will be formulated. Then, the research methodology is designed to answer those questions, which leads to the main deliverable of this project. Lastly, the structure of this thesis will be presented.

1.1. Background

Community Energy System (CES) has been increasingly mentioned as the way to facilitate distributed (renewable) generation through the development of smart grid. The CES is defined by Smart Energy Special Interest Group (SESIG) [1, p. V] as

> ”An energy generation, distribution, and storage system (where required) involving local community ownership and participation for the purpose of creating collective benefits for the community, including reduced bills, revenue generation, investment opportunity and community regeneration.”

Consequently, the CES can be seen as a self-governed common-pool resource [2], since the community members are actively contributing in making and adapting rules that regulate the use of a common-pool resource [3] such as energy generation, distribution, and storage. Those rules are defined as a self-governing institution by Ostrom [4]. Hence, the institutional dynamic in the community plays a significant role in the development of CES.

However, such communities most likely have heterogeneity of endowments (skill, capital, leaderships, etc.) and interest in its population. It implies that some community members have more endowments and incentives to contribute to the system than the others. Since the institution is also dynamic, the result of this heterogeneity is that the participation in community meetings and engagement, where the decision upon several rules are determined, will be dominated by the more incentivized people, even in a fair and democratic setting.

As a consequence, the CES may end up in an oligarchy situation, where the system is managed by a subgroup of members that have more interests or endowments, no matter how democratically constituted originally. This concept is known as *The Iron Law of Oligarchy* [5]. Consequently, this situation raises the issue of the justice in the community since that subgroup of the member may steer the future decisions to be more favourable on one side than the others.

The justice itself is defined as ”central to a well-functioning society with fairness being an expectation in day-to-day interaction” [6, p.2727]. Since the institutions are born from the interaction of the community member, the fairness will be the focus. In this case, the fairness is defined as a focal point that influences the legitimacy of process and outcome from day-to-day interaction in the community [6].

The healthy community is defined as ”a community that relies on their ability to recognise and adapt to change and continually adjust their internal institutional structures to ensure their continuity” (Brown et al. cited in [6, p. 2728]).

This oligarchy situation also can deteriorate the health of CES by affecting several factors that contribute to the health of a community. The health of a community can be measured using several factors: ”cohesion (the ability to cooperate and work together), community mindedness (active participation), neighbourliness (supportive), accepting different points of view (ideas and newcomers), community support groups and communication networks” (Pepperdine cited in [6, p. 2728]).

Since the system is mainly managed by a subgroup of members only, the Oligarch may steer the rules to limit the active participation of others or decrease the community cohesion. As a consequence, this situation can aggravate the health of a community, so the continuity of such a system will be at risk.

At the heart of this, the heterogeneity in the population becomes the main variable that may provoke this oligarchy situation. However, Ostrom [7] states that the effect of the heterogeneity of groups on their capability to sustain and organise effectively is still one of the major theoretical questions in the self-governance of common-pool resources.

Furthermore, there is no study found regarding the effect of the emergence of oligarchy on the health and the fairness in community energy system.

Therefore, the objective of this thesis project is to study the dynamic of Community Energy System that enables to:

- analyse under what condition the oligarchy situation emerges in the development of community energy system, given the institutional dynamic in it, and heterogeneity of the population
- evaluate its effect on the health and fairness of community energy system
- in case the oligarchy situation causes failure and unfairness, able to recommend to prevent or reform it

1.2. Research Question

Based on the thesis project's objective, the main research question and the subquestions are formulated. The main research question of this project is:

> *How does the oligarchy situation emerges and affects the health and the fairness of community energy system?*

To answer the main research question, the following sub-questions are formulated:

1. What is the characteristic of community energy as a bottom-up self-governing system?
2. How is the oligarchy defined in the community energy system?
3. To what extent does the oligarchy could happen?
4. To what extent does the oligarchy influence the health of the community energy system?
5. To what extent does the oligarchy influence the fairness of the community energy system?
6. In case the oligarchy does cause failure or unfairness, how can it be prevented or reformed?

1.3. Research Methodology and Deliverable

A community energy system consists of not only a technical part, such as energy generation, distribution, and storage system but also a social part, namely culture, institution, justice, etc. The interaction and the heterogeneity of the agents in the community makes this system complex. Moreover, this system employs the bottom-up approach, such that the behaviour of the system results from the structured interaction of the agents in the system [8].

Here, Agent-Based Modelling & Simulation (ABM&S) can be used to study the dynamic of this complex system. The bottom-up mechanism in CES can be captured by ABM&S concept [9]. Moreover, ABM&S has been widely used to model complex systems in many areas, ranging from human social, behavioural, cultural, physical and biological systems [10]. Therefore, the modelling and simulation (ABM&S) will be used as the main method for studying the dynamic of CES.

Consequently, several inputs are needed to conceptualise and formalise the model. In this case, the desk research method will be used to provide those inputs by exploring literature studies, theoretical backgrounds, and case studies of CES.

Briefly, the research methodology of this thesis project consists of two primary methods, which is desk research and modelling & simulation. Figure 1.1 shows the schematic representation of the research design of this thesis.

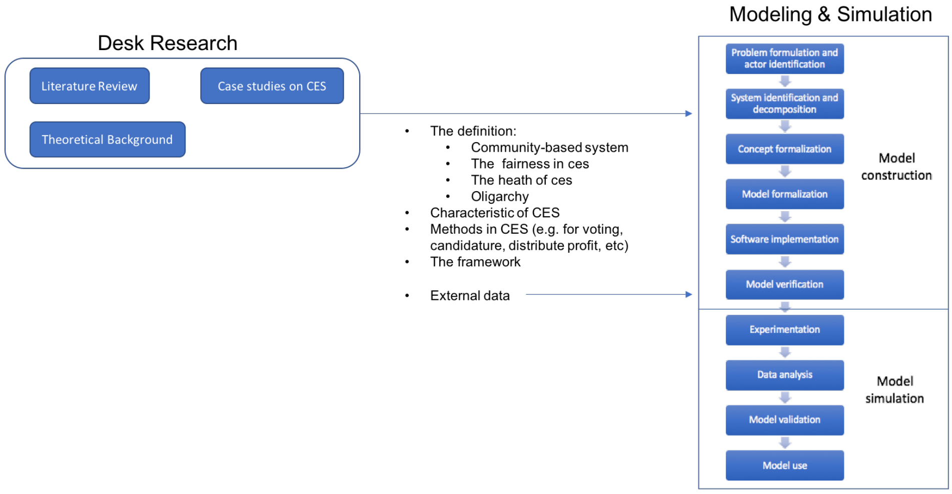

Figure 1.1: Research Design

As a consequence, the main deliverable of this project is the conceptual and the simulation model. Those models have to be able to simulate the emergence of the oligarchy situation in the CES. Therefore, it is important to make sure that the resulted model represents the general concept of CES, not leaning towards a specific case of CES.

1.3.1. Desk Research

The research starts with the desk research. It consists of three activities, which are (1) a literature review, (2) the exploration of theoretical backgrounds, and (3) the exploration of CES' case studies. The aim of this desk research is to give input for the modelling and simulation steps, such as several theoretical definitions, characteristic of CES, methods in CES, etc.

First, the literature review aims to explore the state of affairs research in community energy system. This literature review will return on several theoretical or empirical findings that are relevant for building the model. From those findings, several relevant theories and framework will be explored further.

The ultimate goal of these two activities is to provide the theoretical definitions, such as the definition of oligarchy, fairness in CES, etc. Also, it aims to provide the general characteristic of CES as a self-govern common-pool resource system and the framework that can be used to model its dynamic nature.

After that, several case studies of CES will be explored. The exploration aims to extract the general system description of CES. The system description will give the description on who the agents are, what they do, and how they interact with each other and with their environment, and what the environment consists of. Here, the exploration of case studies will focus on community energy system in Netherlands in the form of energy cooperatives.

1.3.2. Modelling & Simulation

The output of the desk research will be the main input for the modelling & simulation part. The modelling and simulation part will follow the steps for creating an agent-based model by van Dam et al. [11].

First, the problem will be formulated and identified. The main output of this step is the identification of several emergent patterns and the hypothesis on how the oligarchy can emerge in the community energy system.

After that, the community energy system will be identified and decomposed into several subsystems. The decomposition will be based on the framework identified in the theoretical background before. Next, the overall concept defined in this step will be formalised into software data structures and formal ontology in the concept formalisation step.

Then, the model formalisation aims to translate the formalised concept into the pseudo-code. After the pseudo-code is defined, the software implementation of the model will use agent-based simulation software as the main method. Here, the choice is using NetLogo software, since it is widely used software for implementing the agent-based model in the academic world.

As shown in Figure 1.1, the external data are needed which starts on the model formalisation onward. Acquiring those data may be a challenge. It is because the availability database of CES, which evolves and contains a large number of parameters, may not exist because this CES is a recently emerging system. Thus, several assumptions might be made.

After the model can be successfully implemented, the verification of the model will be done so that it will result in verified-simulation model for the experimentation step. The experimentation is designed to answer the sub questions and the main research questions. Next, the result will be analysed using data analysis tool, such as R, so the answer to those questions become more apparent.

Then, the model will be validated. Several methods of validation will be explored. The primary method of validation that will be used is the expert opinion.

1.4. Scientific and Societal Relevance

Several aspects make this thesis project scientifically relevant. First, it is an attempt to produce an essential toolkit to get a better understanding of the dynamic of CES as a bottom-up self-govern institution, especially from the organisational perspective of CES. The conceptual and simulation model enables us to obtain more in a more in depth look the organisational evolution of CES and its effect on the community itself.

Moreover, the iron law of oligarchy is a well-known theory in political parties. Nevertheless, this phenomenon has never been studied in self-govern common-pool resource system, specifically in CES. Thus, this thesis will also contribute to the development of this theory.

The second aspect is related to the use of ABM as the method. ABM is a growing modelling discipline within the study of the emergence. The work presented in this thesis will contribute to the growth of the family of ABM. It is because there is no agent-based modelling aimed to model the emergence of oligarchy.

The societal relevance of this project is that those models can give policy makers the insight on the development of community energy systems. The recommendations, which are built upon the evaluation, can help the community energy member and the policy maker to resist and reform the iron law of oligarchy from happening if it causes damage to the community.

1.5. Thesis Structure

The thesis is developed into three main parts, namely the desk research, the model construction and the model simulation. The desk research consists of the literature review, theoretical background, and case studies. Chapter 2 presents the literature review, Chapter 3 presents the theoretical background used in this research, and Chapter 4 presents case studies of the community energy system as the main input for the model.

Then, the second part is the model construction. Chapter 5 aims to conceptualise the model, which includes step 1 to step 3 of creating the agent based model (Figure 1.1). After that, Chapter 6 introduces the formalisation of concepts identified, up to the point the model is ready to be simulated. Chapter 6 covers step 4 to step 6 of Figure 1.1.

The third part of this thesis is the model simulation. Chapter 7 presents the experiment design for the simulation of the model. Then, the output of the experiment will be analysed in Chapter 8. After that, the model will be validated, which is presented in Chapter 9. After that, the result will be discussed and concluded in Chapter 10. Chapter 11 gives the reflection of this research and the further work that can be done after this project.

I

The Desk Research

2

Literature Review

A literature review on community energy has been done by Schreueur et al. [12]. It results in three main analytical approaches found in this field: (i) institutional framework condition, (ii) interaction at micro-level, (iii) local ownership and public acceptance. Moreover, Schreueur et al. summarise "three important points in their research: (i) different ownership models, (ii) different rationales attached to energy cooperatives and (iii) development processes over time" [12, p. 25]. Since the focus of this project is the dynamic of CES, we will concentrate on the third point, which is the development process of community energy over time.

The development of community energy system connotes two important process [12]: (i) commercialisation and concentration, (ii) institutional alignment and adaptation. Commercialisation and concentration is a process which the community-based initiatives become more commercially and professionally oriented. Institutional alignment and adaptation is a process which several rules and coordination mechanism emerge in the community over time.

Institutional alignment and adaptation process can be seen as a dynamic process of community energy as self-organised and self-governance organisation. Thus, the focus will be on this process. This process can be dominated by the more incentivized people in the community. Thus, it brings the concern regarding the fairness and the health, because the more incentivized people can steer the process that leads to better outcome for themselves. Therefore, this chapter aims to explore the state of affairs research in community energy system through fairness & health perspective and institutional perspective.

First, the definition of community energy system will be explored. Second, the literature on fairness and health perspective in the community will be presented. Third, the institutional perspective of the community will be described.

2.1. Community Energy System Definition

Walker et al. [13] acknowledge that community energy has become mainstream energy policy in the UK with several support funds and schemes. Consequently, it has raised the concern on the definition of community energy project itself, and what differentiates it with other renewable energy projects. They conduct the research which consists of three parts: (i) the creation of a community projects database; (ii) interviews with policy makers and managers of programmes that support the community projects; and (iii) six case studies of renewable energy projects, in which lead participants and local people were interviewed and surveyed [13].

The research from Walker et al. [13] results on two dimension that underlie the view of community energy [13]. First, a *process dimension* concerns on who involved in the project and had influence and for whom the project is built. Second, an *outcome dimension* concerns with how the outcomes of a project are distributed. The result is that community energy project is defined as the one which is driven, maintained, and managed by a group of local people (*process dimension*) and brings collective benefits to the community (*outcome dimension*)[13]. It is defined shortly as a project for and by local people or community.

Meanwhile, Gross [6] takes a broad definition of community by Brown et al. that a community is "a set of people who are brought together by choice or force of circumstance, and who have learned to live, work and play together" [14, p. 124]. Gross emphasises on "the social well-being as the community's ability to respond collectively to the challenges" [6, p. 2728]. This paper [6] relates the importance of the social well-being to the healthy community. Here, the health community is defined as "a community that relies on their ability to recognise and adapt to change and continually adjust their internal institutional structures to ensure their continuity" (cited in [6, p. 2728]).

Additionally, Avelino et al. [15] identify community energy as a part of self-organisation and self-governance system. The authors defined community energy is where communities have a high degree of ownership and control, as well as get collective benefit from the outcomes.

Taking into account a general view of the community, Dongier et al. [16] define a community-based organisation as a membership organisation, in which the member has joined due to the common interests. It can be either located in the same geographical area or not, and it can be formal or informal in form. Community-based organisation differ from the Non-Governmental Organisation (NGO) because it is based on membership and aimed to pursue the interest of its member. Meanwhile, NGO is considered to have a broader scope and pursue commitment that not always benefited NGO's member. Then, community-based organisation differs from local government due to their voluntary nature and the freedom to choose their objectives

It can be concluded that community-based organisation (including community energy) can be seen as self-governance and membership-based organisation [16], made for and by themselves [13], has voluntary nature and freedom to choose their objectives and collectively make their decision [16] [15].

2.2. Health & Fairness Perspective

Social well-being is the community's ability to respond collectively to change [6]. It is a useful construct that contributes to the healthy community. Gross stated that "a community with members who can work together to discuss and accept different viewpoints regarding potential impacts will be in a better position to generate outcomes which will be broadly accepted" [6, p. 2729]. Here, the notion of justice and fairness become important because the unfair process and outcome can hinder the ability of the community to work together and acceptance, thus aggravated the health of the community.

The healthy community is defined as "a community that relies on their ability to recognise and adapt to change and continually adjust their internal institutional structures to ensure their continuity" (Brown et al. cited in [6, p. 2728]). Several factors contribute to the health community, such as cohesion, community mindedness, neighbourliness, accepting different points of view, community support groups and communication networks" (Pepperdine cited in [6, p. 2728]).

The authors [6] explore different types of justice theory, such as distributive justice, procedural justice, social justice and environmental justice. The empirical study from wind energy community in Australia is used to explore the perspective of fairness from the community and relate it to the theory. It results that perceived lack of fairness came from the perceived injustice procedure/process *(procedural justice theory)* which can lead to an illegitimate outcome. These lack of fairness mainly come from three areas: "secrecy, insufficient community discussion and inequitable distribution of benefit" [6, p. 2733]. The secrecy and insufficient community discussion are recognised due to many people-the silent majority- did not have the opportunity at the meetings to have their say or to become fully informed or to influence details of the development plan.

Kass [17] builds the ethical framework for public health program which involves a community in it. One part of the framework relates to the principle of distributive justice, requiring the fair distribution benefit and burdens [17]. The interesting point from the author is that the fair distribution does not mean the equal distribution of resources to all community member [17]. The author also noted that some notions of justice allow and require the inequality distribution of benefits or outcomes [17] [18] [19]. Moreover, how those benefits and burdens can fairly be balanced brings the importance of procedural justice principle. He stated that "the procedural justice requires a society to engage in the democratic process" [17, p. 1781].

Hoffman et al. [20] also mention the importance of strong democracy to sustain the engagement of community members. The authors stated that "this does not mean politics as a way of life but rather developing a system of public participation involving the communication of shared interests, bargaining over those interests that are not held in common, agenda setting, and other less explicitly political activities" [20, p. 7572]. The authors also noted that community energy in its development might face the stealth democracy, where decision-making is carried out largely outside of the public's view and by people that the public do not elect [21]. Also, the existence of community member who prefers individualised rather than collective action, and the less civic time available to average community member might lead to that situation as well [20].

The need of this democratic process in community energy leads to the notion of "Iron Law of Oligarchy" by Michels [5]. The author states that all forms of organisation, regardless how democratic it was constituted originally, inevitably ends in an oligarchy, thus making true or strong democracy practically and theoretically impossible, especially in a large organisation that requires more complex tasks.

2.3. Institutional Perspective

Community energy system has increasingly mentioned as the way to facilitate distributed (renewable) generation through the development of smart grid. However, there is a tendency to be more focus on the technical aspect of smart-grid and neglect social determinant in the development of community energy system, which is the self-governing institution.

Wolsink et al. [2] suggest that this self-governing institution should be approached using Common Pool Resource (CPR) management. The authors stated that "renewable distributed capacity should be considered as common property *(owned and managed by the members of the micro grid community)* that is generating a common good, namely energy based on renewable instead of finite resources that increase carbon in the atmosphere and reduce carbon sink" [2, p. 829].

The CPR management originated from the problem of the tragedy of the common, the prisoner dilemma, and the logic of collective action. Ostrom [4] provides eight design principles for the self-governing institution in CPR condition, which was also adopted by Wolsink et al. [2] in their work. Also Wolsink et al. [2] emphasise the importance to escape from centralised framing to be able to realise the self-governing institution.

Meanwhile, Dietz et al. [22] form a framework for robust self-governance of environmental resources. This framework consists of the general principles and the governance requirements. By applying those general principles, which are arguably adopted from Ostrom's design principles, the governance requirement for robust self-governance should be satisfied.

Leach et al. [23] note that community is dynamic, and heterogeneous, in values and resource priority. They approach institution using a definition from Mearns et al., as "a regularised patterns of behaviour between individuals and groups in the society" [24, p. 103]. Since it is dynamic, the institutional arrangement and adaptation are their key focus. They stated that rather than a fixed framework, rules are constantly made and remade through people practices [23]. It is aligned with structuration theory by Fuch et al. [25].

In the structuration theory, the self-governance and self-organisation system consists of bottom-up process and top-down process. The bottom-up process is the process of institution forming from regularised practices, performed over time. While the top-down process is where the institution constraint and enable the behaviour of individuals in the system [25]. Moreover, Leach et al. [23] also consider the interplay of competing for a set of rule in the context of prevailing power relation in the process of forming the institution, which might result in the rules to favour selective class interest.

2.4. Conclusion

It can be concluded from the literature review of CES that due to the heterogeneity of the population, some members have more endowments (money, skills, time) or interest than others. Since the institution is dynamic, the more incentivized people (the one that has more endowment or interest) can dominate the process of institution alignment and adaptation [4]. As a consequence, the Oligarchy happens.

This situation may make the system unfair and injustice because the rules and the decision resulted from that process may favour the Oligarch most. This justice and fairness in CES are mainly approached using procedural and distributive perspective. Furthermore, this condition can harm several factors that contribute to the healthy community, such as cohesion, community mindedness, neighbourliness, and accepting different points of view [6]. Consequently, the continuity of such system might be at risk.

3

Theoretical Background

The literature review has given several findings regarding the community energy system. This chapter aims to connect those findings to the relevant theories that can be used in constructing the model.

The literature review reveals that community energy system can be seen as self-govern common-pool resources system. Also, the process of institution alignment and adaptation is a dynamic process. Therefore, the first part of this chapter will present the governing the common theory by Ostrom [4].

Since the institution is dynamic, the more incentivized people can dominate the process of institution alignment and adaptation [4]. As a consequence, the Oligarchy happens. Thus, the second part will discuss the theory of the iron law of oligarchy by Michels [5].

The third part is the supporting theory needed to conceptualise or formulate the system as a consequence of previous theories.

3.1. Governing the Common

3.1.1. Common-Pool Resource and Self-Governing Institution

Common-pool resources system is "a system that generates finite quantities of resource units so that one person's use subtracts from the quantity of resource available to others" [26][p. 1317]. The term of a common-pool resource refers to a class of goods with two main characteristics: high difficulty to *exclude* and high *substractibility*. In such system, the tragedy of the common usually happens.

The tragedy is that, in the absence of effective governance, each individual will tend to exploit the common-pool resource units to his/her advantage, typically without limit. Under this conditions, the common-pool resource is depleted and eventually ruined. Therefore, the main purpose of the effective governance is to define clear exploitation rights and create incentives to prevent resource overuse [27].

Ostrom noted that most of this common-pool resource is located far from central government, for example, forest, spring water, etc. [26]. Therefore, most of this system is governed entirely by the appropriators. Here, a self-governed common-pool resource is defined as a system where the appropriators of the resource, are involved over time in making and adapting rules within collective-choice arenas [26]. As a consequence, the rules that govern this such system is known as the self-governing institution.

3.1.2. Institutional Framework

Since the institution is dynamic, it is important to understand the institutional change in self-governance common-pool resource system. There are two well-known institutional frameworks that enable the analysis of the institutional dynamics and its development over time, which are the four-layer Williamson model [28] and the institutional analysis and development framework (IAD) [7]. Ghorbani et al. [29] applied those two institutional frameworks to conceptualise an agent-based model of a social-technical system. They made the applicability comparison of those frameworks for three ABM phases, which are design, implementation and analysis phase. The comparison is shown in Figure 3.1.

In that sense, the IAD framework can incorporate the key feature of the system that important for the process of building an agent-based model. Thus, we will use IAD framework for decomposing the

ABM Phase	Williamson	IAD
Design	Broad definition of layers, rules and behaviors	Explicitly defines the physical world, distinct types of rules and behaviors
Implementation	Provides high level structure for programming	Objects can be defined according to the components of the framework
Analysis	Informal layer and outcomes situated in the same level	Specific focus on patterns of interaction and outcomes

Figure 3.1: Comparison of the frameworks. *Source:* Ghorbani et al. [29]

system. The framework is shown in Figure 3.2, and the following subsections will explain each part of the framework.

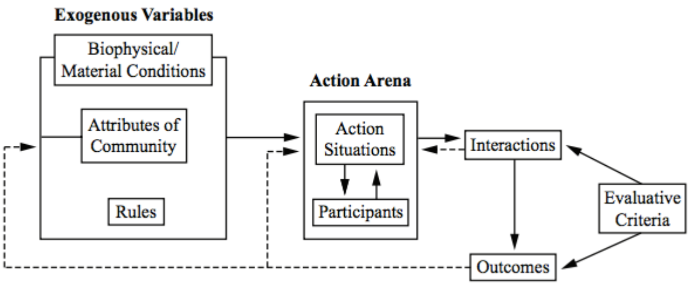

Figure 3.2: The IAD Framework. *Source:* Ostrom [7]

The Action Arena

The focal point of analysis of IAD framework is the 'action' arena, in which individuals with diverse preferences interact, exchange goods and services, solve the problem, dominate each other or fight [7]. This action arena includes two things: an *action situation* and the *participant* in that situation.

An action situation can be characterised using seven clusters of variables [7] [p.14]:

1. participants: the decision-making entities
2. positions: the set of "anonymous slots" into and out of which participants move
3. potential outcome
4. actions
5. action-outcome linkages
6. the control that participants exercise
7. types of information generated
8. the cost and benefits assigned to actions and outcomes

The participants are defined by the following characteristics [29]:

1. individual preferences
2. individual information processing capability
3. individual selection criteria
4. individual resources

The structure of the action arena is affected by three exogenous variables: (1) the rules, (2) the attribute of the *biophysical world*, (3) the structure of *community* in which the arena is placed [7].

The Rules

The term *rules* has been used to refer to many concepts. However, the rules in this IAD context is defined as "*enforced* prescriptions concerning what actions (or outcomes) are *required, prohibited*, or *permitted*" [7, p.18]. Seven types of rules are defined in this framework [29]:

- **Boundary Specify** who is eligible to play a role: who is in and who is out of the game?
- **Position** Determine to what extent a distinction is made regarding the position of the different participants. For example, a buyer or seller on the market has a different role than an auctioneer (and thus different access to information, and different choices).
- **Choice** Specify what a participant must, must not, or may do at a specific point in the process.
- **Payoff** Assign external rewards or sanctions to particular actions that have been taken.
- **Information** Describe what information may or may not be shared by participants and whether they have a set of common, shared information.
- **Scope** Define what outcome variables should or should not be affected by the actions undertaken.
- **Aggregation** Specify who has responsibility for an action: for example, whether a single participant or multiple participants should come to a decision

Biophysical world

The biophysical world is the set of external entities and factors that influence the action arena [29, p. 7]. This biophysical world influences what action is physically feasible, what outcomes can be produced, how actions are linked to outcome, and what's the information set available in that world [7]. The same set rules can lead to different action depending on what event that happens in this world.

Attribute of community

Ostrom defines the attributes of the community that affect action arena, which is [7]:

1. the values of behaviour in the community
2. the level of common understanding that the potential participant share (or do not share) about the structure of particular type of action arena
3. the extent of homogeneity in the preferences
4. the size and composition of the community
5. the extent of inequality of basic asset among those affected

Interaction and Evaluative Criteria

The action arena is where the interaction happens that produce outcomes. The change of the action arena's structure leads to the change of interaction that affects the produced outcomes. Here, the evaluation criteria "are used to judge the performance of the system by examining the patterns of interactions and outcomes"[7, p.13].

These evaluation criteria can be seen as they way to evaluate the procedural or the distributive justice of a system. As Ostrom mentioned, "when participants view interactions as unfair or otherwise inappropriate, they may change their strategies even when they are receiving a positive outcome from the situation" (Fehr et al. cited in [7, p.14]). This emphasises the importance to evaluate the interactions based on procedural justice perspective.

Furthermore, when the interactions cause the positive outcome, the participants may increase their commitment to maintaining the current structure of the action arena [7], which leads to the evaluation of distributive justice.

3.1.3. Framework for analysing institutional choice

While IAD framework has a focus on the action arena where the interaction happens, Ostrom also provides a framework for analysing the institutional-choice situation, which takes an individual view in making choices about future rules [4].

This framework uses the concept of rational action. Here, the individuals will select strategies whose the expected benefits will exceed the expected cost. In an institutional-choice situation, the individuals have to choose between (1) to support the continuance of status quo rules or (2) to support the change in one or more the status quo rules, although more than one alternative may be considered at a time [4]. This framework is shown in Figure 3.3.

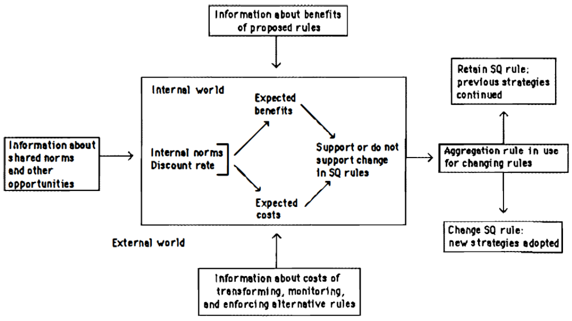

Figure 3.3: The Institutional-choice Framework. *Source:* Ostrom [4]

3.2. The Iron Law of Oligarchy

The Iron Law of Oligarchy is a concept by Michels [5] which claims that in a complex organisation, no matter how democratic constituted originally, eventually will develop into an oligarchy. He observes that in this particular situation the organisation becomes more dominated by the minority class- the more dominant one. He stated that complex organisation could not function purely as a direct democracy because of the mechanical and technical impossibility of direct government by the masses. Thus, the organisation will always need a delegation to individuals within the group.

The principal cause of oligarchy is the technical indispensability of leadership. This process is begun as a consequence of the differentiation of functions in the organisation. At the outset, leaders arise *spontaneously*; their functions are *accessory and gratuitous*. Soon, they become professional leaders, and in this second stage of development they become *stable and irremovable.*" [5, p.706].

Michels noted that the modern organisation has tried to cure this oligarchy by putting effort to retain the democratic essence, such as by making a rule that the leader can only lead for brief periods only, and by direct election. However, this does not guarantee the oligarchy situation does not happen. Another contributory cause is the noble human sentiment of gratitude, "the failure to reeled a comrade who has assisted in the birth of the party, who has suffered with it many adversities, and has rendered it a thousand services, would be regarded as a cruelty and as an action to be condemned" [5, p. 220].

Moreover, the leader has become harder to replace over time since they have become a specialist with a determinate function. This specialist becomes indispensable. Even though it will be replaced formally after several periods, but their ideas and says may still rule in the next leadership position.

Additionally to this skill power, as observed by Michels [5], the leaders usually have financial power. They are unpaid, purely honorary. They are usually rich and from a dominant class that able to spend money and time devoted to an un-remunerative occupation. Related with this financial power, Michels also highlights the dilemma. The underpayment for the leader role can hinder the frequent changes in the leadership position, while the overpayment can give the incentive to abuse this power through the dictatorship of the leader, or collusion [5].

At the center of this is the need of leadership in the organisation because the direct government by the mass is impossible. It is unavoidable phenomenon since the leader will always be required in the complex organisation. On the other hand, the power is conservative. This power leads the autocratic tendencies of leader. The exercise of this power cause the oligarchy situation benefits the leader or the minor-dominant class at the cost the mass. In short, Michels [5, p.663] formulates as such:

> *"It is an organisation which gives birth to the stable dominion of the elected over the electors, of the mandataries over the mandators, of the delegates over the delegators. Who says organisation, says oligarchy."*

3.3. Leadership Theory

Since the leadership is the central point of the oligarchy, we need to research further to leadership theory to find what factors that make individual is distinguishable as a leader. The leadership theory has been evolving from simply described as an individual characteristic into more dyadic, shared, relational, strategic, global, and complex social dynamic [30]. As a consequence, the leadership theory has a broad perspective, ranging from authentic leadership to e-leadership [30].

It is essential to know what makes someone want to be a leader, and how the member chooses a particular person to be the leader. Here, the focus will be on the process of the emergence of the leader from the mass.

The literature regarding leadership theory is obtained by using the keyword of "leadership theory" and is chosen from the most cited. From the top 5 of the most cited ones, the more recent literature is chosen. It leads to one of the well-known theory that focuses on the social identity and self-categorisation processes in organisational context by Hogg et al. [31]. In this case, there is three processes that lead to the emergence of leader: (1) self-categorisation, (2) social-attraction, (3) attribution.

The self-categorisation constructs a perceived prototypicality within the group so that some people are more prototypical than others [31]. Usually, "the person who occupies the contextually *most prototypical* position embodies the behaviours that others conform to and, thus, appears to have exercised *influence* over other group members" [31, p.128].

The social attraction "ensure that the more prototypical members are liked more than less prototypical member" [31, p.128]. Here, the social attraction is the process that makes *the more prototypical member more popular* and instantiates an intra-group status differential between leader(s) and follower(s). The final process is the attribution, which the more prototypical member is being attributed as a leader in the particular group.

One of the interesting point made by Hogg et al. [31] is that the process of self-categorisation, social attraction and attribution can lead to the exercise of power by the leader. The process creates the status-based structural differentiation of leader and followers. As this structural differentiation grows, the leader becomes more separated from the group, thus can aggravate the empathy and social bonds that guard the abuse of power by the leader. This abuse of power leads to the more powerful leader with rigid hierarchical leadership structure.

Hogg et al. [31] also mentioned that the scenario when there is a rigid hierarchical leadership is more likely to emerge *when the group is more cohesive and homogeneous*. As a consequence, the group is more consensual and agree upon the leader's decision. On the other hand, the scenario when the group is more diverse and less cohesive, the power base of the leader is more fragmented, thus enables numerous new contenders to emerge.

3.4. Complex Network

The complex network is widely studied across many fields of science to study the real system network. The main outcome of this activity has been to reveal that, " most of the real networks are characterised by the same topological properties, which are relatively small characteristic path lengths, high clustering coefficients, fat tailed shapes in the degree distributions, degree correlations, and the presence of motifs and community structures" [32][p.187].

Those properties are categorised into two main categories: (1) the small-world property, and (2) scale-free degree distribution [32] [33]. The small-world property in the real network is shown by the presence of clustering and the short average path length. This property was first investigated, by Milgram in the 1960s in a series of experiments to estimate the actual number of steps in a chain of acquaintances [34].

Then, the scale-free degree distribution reflects the heterogeneity in the interaction structure. This property makes the connectivity distribution in the complex network has a power law distribution [33]. It makes what is so-called "rich get richer" phenomenon in the complex network.

A well-known network model that able capture those properties is called scale-free models [32]

[33]. Wang et al. [33] develop a model algorithm that able to generate the scale-free model. This algorithm becomes the basic algorithm for the agent-based model of the scale-free network in NetLogo, so called preferential attachment model [35].

4

Case Studies of Community Energy System

Community energy has been an emerging topic as an energy transition towards renewable energy has raised public attention. Consequently, it becomes the mainstream energy policy in several countries, such UK, Denmark, Germany, and Netherlands.

In this case, the exploration of CES case study will focus only in Netherlands. In Netherlands, the community energy system mainly emerges from community initiatives for renewable energy in the form of (renewable) energy cooperative. Almost 500 community energy initiatives were registered in 2014 [36] [37].

Oteman et al. [38] distinguish two different types of initiatives in the Netherlands. The first type is the classic cooperative, in which members collectively own and exploit one or more renewable energy generation, and sell the energy generated to the large renewable energy supplier, such as GreenChoice and Eneco [38].

The second type is the more recent type of community initiatives as often referred as local renewable energy companies (LDEB). This initiative aims to promote energy savings, promote private renewable energy production, facilitate cooperative renewable energy production, and supply renewable energy to their members [38][p. 17].

In short, the main difference is that the type 1 energy cooperative sells the collective energy generated to the larger energy supplier, while the type 2 energy cooperative not only arrange the collective energy generation but also act as the energy supplier to its member.

Here, we will take five examples of CES. The first three cases will represent the type 1, and the rest represents the type 2. After that, the result of a survey from Binod et al. [39] about the willingness to participate in ICES (Integrated Community Energy System) in Netherlands will be discussed.

4.1. The Cooperatives

4.1.1. De Ramplaan

De Ramplaan energy cooperative was initiated by the resident of Ramplaankwartier, a neighbourhood in Haarlem, which decided to put an effort in improving the sustainability of their neighbourhood. Currently, the cooperation consists of 220 members, 1609 solar power parts, and 1349 solar panels [40]. The membership itself consists of three elements: a formal contract of membership, an investment of 325 euro per solar power part with a minimum investment of 2 solar power parts and a contract with energy provider Qurrent.

In return, each member has an equal vote in the decision concerning the cooperative and depend on their investment, partly owns of the collective solar PVs. Also, the cooperation with Qurrent gives the members additional discount in their electricity bill from Qurrent, which is € 27,5 for the first year and € 12,5 [41]. This membership is open for both natural person and legal entities (with a special condition) that are located in the postcoderoos area.

The cooperative is led by a board that consists of minimum three persons that are chosen by the member. The member of the board can be member or non-member. They work in a voluntary basis

[42]. The work took each board commissioner about 6-8 hours a week during the preparation and implementation phase [40]. Also, the member can appoint a supervisory board that has the main task to supervise the work of the board and gives advice to both the board and the member. Additionally, apart from two main bodies that appointed by the member, this cooperative has also a foundation. The foundation of the Ramplaan has two main task, which is conducting research regarding the development of the cooperative and promoting behavioural changes such as raising awareness and providing support to the residence.

The members gather at least once a year to discuss the end year balance, the future policy, budget allocation, and the change of the board if it is deemed necessary. The decisions taken in that meeting are decided based on the majority vote (50+1) with at least two third of the member presents [42]. Then, the daily decision is taken by the board with certain cases which they have to inform the supervisory board and the member.

The cooperative does not regulate much about the operational side of the energy generation and distribution since it is mainly handled by Qurrent as the energy supplier. Although, the members can monitor their own consumption through energy meters, neither the foundation nor the cooperative have tried to find a way to monitor why and to what extent members were engaged, how much the energy bill decreased and how to measure the success of their arranged meetings and promotion activities yet [40].

4.1.2. DEcAB (Duurzame Energie coöperatief Altena Biesbosch)

DEcAB is committed to strengthening the use and production of renewable energy in Altena Biesbosch region. DEcAB currently facilitates investment on the production of electricity from solar energy collectively or privately [43]. DEcAB was founded by and for residents, businesses, and institutions of Altena Biesbosch.

The membership of this cooperative is open for residents of Altena or companies and organisation with an office in Altena. The member has to pay membership fee € 12.5 per year. By becoming a member, they will have equal votes at member's meeting and decide the activities of the cooperation. Furthermore, the member holds no liability for any debts of the cooperative. The administrative role of this cooperative is done by the board, which consists of 4 persons.

As aforementioned, this cooperative aims to use and produce renewable energy especially from solar energy. Here, the investment can be done by the member privately and collectively. For private investment, DEcAB will facilitate the purchasing and the installation of solar panel [44]. For collective investment, the DEcAB arrange solar investment project, such as Energie van de Boer [45]. In this project, the member needs to invest at least one solar panel and maximum ten panels, which costs € 330 a unit. Then, the member has to pay a membership fee ranging from € 20-50 depend on the number of solar panels they invest.

Then, the DEcAB delivers the extracted power to a renewable energy supplier. The member will get 13 cents/ kWh off from the energy supplier for their energy bill. This discount is guaranteed for the next 15 years by the government. The energy supplier here is Duurzame Energie Unie. However, the member that can participate in this is constraint into certain zip code due to the postcoderoos policy in Netherlands.

4.1.3. Vallei Energie

Vallei Energie is an energy cooperative that generates local green electricity in Barneveld, Ede, Nijkerk, Scherpenzeel, Renkum, Wageningen, Renswoude, Rhenen and Veenendaal [46]. This cooperative works on seven principles: (1) Voluntary and open membership, (2) Democratic participation, (3) Economic participation of members, (4) Autonomous and independent, (5) Education, training and information focus, (6) Cooperative of cooperatives (co-operation between co-operatives), (7) Attention to the local environment.

The membership of this cooperative is open for a natural and legal person. The cooperative gives shares to raise capital for achieving its core objective. Here, each member can invest on two type of shares: (a) investment to the cooperative for the specific purpose, such as the development of cooperative, and (b) investment to the concrete project [47]. For type A investment, the participation cost is 50 euro per unit share with maximum 200 shares, while type B investment, the participation cost depends on the project that is decided by the general meeting. Both participation requires membership fee € 12 per year. In return, the member will get the discount on the electricity and equal one vote at the general meeting. Here, the cooperation sells the energy generated to renewable energy supplier Duurzame Energie Unie.

The management of the cooperative is done by the board of cooperative. The general meeting, a forum in which the member and the board gather to decide policy and future direction of this cooperative, determines and appoints the board with minimum three persons, and maximum seven persons. This meeting is held minimum twice a year. The board members have to be the member of the cooperative and are appointed for four years. They work on voluntary basis, but the expenses related to the cooperative work are reimbursable.

The decision power of the board without informing the general meeting is limited to certain aspect regulated on the formal regulation [48]. Moreover, the general meeting can also decide to set up a cooperative council which has the main role as a supervisory body. There are specific requirements to be a cooperative council member in the regulation, and the member of cooperative council can be a non-member of the cooperative [48].

4.1.4. Texel Energie

Texel Energie was established by three islanders and formally become the first energy cooperative in the Netherlands in 2007. It is located on Texel, a Dutch island located on the North Sea. In 2012, Texel energie consists of 3000 members and 4000 customer connections [15].

Currently, the main business of Texel Energie is to buy, resell and produce renewable energy through renewable energy project funded by the member [49]. To become a member of the cooperative, each person has to pay 50 euros per year, which resembles one share in the company. In return, they will get a discount on the energy price and one vote, no matter how much their share in the company. This voting casts in general meeting to determine the future policy of the cooperative.

In this case, the members are treated like the shareholders of the company. Besides they own share in the company, they also able to invest in renewable energy generation individually or collectively. On the other hand, they also accept customers, to whom they sell or resell their produced energy but do not have any shares in the cooperative. Recently, TexelEnergie together with Foundation Urgenda and cooperative Windunie took the initiative to establish an umbrella organisation of local energy companies, called the Renewable Energy Union (DE Union)

Historically, this cooperative was initiated by a foundation, which consists of twelve promoters. Then, at the inaugural meeting, the cooperative was legally established, and the board was elected, which consists of seven persons. After that, one of the member of the board was selected to be the director of the cooperatives.

This cooperative works as a non-profit organisation, with a transparent business structure to the member. The member pays the offset between the collective energy production based on their share and the energy consumption, with 0,25 euro cents less per kWh per m3 gas than the standard variable rate of the region supplier. Moreover, there is frequent newsletter and social media that facilitates distribution of information to the member

4.1.5. Energiecooperatie Coevoorden

Energiecooperatie Coevoorden is a cooperative society which the members invest 10 euro per year. Through this membership, the member becomes co-owner of the operating company named Coevorden Energy BV, which handles the daily affairs of this cooperative [50]. This company reports to the board of the cooperative.

Each member has one vote to decide the future direction of the cooperative and the operating company. The member can cast their vote at the meeting, which is held at least two times in a year. Also, there is an election of the Board which member can vote for.

Unfortunately, the court recently has declared Coevorden Energy BV bankruptcy on 21 Feb 2017.

4.1.6. Eemstroom Amersfoort

Eemstroom was established in 2012 as an energy cooperative. It was started with the supply energy, but their overarching objective is related to the sustainable local economy and regional self-sufficiency [51]. This cooperative only has the member, which is the co-owner of the cooperative as well as the customer of Eemstroom.

The organisation structure of this cooperative consist of three main bodies that handle the administrative and advisory role, which are the board, advisory board, and the council of members [51]. The council of members is the body that represents the member, the board holds the administrative role, and the advisory board advises both member and the board. Any member can sign up to be the council of members. Once a year, there is a general meeting, and the Council of Members elects the board and advisory board.

The member of Eemstroom has equally one vote, and they have to pay 10 euro per year for the membership fee. The members can invest in collective or private energy generation and pay their electricity bill based on the offset energy quantity between their energy consumption and energy production using the electricity market price. The Eemstroom has a newsletter and social media (facebook and twitter) as the information and communication media to its member.

4.2. A Survey of Willingness to Participate in ICES

Binod et al. [39] conducted a survey that defines the willingness to participate in ICES (Integrated Community Energy System) in the Netherlands. This on-line survey was distributed to 956 Dutch citizens of which 599 completed the survey. This survey reveals several factors that able to predict the willingness to participate. The out most significant factors are: (a) community trust, (b) environment concern, (c) energy independence, (d) education. The prediction model that will be used for obtaining the willingness to participate is based on Binod et al. [39], shown in Equation 4.1. This equation uses the standardised coefficient.

$$willingness - to - participate = 0,307 + 0,271 * a + 0,147 * b + 0,158 * c + +0,117 * d \quad (4.1)$$

Moreover, the survey also reveals that the willingness to invest and volunteer in ICES are positively correlated with the willingness to participate. However, the survey is the only proof that there is a positive correlation between those variable, not the causation relationship between those variables.

Spearman's rho	Willingness to invest	Willingness to volunteer
Willingness to invest	1	
Willingness to volunteer	0.458**	1
Willingness to participate	0.586**	0.528**

Table 4.1: Willingness correlation matrix

4.3. Conclusion

From several case studies mentioned before, the community energy system in Netherlands has a holonic structure. A holonic system (or holarchy) is "composed of interrelated subsystems, each of which is in turn composed of sub-subsystems and so on, recursively, until reaching the lowest level of 'elementary' subsystems" [52][p. 283]. Each intermediary sub-system plays a dual role and is both: an autonomous whole controlling its parts; and a dependent part of a supra-system [53].

Here, the second type, the LDEB, consists of the first type of community energy initiatives [38]. The LDEB, like Texel Energie, Energiecooperatie Coevoorden, and Eemstroom Amersfoort has individual and collective sub-system. The collective part resembles the first type of cooperative.

Also, the renewable energy supplier, such as Qurrent and Duurzame Energie Unie, works in the base of cooperatives as well [54] [55]. They have members and customers. The member can co-decide the future policies in this organisation and choose to invest the renewable energy generation privately or collectively through the project that initiated by those organisations or by themselves.

Each type also have the same organisation structure. The management role is led by the board, which the member vote for it in general meeting. It also has more or less the same governance rules regarding the investment, the voting procedure, and the membership. The members usually mentioned to have equally one vote, no matter their share is. They usually vote in member meeting, which is held once to twice a year, to decide the future policy of the cooperatives and select the board. The holonic structure of the community energy is described in Figure 4.1.

However, type 1 cooperative has more strong community sense, since the membership is usually bounded by the same neighbourhood (mainly by the zip code). Moreover, this cooperative does not accept customer-ship like LDEB, thus ensure the clarity of system boundary and make this system is

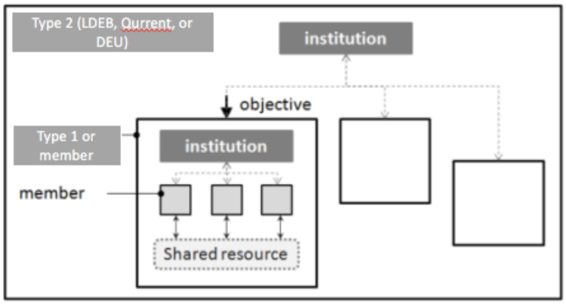

Figure 4.1: Holonic structure of community energy system. *Source:* Adapted from [52]

for and by its member. In that sense, the self-governed common-pool resource is more apparent in this type of cooperative, so we will focus on this type of cooperative to be modelled in the later stage.

Moreover, the survey has given the input to formulate the willingness to participate in the community in the model. Also, it reveals that the willingness to invest and volunteer are positively correlated with the willingness to participate. Thus, we assume that in the later stage, the willingness to invest and volunteer can be represented by the willingness participate value.

4.4. Implication for The Model

The case studies have given us the several concepts that can be inputted into the model. The fact that the inputs are extracted from the case studies make this model is uniquely applied to CES. The most prominent character of CES that differentiate it from the political or commercial organisation is the motivation underlying the participation of the member. Furthermore, the technology as the common-pool resource makes it different from the other community-based system with a ”natural” common-pool resource, such as water, forest, etc.

Since we are interested in the dynamic CES as the self-govern common pool resource, those inputs will be structured in IAD framework [3]. From this documentation, some missing components can be identified, in which the assumptions have to be made.

4.4.1. Action Arena

Action arena is the place where the interaction happens. From the case studies, it can be concluded that the action arena, in this case, is the member meeting (member assembly), where the members meet and discuss the further development of cooperatives.

Action Situation

1. Participant: all the member of cooperatives
2. Positions: member and board
3. Actions:
    - Discuss and interact: the structure of interaction is unknown. Nevertheless, scale-free network structure has proven able to model the interaction in social network [32]. Thus, it is assumed that the interaction happens in this network topology
    - Select board
    - Decide collective investment or other development plans
4. Potential outcome:
    - Development policies
    - Collective investment
    - Elected board
5. Function that maps actions to outcome: Voting

6. Information: Since the board holds leadership and management positions, it is safe to assume that the board has better information

7. Cost and benefit assigned to action and outcome: Unknown from the case study. However, Ostrom [4] gives the framework for analysing institutional choice. This framework uses the perceived benefit and cost term from individual point of view

Participants

1. Individual preferences: From the case studies, we know that some of the member can opt to be a board, and can opt to attend the meeting

2. Individual processing capability: Since the board is assumed to have better information, the individual processing capability is different based on the position

3. Individual selection criteria: Unknown, but it can be assumed that it comes from the perceived benefit and cost of the individual

4. Individual resources:
    - Basic resources: money, skill, time
    - Specific resources: the investment in electricity generation technology

4.4.2. Exogenous Variable

Biophysical world

1. Energy supplier: The cooperatives usually have a formal contract with one energy supplier.

2. Technology: The common invested technology for electricity generation is solar panel

3. Subsidy scheme: such as poscoderoos

Attribute of community

1. The values of behaviour in the community:
    - Voluntarily work for board
    - Sustainability
    - Energy independence
    - Willing to participate and invest
    - Community trust

2. Distribution of resource: Distribution of "ownership" in collective investment is based on the investment share

3. Homogeneity of individuals: no clear statement from the case studies, but we can assume that the individuals are homogeneous in structure, but heterogeneous in resources (endowments)

The rules

1. Position rules: some case studies state that only member can be a board [42], [46], and others state that the external person can be a board [51]

2. Boundary rules: The membership is bounded by post code

3. Authority rules:
    - The board leads and manage the cooperatives. The board usually brings proposal for the development of cooperatives (e.g. the business case, or new investment opportunity)
    - All members have equally one vote

4. Aggregation rules: The total energy generation and consumption is managed by energy supplier

5. Scope rules: Only the member can vote in the general assembly. Some cases state that it is possible to vote by proxy [42].
6. Information rules: The board has better information than the member
7. Payoff rules:
    - For every investment in electricity generation, the member get the reduction of electricity bill (they only pays the offset between electricity generation and electricity consumption)
    - Some cases state that the energy supplier gives member discount to the cooperatives

II

Model Construction

5
The Conceptualisation

The desk research has given the main input for conceptualisation stage. This chapter presents the process of translating model input section 4.4 into a conceptual model. It covers step 1 to step 3 of steps creating the agent-based model by van Dam et al. [11]. Firstly, the problem that the model aims to address will be formulated. Secondly, the community energy system will be identified. The identification of the system aims to give the main concept of the model and the dynamic of the model.

Thirdly, the core definition of the oligarchy, the health, and the fairness will be conceptualised and defined in the model. Fourthly, the system will be decomposed, so its internal structure is well-defined. During this process, several assumptions have to made. Lastly, the concepts will be made explicit, formal and computer-understandable as a preliminary stage towards model implementation [11].

5.1. Problem Formulation

As aforementioned, the first step is to formulate the problem that the model wants to address. There is a series of questions that need to be answered that help in this first step of model development. We will follow those question, which is presented by van Dam et al. [11].

What is the lack of insight that we are addressing?

As mentioned before, we want to gain the insight on how the oligarchy situation emerges in community energy system and influence the health and fairness in it.

What is the observed emergent pattern of interest to us?

Based on the case study of the cooperatives in Netherlands, the member usually accesses their right to vote for future policy and select the board at the member meetings. In that sense, there are some emergent patterns happened in community energy system as a consequence of the interaction of the member in the meeting.

First, there is the emergence of the leader among the member of the community energy system. It is shown by the establishment of the board through mostly voting procedure by the member. Second, there is the emergence of the institution where some rules are made and remade in this meeting.

Is there is a desired emergent pattern, and if so, how is it different from the observed emergent pattern?

In this project, the desired emergent pattern is the emergence of oligarchy. As mentioned before, this situation is shown by the stable domination of the minority in the organisation.

What is the initial hypothesis on how the emergent patterns emerge?

Our initial hypothesis is that because the institution in this system is dynamic and the member is heterogeneous in the endowment and motivation, the leaders can exercise their dominance, thus lead to the emergence of rules that benefit them more or stabilise their dominance even more. Thus, the oligarchy happens.

At the center of this, the action arena [7] is the place where the observed emergent pattern happens, affect each other, thus lead to the emergence of the desired patterns. In particular case, we are interested to look at the dynamic structure of the action arena that leads to the emergent patterns. In that sense, the action arena in the community energy system is the general assembly where the members gather to discuss, vote for the leader, and decide the future policies or regulations.

5.2. System Identification

This section aims to convert the model input section 4.4 into the main concept of ABM. Then, the concept will be formalised into the model dynamic.

5.2.1. Main Concept

The model aims to conceptualise the community energy system, which is taken from several case studies of the cooperatives in Netherlands. There are four main concepts in the model: (1) the agents, (2) the board, (3) the institution, and (4) the action arena. The big picture of this system is illustrated in Figure 5.1, which is adapted from the IAD framework.

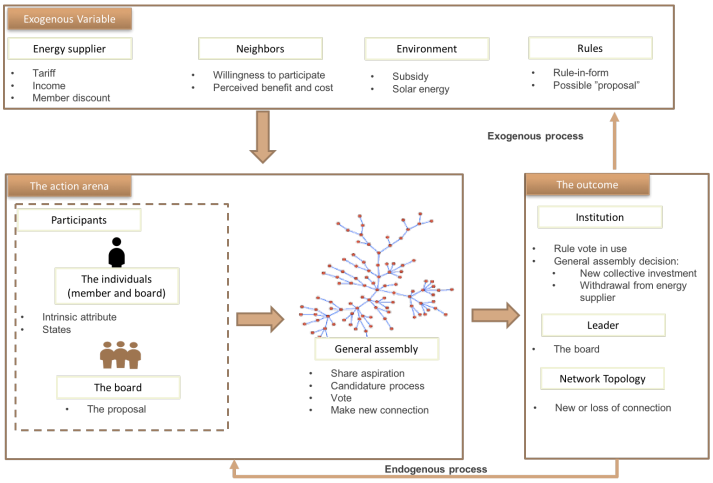

Figure 5.1: The big picture of the model. Adapted from IAD framework [7]

Agents

There are three agents in the model: (1) the cooperatives, (2) the energy suppliers, and (3) the neighbours.However, the agent in this section refers to the cooperatives, which is the main agent in this model.

The agents are all cooperatives member in the model, which are connected in a scale-free network. This network is dynamic, in which the agent can make a new connection based on the preferential attachment. A subset of the member is the board, which represents the leader of the cooperatives.

The agents are heterogeneous in education, time availability, initial electricity consumption, initial balance, initial number of connection, yearly income, environmental concern, and energy independence. We will call those are the intrinsic attribute of the agent because those variables will not be changed during the simulation.

On the other hand, the agents have several states that are changing during the simulation. The states of the agent manifest in the value of their community trust, willingness to participate, power, investment, electricity consumption and balance.

Boards emerge and propose the change of the governing institution

Since the agents are heterogeneous, some agents are more prototypical and more socially-attractive than the others. The prototypically and social attractiveness are evaluated based on agent's **intrinsic attribute** (education) and agent's **state** (number of connection, investment, willingness to participate).

Also, to be a candidate, there is a hard constraint, which is the time availability of an agent. Even the most prototypical and socially attractive agent might not be a candidate if they do not have enough time availability. Thus, some of the agents will opt to be a candidate for the board. This will be called

Intrinsic Attribute	State
Education	Willingness to participate
Time availability	Community trust
Initial electricity consumption	Investment
Initial balance	Number of connection
Initial number of connection	Power
Yearly income	Electricity consumption
Environment concern	Balance
Energy independence	Individual aspiration
	Collective aspiration

Table 5.1: Agent's attribute

candidature process, which represents the self-categorisation and the social-attraction process by Hogg et al. [31]

Then, the agents will vote for the favourite candidates as a board. This favourability is based on whether the candidates are in their connection list or whether they have the same individual aspiration or not.

The board is an emergent phenomenon. It is because the process of an agent becomes a board is, not only influenced by the individual's intrinsic attribute, but also the state of the agent. The state of the agent cannot be predicted since it is born as a consequence of the outcome of the exogenous and endogenous process in the action arena. Thus, the establishment of the board can be seen as an emergent behaviour.

After the board is established, based on the individual evaluation of each board members, the proposal of new institution will be determined by majority voting. The proposal of the new institution is limited into two: (1) the cooperatives make a new investment of the electricity generation (*shared strategy*), (2) the cooperatives must withdraw their cooperation with energy supplier (*rules*). The result will be called as ***"what-to-vote case"***. It can be option 1, option 2, both or neither of both. The proposal will be brought to the general assembly to be voted for. So, the proposal contains only the idea from the board, for example, it does not propose the capacity of the new investment in electricity generation, this will be decided in general assembly.

In this case, the institution is quite static and limited. It reflects from the case studies of type 1 cooperatives that mostly the general assembly decides this two things. It also aims to scope down the complexity of the model, since the outcome not only will directly affect the action arena, but also the exogenous variable. Limiting the institution option will reduce the complexity in modelling the consequences of those institutions from the endogenous and exogenous process. Thus, the emergence of the institution can be seen as the emergence of rule-in-form into rule-in-use.

Agents determine their individual aspiration

The outcome of the action arena will be evaluated based on the evaluative criteria. The evaluative criteria in this model are the perceived benefit and cost. The outcome is defined as the difference between the benefit and the cost. **This outcome of the action arena will affect the state of the agents mentioned before**.

Then, based on their intrinsic attribute and their states, the agents will determine their individual aspiration. This individual aspiration contains whether they support the proposal from the board or not.

For example, if the board proposes to make a new investment in electricity generation (option 1), each member will evaluate whether they have enough balance to pay one share of the collective investment and whether they have enough willingness-to-participate more or equal to the investment threshold. If so, they will vote for the proposal as their individual aspiration.

If the board proposes to withdraw the cooperation with the energy supplier (option 2), each member will evaluate whether their profit from the cooperation with energy supplier lower than the threshold. If so, they will vote for the proposal as their individual aspiration.

Action arena produces outcome that change the state of an agent

The focal point of IAD framework is the action arena. Here, the action arena is the general assembly, where the agents interact. There are three main things that happen in this action arena: (1) the agents influence each other's aspirations, (2) the agents vote for leader and institution (the rule-in-use), and (3) the agents add new connection if they attend this action arena.

First, the sharing aspiration among the agents is when the power plays. The power to influence depends on the **intrinsic attribute** of the agent (education) and the **state** of the agent (number of connection, balance, willingness to participate).

In this process, an agent that has the power lower than the power of the board at a particular time will be influenced. This particular agent is called **the follower**. The follower will copy individual aspiration of another agent *in the connection list and in their neighbourhood*, that has the most power and the power is more than themselves, no matter their position as a board or not. Thus, the follower is not programmed to copy the aspiration from the board directly.

The mechanism of the sharing aspiration also enables the model to produce **the contender** for the leader. The contender is the powerful agent that has never be a board, but has a high influence on the community and has different aspiration from the board. The aspiration resulted from this process is called collective aspiration

Second, the agents vote in the general assembly. There are two options of voting procedure, the 50%+1 and the 2/3. The choice depends on whether the quorum (2/3 of the member attend the general assembly) is satisfied or not. It is assumed that the member cannot vote by proxy. The member will vote whether they accept the proposal from the board and the upcoming board.

Third, when an agent attends the general assembly, its number of connection increases. The agent will get one additional connection every time they attend the general assembly using the preferential attachment rule. Here, the agent connects randomly with another agent that has more connection.

Thus, there are three main outcomes of this action arena: **(1) the institution** (general assembly decision), **(2) the chosen board**, **(3) the change of network topology**. Those outcomes will affect directly to action arena (endogenous process) and the exogenous variable (exogenous process).

Since the general assembly decision and the board are a consequence of the interaction of the agents (sharing aspiration and vote), it can be claimed that the action arena is the place where the emergence of institution and leader happen.

5.2.2. Model Dynamic

The model conceptualisation provides the baseline to build the model, which is shown in Figure 5.1. Then, those concepts need to be arranged so that it can model and simulate the dynamic of CES. In general, those concepts are translated into flow chart in Figure 5.2.

It starts with the initial condition, where there is no leader, institutional free, and scale-free network structure among agents. Then, the agents' attribute and initial state are initialised.

The general assembly is assumed to happen in every tick. So, every tick, the agent will evaluate the outcome of the general assembly and update its state. After that, the board will determine the proposal for institutional change. This proposal will be evaluated by every member of the cooperatives and results on the individual aspiration of the agents.

Then, the agent will check whether they are *followers* or not. If they are, then their aspiration will be influenced by the more powerful agent. Thus, there is a possibility that its collective aspiration is different with its individual aspiration. The collective aspiration will be stored as a list to be voted in the general assembly. Worth to be noted that the collective aspiration list only contains the aspiration of the agent that opts to attend the assembly.

After that, the agent will be questioned whether it satisfies the requirement to be a board. If it is the case, then it will be a candidate that will be voted in the general assembly. Then, the voting will result in the possible new institution and the chosen board, which will be implemented by the agent.

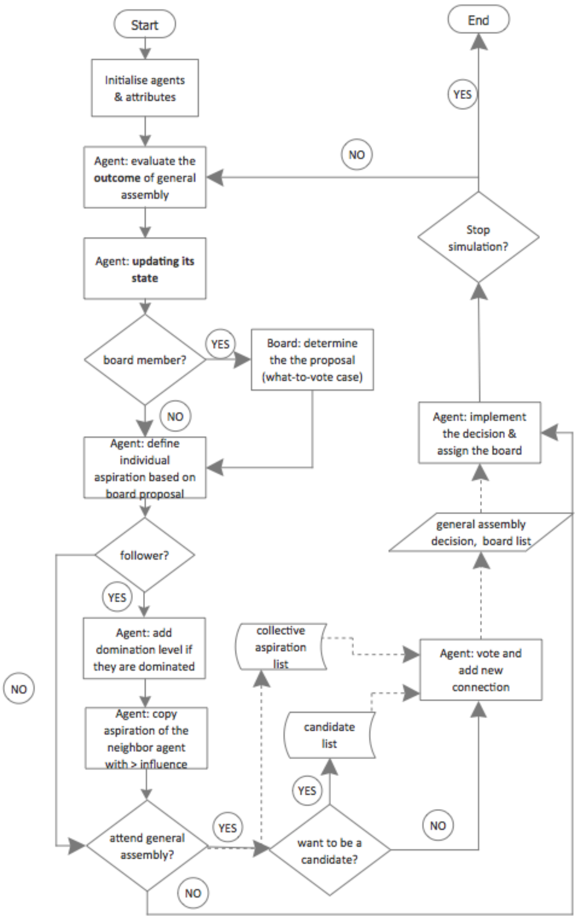

Figure 5.2: Model dynamic

5.3. Core Definition

This section aims to translate the core definition from the theoretical background into the model. By doing so, the concept can be formalised, and several hypotheses can be constructed.

5.3.1. The Emergence of Oligarchy

The oligarchy

To evaluate whether the oligarchy emerges in the system and to what extent, first we have to look back on the definition of oligarchy. Theoretically, the oligarchy situation is defined as the stable domination of the elected over the elector. Thus, four main things have to be defined in the model to detect the oligarchy when it happens:

- The Elected

The elected in this context is a group of the agent who has ever elected as a board. This group will be called the minority group.

- The Elector

The elector in this context is the majority group, which is a group of the agent that has never become a board.

- Stable

The stable part is defined as how often anyone in the minority group has been elected to a board. The more often the agent in this minority group is being elected, indicates the stability of the leadership from this minority group. For example, agent one is elected to be a board at the particular tick. Then, agent 1 will be included in the minority group, and its size will be increased by 0.5. Then, the elected level will be calculated as the average size of the people in the minority group, divided by 0.5, no matter they are the new board or ever been elected before. It will give the system perspective for the overall stability of this minority group.

Moreover, the minority group will be evaluated by its collective aspiration (there is only one minority group). So there is a possibility that there are some different aspirations in this group that decrease its group unity, thus decrease its stability. The less number of minority group indicates the overall stability of this group.

- Domination

The domination part is where the exercise of power comes along. It indicates how strong the minority group exercises its power. It can be measured by checking whether an agent will copy the aspiration from the minority group or not before the sharing aspiration happens.

As mentioned before, the agents interact in a scale-free network topology. Thus, the domination here counts only the direct domination by the elected, which only happens when the agent has anyone in the minority group in its connection list.

- The Oligarchy

From the definitions mentioned before, the oligarchy can be formulated as such:

Oligarchy = Stable (elected level of minority group * 1 / number of minority group) * Domination (minority group over the elector)

The emergence

As aforementioned, the main interest of the model is to see the emergence of oligarchy in community energy system. Therefore, the desired system behaviour in the model is the emergent behaviour of stable domination of the minority group. Whenever there is an indication of stable domination of the minority, then it can be concluded that the oligarchy emerges.

The emergent behaviour is the behavioural phenomena that cannot be deconstructed solely in terms of the individual agent [56]. It is known as the consequences of the interaction of the agents in the system [8].

First, the existence of board is a phenomenon of the emergence of leadership. Thus, which agent is chosen as the board and how often it is eventually chosen, which is the representative of the stable part of the oligarchy, cannot be deconstructed in terms of individual agent and it happens as a consequence of agent's interaction in the action arena.

Also, the number of minority group and how powerful they are to dominate is a behavioural phenomenon that has no centralised control and yet behaves cohesively as a group [11].

Second, the domination of the minority group is unpredictable from the agent level. It is because the way the agent makes a new connection is random with a preferential attachment mechanism. So, the agent is not programmed to be connected with the minority group, even though the minority group might have many numbers of connections.

Moreover, the way agent is located randomly assigned. Thus, the agent will not always be able to copy the influence from the minority group directly. Also, the power of the agent is dynamically changing as a consequence of the outcome of the endogenous and exogenous process in the action arena. Thus it cannot be predicted from the individual agent.

Since the formalisation of the oligarchy conveys the character of the emergent behaviour, it can be said that the oligarchy value in this model will be able to detect the emergence of oligarchy.

Adaptability of the oligarch

Then, the next question is how the minority group adapts to shock, for example when they realise that the oligarchy value in the system drop to zero, thus they lose their ability to dominate. This is an important question because this adaptive response is a crucial element that makes the agent, in this case, the minority group, can evolve.

Markus et al. [57] gather qualitative evidence of individual Ukrainian oligarchs, which focus on the wealth of the oligarchs (e.g., the wealth origin, business wealth, and amount of wealth) and analyse which strategies that increase the adaptability of the oligarch to the shock. The strategies considered are the direct and indirect strategy. It results that the indirect strategies give better adaptability to shock. These indirect strategies consist of party finance and media ownership.

Using this analogy, we can assume that the minority group will use the indirect strategy as the adaptive response when the oligarchy level drops to zero. Indeed, there are no such things like party finance and media ownership found in the CES' case studies, but the essence of media ownership is about the propaganda coverage, which is a key asset in political struggle [57].

In this model, this propaganda coverage strategy can be applied by increasing the coverage of minority group's influence. Initially, the propaganda coverage will be 0. If the shock happens (when the oligarchy value drops to zero), it is assumed that the board can increase its propaganda coverage range by 10%. This propaganda coverage will increase its power to influence.

5.3.2. The health of the community energy system

The health of the community is defined as the ability of a community to adapt to the change and adjust the institutional structure. Pepperdine states several factors that contribute to the health of community such as "cohesion, community mindedness, neighbourliness, accepting different points of view (ideas and newcomers), community support groups and communication networks" (cited in [6, p.2728]).

In this case, there are only two factors that will be analysed further as the representative of healthy community factors, which are the community cohesion and the community mindedness. Thus, the health of the community is defined as:

$$\text{Health of the community} = \text{community cohesion} + \text{community mindedness}$$

Community cohesion

Cohesion is defined as "the ability to cooperate and work together through **decision making** and **leadership**, as a function of **a unified community**" (Pepperdine cited in [58, p.58]). There are three important notions in the definition that need to be translated into the model: (1) the decision making, (2) the leadership, (3) the unified community.

First, the *decision making* in the community happens in the general assembly, where the decisions are taken based on voting. Second, the *leadership* manifests in the process of determining the proposal brought to the general assembly. Thus, the *unified community* can be evaluated when the proposal brought by the board leads to the decision in the general assembly.

However, the minority group can exercise power to influence the aspiration of the follower, which can lead to the agreement of the follower to the board's proposal, *especially when there is only one minority group,* so the cohesiveness preserves.

Nevertheless, the contender may exist in the system. Their existence can cause the difficulty for the minority group to exercise power. Thus the cohesion will be harder to achieve. It is aligned with the argument from Hogg et al. [31] that the exercise of power by the leader is more likely to emerge when the group is more cohesive and homogeneous (less contender exists)

Thus, we can construct a hypothesis that the community cohesiveness is influenced by the strength of oligarchy and the existence of the contender in the system negatively correlates with the strength of oligarchy.

Community mindedness

The community mindedness is the willingness of the community member to invest resources (**time**, skills, and **money**) and has **an active participation**.

First, the willingness of community member to invest in time and have active participation can be valued from the attendance of the community member.

Second, the willingness to invest money can be evaluated from the average investment in **collective** electricity generation. The higher the value means, the more willing the community member to invest in collective electricity generation.

On the other hand, measuring the investment of skill is not possible, since the skill is represented by the education value, which the value is static in the model.

5.3.3. The fairness of the community energy system

The fairness is a focal point that influences the legitimacy of the process or the outcome from the interaction of community member. In this definition, the fairness is approached using the **procedural perspective** and the **distributive perspective**. The (perceived fairness) is embedded in the community trust value of an agent. It is because when the people **perceived fairness**, they are more likely to **trust and accept** the decisions resulting from the process, and the institution that makes the decisions [6].

From the procedural perspective, the fairness is perceived based on the existence of secrecy and the sufficiency community discussion. The quorum in this model can be an indication of the sufficiency community discussion. The 2/3 attendance rule (the quorum) is a common rule that has been applied in many voting procedures (e.g., UN general assembly).

Thus, it is assumed that this quorum is the indicator of the sufficient discussion. Moreover, the perceived secrecy can be increased as the agent is not involved in the process decision-making, which happens in the general assembly.

From the distributive perspective, the fairness is influenced by whether the outcome favours to a particular group or not. Therefore, the more agent perceives the discrepancy of the outcome; its perceived fairness gets lower.

The combined effect of from the procedural perspective and the distributive perspective creates the perceived fairness of an agent, which is represented by the community trust value of an agent. As a consequence, the fairness of the community can be evaluated by extracting the average community trust value of the agent in the system.

The interesting point is that the definition of community cohesion and mindedness seem related to the fairness. This notion is also argued by [58] that some factors in the health of the community can easily be seen to relate to justice or pro social issues (e.g., cohesion and community mindedness).

Therefore, a hypothesis can be constructed that there is a positive, strong correlation between the fairness and the health of the community.

5.4. System Decomposition

After the problem has been formulated and the system is identified, the next step is to decompose the system. In this step, the aim is to decompose the internal structure of the system.

As aforementioned, the initial hypothesis is that the action arena [7] is the place where the observed emergent patterns happen, affect each other, thus lead to the emergence of the desired patterns. In this case, the action arena is the general assembly where the institution and leader emerges. Thus, the system identification and decomposition will focus on identifying and decompose this action arena. The IAD framework of Ostrom [7] will be used to structure this process.

First, the exogenous variables will be identified. It consists of the biophysical world where the system is placed, the attribute of the community, and the rules. Then, we will describe the structure of action arena which consists of the participants, the action situation. After that, the interaction and the evaluative criteria will be formulated.

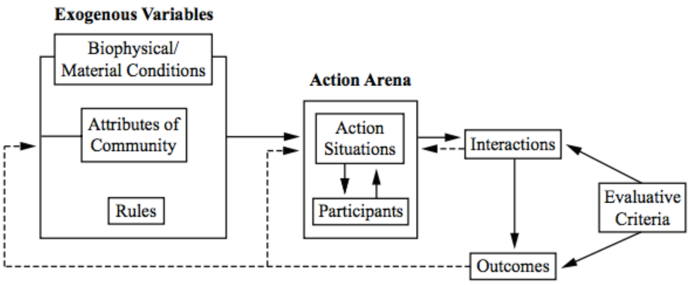

Figure 5.3: The IAD Framework. *Source:* Ostrom [7]

Here, the assumptions have to be made to formalise several concepts that ill-defined from the theoretical background or the case studies. The complete documentation of the assumptions can be found in Appendix A

5.4.1. Biophysical World

There are several external entities that influence the cooperatives. First, there is an **energy supplier** that manages the operation of electricity distribution within the cooperatives. The energy supplier receives energy generated by the cooperative and sells it to the electricity market at market price. The member of cooperative will only pay the electricity bill as the offset of electricity consumption and generation at fixed tariff (€/kWh). The energy supplier can opt to give member discount for a period of time. Moreover, they can increase the tariff if their income is equal or less than 0.

Second, reflecting the real CES that can recruit the new member, this 'potential' member is called the **neighbours**. The neighbours are located surrounding the cooperative but not part of the cooperatives. They will check on the profitability of cooperative membership from the members of cooperative that are located close to them. If it results that becoming a member is profitable (benefit > cost) and they have enough willingness to participate, then they will become the member of the cooperative.

Moreover, the technology incorporated in this model is **assumed** to cover only one type of energy generation technology, which is **solar energy**. The member of cooperatives can invest on those technologies collectively or privately and feed the electricity generated to the energy supplier. Then, the energy supplier calculates the subset of each member's energy consumption and energy generation and put it into their energy bill.

Moreover, the current community energy system is mostly incentivised by government policies, such as postcodeeros in Netherlands or FIT scheme in Germany. Thus, this **subsidy** scheme will be assumed as one of the external factors that influence the cooperatives through the deduction of the final energy bill that the member of cooperative pays. The summary of the biophysical world of this model is given in Figure 5.5.

5.4.2. Attribute of community

The cooperatives consist of the member and the board that actively participate and contribute to this community. Thus, the **willingness to participate** to this cooperative is one of key important feature

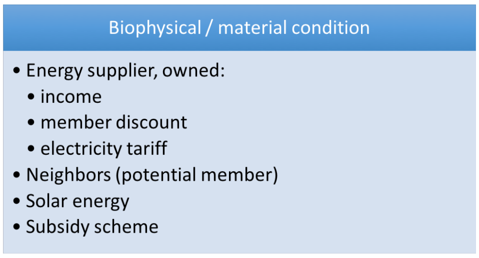

Figure 5.4: Biophysical world

that defines the community energy system. In this case, we will use the formulation of willingness to participate in ICES by Binod et al. [39]. Here, the willingness-to-participate in cooperatives is resulted from (a) community trust, (b) environment concern, (c) energy independence, (d) education. The prediction model that will be used for obtaining the willingness to participate shown in Equation 6.1 [39]. This equation uses the standardised coefficient.

$$willingness - to - participate = 0,307 + 0,271 * a + 0,147 * b + 0,158 * c + +0,117 * d \quad (5.1)$$

In this model, the dynamic factor that influences the willingness to participate is the **community trust**. As mentioned by Lind et al. (cited in Gross [6][p. 2730]), "people who feel that they have been treated fairly are more likely to accept the decisions resulting from the process and trust the institution that making the decisions". Thus, the community trust will be the variable that reflects the perceived fairness of the agent.

This model will approach the perceived of fairness using the distributive and procedural justice perspective. From the distributive perspective, the fairness perception is mainly influenced by whether there is outcome favourably to a certain group of the member or not [6]. Therefore, in this model, the community trust of an agent gets lower as the person perceives more discrepancy in the outcome from their social connection.

From the procedural perspective, the fairness perception is mainly influence by the existence of secrecy and insufficient community discussion [6]. As a consequence, the quorum represents the sufficiency of community discussion, and the attendance of a member represents the secrecy part. Thus, the community trust will get lower when the quorum is not satisfied, and it gets higher as the member attends the general meeting. The representation of this is shown in Figure 5.6.

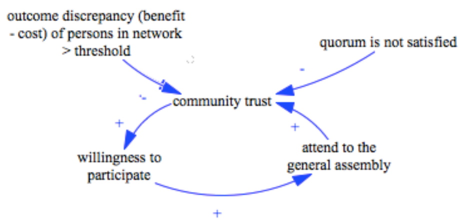

Figure 5.5: The community trust relationship

Moreover, the survey [39] also reveals that the willingness to invest and volunteer in ICES are positively correlated with the willingness to participate. The willingness to invest will influence whether the members want to invest collectively or privately and the willingness to volunteer will affect whether the members want to be a board. However, the survey only proves that there is a positive correlation. Thus, we assume that the willingness to invest and volunteer can be represented by the willingness to participate value.

Furthermore, the key attribute of the community is **the heterogeneous population**. Here, the cooperative consists of the board and the member. Each of them will have heterogeneity of endowment (skill, money, and time), electricity consumption, and number connection. The electricity consumption is assumed to follow the normal distribution.

On the other hand, reflecting the cooperatives, the electricity generated from the collective investment of solar energy will be distributed based on individual's share. Also, the number social connection of cooperative's member will be heterogeneous, which will be distributed based on the exponential distribution.

Additionally, there will be **imperfect information** introduced in the model. Here, the board will know better about some information in the community than the member. This imperfect information will affect how the agent "perceived" the outcome of the action arena. The summary of community attribute is shown in Figure 5.7.

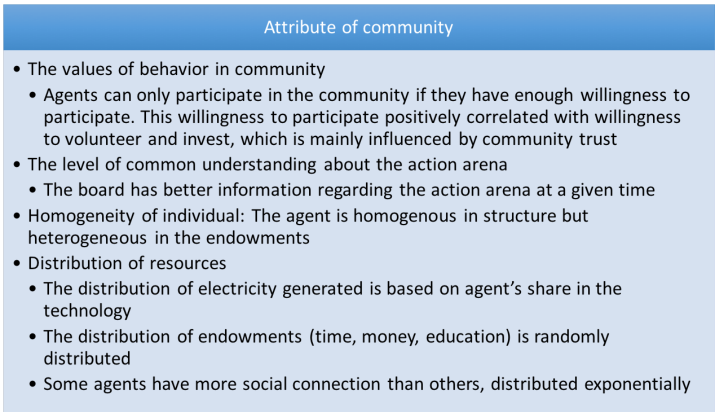

Figure 5.6: Attribute of Community

5.4.3. The Rules

The rules in IAD context defines the play of the game in the framework. The literature review mentioned before explains seven types of rules in this framework. Here, we identify the rules that play a role in this system. The summary of the rules is shown in Figure 5.8.

Reflecting the general description of CES, the cooperative consists of people that have enough willingness to participate in the community. They have equally one vote, and it is **assumed** that they have to attend to the general assembly to be able to use this right **(they cannot vote by proxy)**.

Each agent in the cooperative has the authority to define their individual aspiration. However, this aspiration can be changed as the agent influences each other in the network. Meanwhile, **the board has more authority than the member** since they hold the leadership and management position. They can determine on what the general assembly will vote for, which will be called *"what-to-vote"* case. This case can be either the proposal for new investment or withdrawal from the energy supplier.

Regarding the information rules, **the coverage** value aims to describe the information spreadability in the community. The information contained in this case is, (1) **the outcome** (perceived benefit - cost of) the agent and (2) **the individual aspiration of the agent**. The coverage value will influence how far the agent can "see" the outcome discrepancy and how big the neighbourhood in sharing aspiration context.

Moreover, the investment in energy generation either by collective or private will increase the generation capacity of an agent, which will impact on the electricity bill that the agent pays, so affect their balance. This balance will also be affected by the current income (c.income) that the agent receives every tick. This income is assumed to be distributed using the normal distribution.

5.4.4. Action Situation

Action situation is the place where the agents interact. The action situation, in this case, is the general assembly of the cooperatives. The participant of this general assembly is the active board and the member who opt to attend the general assembly. In this place, the agents are connected by their social network. This social network is represented using the scale-free network structure. This network structure is subject to change as the new nodes can be added if there is a new member and new link emerges since the agent tries to socially connect with their surrounding.

The important rules for this network dynamic are **the creation of a new link**. The creation of a

Rules

- Position rules : the agents can be member or board
- Boundary rules:
  - The agents can be member of the cooperatives as long as the have enough willingness to participate and the benefit more than the cost
  - The member can vote as long as they attend the general assembly
  - The additional new member is limited to certain number at given time
- Authority rules:
  - The agents define their individual aspiration on their own
  - The board can define what-to-vote for the next general assembly
- Aggregation rules
  - Total energy generated by the community determine the profitability of the energy supplier
  - Decisions on general assembly can be reached through voting procedure
- Scope rules
  - If the member has willingness to participate below certain threshold and they do not perceived the cooperative is profitable, the agents die (they withdraw their membership)
  - If the general assembly decides to go out from energy supplier, the energy supplier dies
- Information rules
  - The agents can evaluate the discrepancy of outcome (benefit-cost) from only % coverage of agent in their social connection by seeing their perceived benefit and cost. This discrepancy of outcome will influence the community trust
  - The board has better information than the member regarding the market price and investment in the community
- Payoff rules
  - If the agents choose to invest, their energy generation capacity increases, thus lead to lower electricity bill
  - The agents receive an income that increase their balance

Figure 5.7: The Rules

new link happens when the agent attends the general assembly and create a new connection using the preferential attachment rule [35]. The agent will find any agents that have more connection than themselves and connect to one of them randomly. If the agent chooses not to attend the general assembly, their number connection stays the same.

Through this network, **the agents share their aspiration, influence each other, and vote**. In the end, the decision of the general assembly is something that emerges from the interaction of the agents, since no single agent can steer the decision of general assembly. The valid decision in the general assembly is taken based two procedures. Based on the majority voting (50% + 1) if the quorum (at least 2/3 of the total member attend the meeting) is satisfied, and if the quorum is not satisfied, then the decision is taken based on majority voting with minimum 2/3 present member vote in favour. It is assumed that the member of cooperatives cannot vote by proxy.

The potential outcomes of this action situation are the general assembly decision. Since the board has the authority to decide the what-to-vote case in the general assembly, the general assembly decisions depend on this board decision. The member can vote for several things, which can be a new collective investment in solar energy, give salary to the next board, and go out from the energy supplier.

Also, one of the potential outcomes is the chosen leader of the cooperatives, which consists of maximum three agents from the member. The board can be re-elected for the next period. Those outcomes aim to represent two observed emergent behaviour mentioned before, which are (1) the emergence of the institution and (2) the emergence of the leader. Moreover, the authority rules of the board to determine what-to-vote in general assembly enables the model to test the hypothesis of the emergence of the oligarchy that is led by the emergence of leader and institution.

In this action situation, the agents will have information on the final decision of the general assembly, the voting rule that active in the particular period, and the selected board. The cost and benefit assigned to action and outcome are called perceived cost and benefit because there is imperfect information plays a role in determining the value of it. We will assume that the perceived benefit and cost will have a value between 0 and 1. The detail about perceived benefit and cost will be explained further in evaluative criteria section.

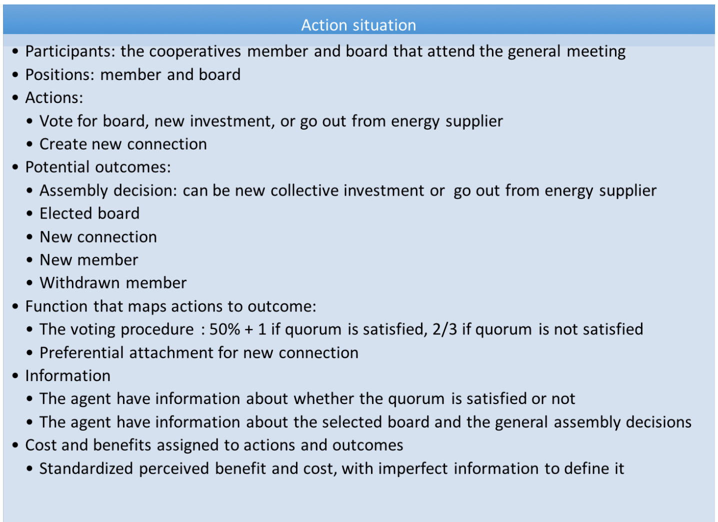

Figure 5.8: Action Situation

5.4.5. Actors/ Participants

The actors in this action arena are the member and the board of cooperatives. Each of them will have individual preferences. **First, the agent will choose whether they want to be the candidate or not**. This candidature process represents the self-categorical and social attraction of the leader [31]. The process of self-categorical is the process to construct the perceived prototypicality, so that some people are more prototypical than others [31]. In that sense, the member of the cooperative will measure how prototypical they are to the community by assessing whether they have the willingness-to-participate, the education, and the investment more or equal with the average people in the community.

The process of social attraction is described by assessing the number connection of an agent. If the agent has number connection equal or more than the Pareto of number connection of the community, the agent has the more social attraction. This Pareto number represents 20% of highest connection in the community. If in the end, there are less than 3 persons in the candidate list, the member can opt to give salary to next board if they have the balance to afford it, so the attractiveness to be a board seems to increase.

Second, they will choose the leader that they will vote for. This process represents the attribution process of the leader [31]. In this case, the member of cooperative will prefer the leader that has similar aspiration and is connected to them in social connection. As a consequence, the experience level of the elected board will increase. This experience is represented by the size of the agent. The bigger the size of the agent means they have been (re-)elected to the board for many times, thus the experience increases. If there is no consensus achieved through this vote, the board will be selected based on the experience as the board. The cooperatives will assess the average board's size to measure the experience level needed to lead this community. Then, they will select the individual that has experience level equal or more than this level. If there is still no one that satisfies this condition, the community will select the individual that has been at least elected one time as a board.

Third, they prefer to create a new connection with who has more connection than themselves randomly in the general assembly. Moreover, the agents will have different individual information processing capability depending on their position as the board or member. The board will have better information regarding the market price of electricity and the investment in the community than the member. This imperfect information will affect how they evaluate the outcome of general assembly decision. This outcome is defined as the difference between perceived benefit and perceived cost (benefit - cost).

Furthermore, each agent will have **individual selection criteria on how they define their individual aspiration**. This individual aspiration depends on the "what-to-vote" case decided by the board. If the board propose for new investment, the member of cooperative will assess whether they want to invest and whether they invest individually or collectively. If the board propose for go out from an energy supplier, the member can assess whether it is profitable to go out or not by evaluating the (perceived) reduced bill. This reduced bill is defined as the gap between the tariff that the supplier gives and the market price. If it is higher than a certain threshold, then they will opt to go out from the energy supplier. As mentioned before, due to the imperfect information, the value of the market price will differ for each agent.

Also, depending on the willingness-to-participate and the time availability, **the agent can select to attend the general assembly or not**. If the member of cooperatives has the willingness-to-participate more than a certain threshold and they have time to attend, then they will select to attend. The aggregate of this attendance will affect whether the quorum of the general assembly will be satisfied or not.

The member and board of cooperative also have **individual resource regarding money, time availability and the investment**. When they invest either collectively or individually, they will add capacity in their energy generation, thus can lower their electricity bill, while the electricity consumption will be increased each time. The additional of electricity consumption each tick will be assumed to be a certain percent of the initial electricity consumption and is distributed by normal distribution within the population of the cooperative.

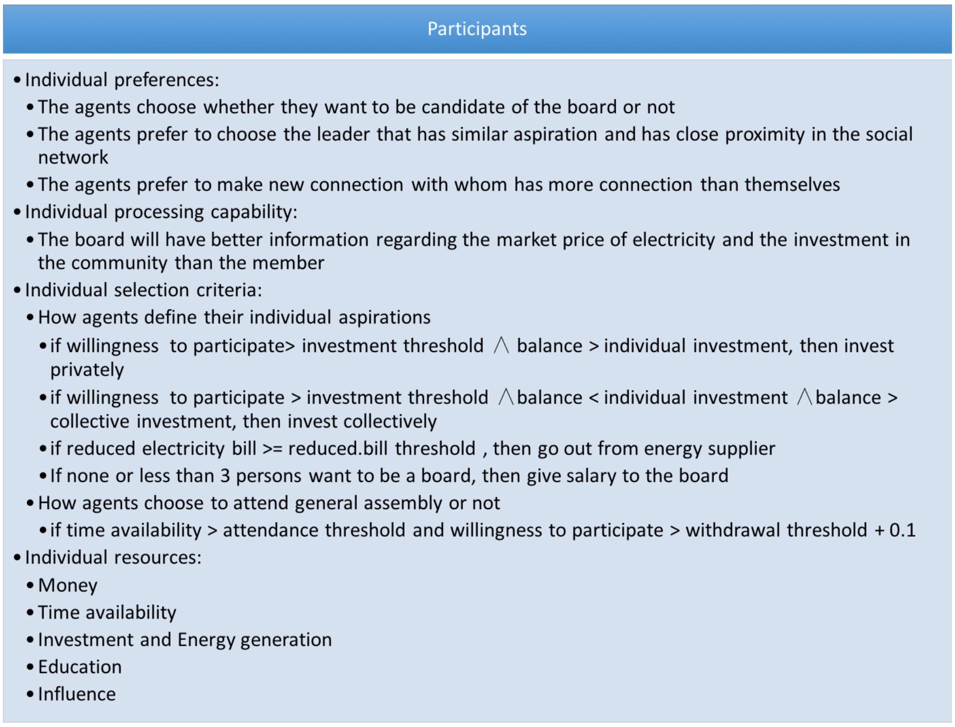

Figure 5.9: Participants

5.4.6. Interactions

As aforementioned, the agents interact in the social network. In this social network, the agents can influence each others' aspirations. The ability to influence reflects the "power" of each agent. As mentioned before by Michels [5], this power plays an important role for leadership in the complex organisation.

In this model, **the follower will copy the aspiration** of another agent in their connection if one of them has more influence than them and is located in its neighbourhood, otherwise, they will stick to their-own aspiration. If there is more than one agent in the connection that has more influence than them, the agent will choose the one that has the highest influence.

This influence depends on the willingness to participate, the education, the money, the number connection of an agent. The education reflects the skill power of an agent. The money reflects the financial power. The willingness to participate reflects the motivation or volunteering power, and the number of connection reflects the social attraction power.

5.4.7. Evaluative Criteria

As mentioned before, the evaluative criteria are used to judge the performance of the system [7]. Here, we will use institutional-choice framework for evaluating the system performance [4].

The agent will **evaluate the benefit and cost of current situation**. These ”perceived” cost and benefit represent the internal world of an agent. The result will affect the perceived profitability to be a member of the cooperative, and the outcome (benefit - cost) will affect the level of community trust of an agent.

The perceived benefit will be derived from (1) the benefit of their own investment (how much the agent pays with and without investment in solar energy), (2) the (perceived) reduced bill that they get from the cooperation with energy supplier compared with their peer, (3) the motivation benefit caused by their investment in solar energy, (4) the salary benefit if the agent is one of board member, and the cooperative decides to give salary to the board.

The perceived cost will be derived from (1) the cost of investment of an agent compared with their income, (2) the total cost of investment of an agent compared with their peer, (3) the time cost if the agent is one of the board member, (4) skill cost if the agent is one of the board members.

The outcome is defined as the difference between the perceived benefit and cost (benefit - cost). Later, the agent in the cooperative will evaluate and compare this outcome with their peer and result on their perceived outcome discrepancy in the community. As aforementioned in subsection 3.2.2, this outcome discrepancy will affect the community trust that an agent has. As a consequence, the willingness-to-participate will also be influenced by this outcome.

5.5. Model Assumption

The system decomposition points out some assumptions that have to be made to fill the missing component in IAD framework and to formalise it into the model. This section summarises those assumptions. The assumptions will be documented based on its place in the IAD framework.

Action Arena

It is assumed 1 tick = 1 year. It is assumed that there is only one general assembly per year.
Action Situation

1. Participant: initial cooperatives = 200 (Vallei Energie = 235 [46], De Ramplaan = 220 [40])
2. Actions:
   - It is assumed that the interaction between agent is structured in scale-free network, and limited to certain range of coverage. It is assumed that the coverage value represent the information spread-ability in the community
   - It is assumed that the member can only add new connection if they attend to the general assembly
   - There is no reduction of number connection if the agent chooses to not attend in general assembly meeting
3. Potential outcome:
   - Development policies: withdrawal from energy supplier
   - Collective investment: It is assumed that the member can only invest one share
   - Elected board
     - If the general assembly decides to give salary to the board, the salary is assumed to be 200 euro per board member
     - Work.hour of the board is assumed to be 6 hours/ week, taken from the actual work hour of the board in De Ramplaan Cooperatives [42]
     - Maximum number of the elected board is three agents
4. Function that maps actions to outcome:
   - The member uses preferential attachment function to add new connection at the general assembly
   - There are two voting procedures, which are 50+1 and 2/3, based on whether the quorum is satisfied or not. The quorum is assumed to 2/3 of the total member of the cooperatives [42]
5. Information: Since the board holds leadership and management positions, it is safe to assume that the board has better information
6. Cost and benefit assigned to action and outcome: It is called the perceived benefit and cost in the model. The outcome = perceived benefit – perceived cost

Participants

1. Individual preferences: The member prefers to choose a leader that has similar aspiration and located in their neighborhood
2. Individual processing capability: Since the board is assumed to have better information regarding the market price and the investment in the cooperatives
3. Individual selection criteria:
   - How they define the individual aspiration (see subsection 5.4.5)
   - How they select whether they want to attend to the general assembly or not (see subsection 5.4.5)

Exogenous Variable

Biophysical world

1. Energy supplier
   - The tariff is drawn from Qurrent energy tariff, which is 0.1903. The real.tariff represents kale inkooprijs in that table which is 0.035, and diff represent the fixed cost that needs to be paid (diff = tariff – real.tariff) [59]
   - The member discount is assumed to be 17.5 €/ year, drawn from the member discount given by Qurrent to De Ramplaan Cooperatives [54]
2. Technology: Only one type of energy generation is included in the model, which is solar energy

Attribute of community

1. The values of behaviour in the community:
   - The willingness to volunteer and willingness to invest can be represented by the willingness to participate value, since it has positive correlation [39]
2. Distribution of resource:
   - Distribution of money: c.income represents the yearly income of an agent aimed to pay their yearly electricity bill. It is assumed that this yearly income to be normally distributed with average of 1500 €/ year and standard deviation of 200€/ year [60] [p. 107]
   - Distribution of time availability: Time availability of each agent in cooperatives is assumed to be distributed normally with average 30 hours/week and standard deviation 10 hours/week. It is derived from the assumption that they have a full-time job in weekdays, and just want to allocate their free-time on the weekend to participate in ICES.
   - Distribution of initial electricity consumption: Initial electricity consumption per household is assumed to be normally distributed with 6570 kWh/year in average and 500 kWh/ year in standard deviation [60] [p.107].
   - Distribution of additional energy consumption: It is assumed that the electricity consumption grows at the same rate during the simulation. The rate is determined by a percentage of initial electricity consumption. The percentage is assumed to be normally distributed with mean = 0.2 and the standard deviation = 0.1 (add.e.consumption = random-normal 0.2 0.1 * e.consumption)
   - Distribution of education: Education is assumed as a categorical variable with an integer value between 1 – 4. It represents four levels education in demographic data of Netherlands (university degree, higher vocational education, secondary vocational education, and high school)
   - Distribution of initial number of connection: The distribution is based on exponential distribution to model the scale-free network [33]
3. Homogeneity of individuals: no clear statement from the case studies, but we can assume that the individuals are homogeneous in structure, but heterogeneous in resources (endowments)

The rules

1. Position rules: only member can be a board [42], [46]
2. Boundary rules:
   - The member of cooperatives cannot vote by proxy
   - The additional new member is limited to certain amount (10) at a given time
3. Scope rules:
   - If a member withdraws its membership, that particular agent cannot be a member again in the future

- If the general assembly decides to withdraw the cooperation with energy supplier, the energy supplier will die (they cannot make the collaboration again in the future)

4. Information rules: The board has better information than the member

5.6. Concept Formalisation

After the identification of the agents, their interaction and its interaction structure, it is time to formalise those concepts. There are two options for formalising the concepts, which are through software data structures and formal ontology [11]. Here, we will formalise using software data structures and sequence diagram.

5.6.1. Sequence Diagram

From the system identification and decomposition mentioned before, it can be concluded that there are three main agents, which are the cooperatives, the suppliers, and the neighbours. The sequence diagram explains the life line of each agent and observer in one tick from top to bottom. In this case, one tick represents one year. It is assumed that there is only one general assembly in one year.

Conceptually, there are five main things that the agents in the cooperatives do during one general assembly cycle. The agent implements decision of the general assembly, evaluate it, define the individual aspiration, the board analyses and decides the what-to-vote for next general assembly and the agents vote at general assembly. Those activities are translated into five main procedures in this model, which are implement-decision, evaluate-decision, what-to-vote, define-aspiration, vote and eot as the additional procedure, noted with larger font size in Figure 5.11.

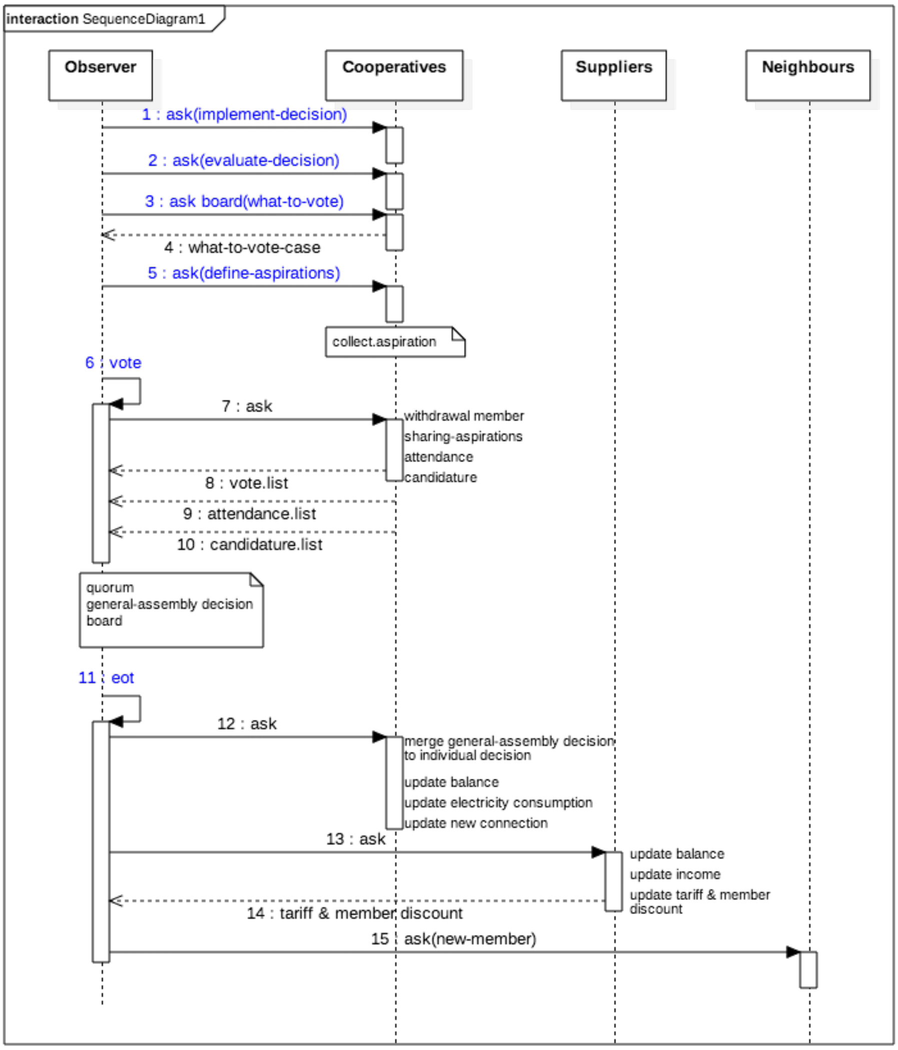

Figure 5.10: Sequence Diagram

In the implement decision procedure, the cooperative implement the general assembly and individual decision. The individual decision is the private investment decision and the general assembly decision can be collective investment, go out from energy supplier or give salary to the board decision. Depending on what was decided on the general assembly, the cooperative will run different procedure based on the decision. After they implement the decision, they will calculate the resulting electricity bill and update their total investment in electricity generation.

After the cooperative implement the decision, they will evaluate it based on the evaluative criteria mentioned before. In this case, they will calculate the perceived benefit and cost caused by the decision, thus the perceived outcome is obtained. Then, the cooperative will evaluate and compare this outcome with their peer, which results on the outcome discrepancy value. Together with the quorum and the attendance of the last general assembly, the community trust value is updated. This community trust then will influence the willingness-to-participate value of the agent.

After each agent in the cooperative evaluate the decision, it is time for the board to determine the ”what-to-vote” case. As aforementioned, this what-to-vote case can be a proposal for new electricity generation investment, or withdrawal from energy supplier, or both. This decision is taken by the majority voting of the board member.

Then, depending on what is decided by the board, the member of cooperatives will define their individual aspiration. If the proposal is to make new investment, the member will select whether they want collective investment or private investment or neither of them. This selection is based on their balance and their willingness-to-participate, which reflects the willingness-to-invest. If the proposal is to go out from energy supplier, the member can assess whether it is profitable to go out or not by evaluate the (perceived) reduced bill. If it is higher than certain threshold, then they will opt to go out from energy supplier.

Then, the vote procedure starts with the withdrawal of the membership. If the agent has the willingness-to-participate below certain threshold and the perceived outcome is negative, then they will withdraw the membership. After that, the cooperative will share and influenced each other aspirations. This sharing aspiration procedure results on the final collective aspiration of the agent that will be brought into voting.

Next, the cooperative chooses whether they want to attend to general assembly or not, resulting on the attendance list. This attendance list will impact on the voting procedure that will be run. If the quorum is satisfied, then the 50+1 procedure will be run, otherwise 2/3 procedure. The final collective aspiration of each agent will be aggregated and counted based on the voting procedure. Thus, it results on the general assembly decision if the condition is met.

The following procedure in the voting procedure is the candidature procedure. This procedure follows the candidature process mentioned before and results on the candidate list. The cooperatives then will select their favourite candidate to be a board based on the preferential criteria mentioned before. Then the majority choice of the cooperatives will become the board.

The final procedure in this model is the end-of-tick (eot) procedure. Basically, this procedure contains the update procedure for each agent in this model. This includes updating the membership of the cooperative, the connection for the cooperative that attend the general assembly and the tariff from energy supplier.

5.6.2. Software Data Structures

Starting with the concepts and the life line of each agents, we need to convert them into language primitives of NetLogo. NetLogo has 6 basic primitives, as follows:

- Numbers: both integer and floating points
- Strings: set of characters
- Boolean: true/false values in logic
- Turtles/patches/nodes/edges and breeds of them: (type of) agents
- Agent/patch sets: collections of agents and/or patches
- Lists: may contain any of the primitives

Thus, we will elaborate the attributes of each agent into NetLogo primitives, as shown below.

Cooperatives have:

- will.participate : floating point >= 0, <= 1
- board: integer 0 (not board member) or 1 (board member)
- e.consumption : floating points (in kWh/year)
- e.generation : floating points (in kWh/year)
- time.avail : floating points (in hour/week)
- education: integer >=1, <=4
- balance : floating points (in €)
- attendance: integer 0 (not attend), 1 (attend)
- influence: floating point >= 0, <= 1
- community.trust : floating point >= 0, <= 1
- env.concern : floating point >= 0, <= 1
- e.independence: floating point >= 0, <= 1
- investment: floating point (in €)
- perceived.cost: floating point >= 0, <= 1
- perceived.benefit: floating point >= 0, <= 1
- cb: floating point >= 0, <= 1
- reduced.bill : floating point >= 0, <= 1
- market.price : floating point (in €)
- outcome.discrepancy : floating point >= 0, <= 1
- decisions: list
- collect.aspiration: list
- investment.list : list
- connection.list : agent-set
- numb.connection: integer
- candidature: integer 0 (no), 1 (yes)
- e.bill : floating points
- invest.benefit : floating point >= 0, <= 1
- c.income : floating points
- this.year (investment this year) : floating points (in €)
- add.econsumption: floating points (in kWh/year)
- real.cost: floating point >= 0, <= 1
- real.benefit: floating point >= 0, <= 1
- real.cb: floating point >= 0, <= 1

Suppliers have:

- income : floating points
- balance.supp : floating points

Neighbours have:

- n.balance: floating points
- n.education: integer >=1, <=4
- n.time.avail: floating points (in hour/week)
- n.env.concern : floating point >= 0, <= 1
- n.community.trust: floating point >= 0, <= 1
- n.e.independence: floating point >= 0, <= 1
- n.will.participate: floating point >= 0, <= 1

The environment has:

- real.market.price: floating points
- total-investment: floating points (in €)
- total-e.generation: floating point (in kWh)
- total-e.consumption: floating point (in kWh)
- min-invest : floating points (in €)
- max.invest: floating points (in €)
- min-bill: floating point >= 0, <= 1
- max-bill: floating point >= 0, <= 1
- min-i.benefit: floating point >= 0, <= 1
- max-i.benefit: floating point >= 0, <= 1
- salary: floating point
- subsidy: floating point
- quorum: integer 0 (not satisfied), 1 (satisfied)
- no.supplier: integer 0 (no), 1 (yes)
- pareto: integer
- tariff: floating point
- member.discount: floating point
- majority: list
- voteboard.list: list
- rule.vote: list
- assembly.decision: list
- avg.participate: floating point

- diff: floating point
- real.tariff: floating point
- case: list
- case.0: anonymous procedure
- case.1: anonymous procedure
- case.2: anonymous procedure
- case.3: anonymous procedure
- case.4: anonymous procedure
- what-to-vote-case: list
- what.to.vote: list
- what-to-vote0: anonymous procedure
- what-to-vote1: anonymous procedure
- attendance.thres: floating point >= 1, <= 5
- investment.thres: floating point >= 0, <= 0.8
- reduced.bill.thres: floating point >= 0.001, <= 0.01
- withdrawal.thres: floating point >= 0, <= 0.5
- subsidy: floating point >= 0, <= 0.1
- discrepancy.thres: floating point >= 0, <= 1
- coverage: floating point >= 0.1, <= 1
- work.hour: integer

6
The Formalisation

This chapter introduces the formalisation of concepts identified before, up to the point the model is ready to be simulated. Chapter 6 covers step 4 to step 6 of Figure 1.1.

First, the concept will be translated into pseudo-code, presented in Appendix A. Then, the pseudo-code will be implemented in NetLogo (Appendix B). Last, the model will be verified to ensure we build things right.

6.1. Model Verification

This section aims to check whether we built the model right. First, the recording and tracking agent's behaviour testing will be performed. Second, we will perform single-agent verification checks, in which the behaviour of car owners is verified. Third, the model will be verified in minimal model interaction. The NetLogo model that is used for the verification (including the verification coding) can be found in Appendix C.

6.1.1. Recording and Tracking Agent's Behaviour

Since we are using many functions and anonymous procedure in the model, it is important to make sure that the input and the output of the particular function is correct and the code calls the correct procedure. First, we want to make sure that the input and the output of the function is correct. Here, we use print command in NetLogo to be able to track the input and output. For example, in "to-report cost" procedure, before it returns the final value of perceived.cost, the "print" command is added to be able to see the value processed in that procedure. The code is shown on Figure 4.1 and appendix B. It is done for every function in the model.

```
to-report cost [a b c] ;balance investment board
  ; my cost from inside factor
  ; what i invest compare with my balance
  let ori this.year / c.income

  ;my cost from outside factor
  let invest 0
  let time.cost 0
  let skill.cost 0
  let perception-min-invest 0
  let perception-max-invest 0
  set perception-min-invest min-invest * (1 + random-float 0.05 - random-float 0.05)
  set perception-max-invest max-invest * (1 + random-float 0.05 - random-float 0.05)
  print (word "min-invest" perception-min-invest "min-invest"  perception-max-invest)

  ;somehow i know better about my cost if im the board
  ifelse c = 1 [
    print (word self "im here")
    set invest max (list 0 (b - min-invest)) / max (list 1 (max-invest - min-invest)) ; how my cost of investment compared with others
    set time.cost work.hour / time.avail
    set skill.cost 1
  ][
    ;because the do not know others investment so the min and max is merely approximation
    set invest max (list 0 (b - perception-min-invest))/ max (list 1 (perception-max-invest - perception-min-invest))
    ;ifelse ticks != 0 [set time.cost 0.2] [set time.cost 0]
    set time.cost 0
    set skill.cost 0
  ]
  let total.cost max (list 0 ((ori + invest + time.cost + skill.cost) / 4))
  print (word "ori" ori "invest" invest "time.cost" time.cost "skill.cost" skill.cost)
  report total.cost
end
```

Figure 6.1: Code for recording and tracking agent's behaviour

Second, we have to make sure that the “to-implement-decision” runs the correct anonymous procedure. It is done by adding additional line procedure at the beginning of “to implement-decisions” procedure to print the “decisions” variable. Then, add additional line procedure on every case, print (word self ”im here” ”case.0”). Then, we can match the output of those additional procedure to make sure that the agent runs the correct case.

Third, the important procedure that needs to be traced is the voting procedure. Here, the “assembly.decision” variable has to return the decision that majority voted. It is done by add some code in “to vote.case0” and “to vote.case1” procedure. Here, we print the “rule.vote” variable and “assembly.decisions” at the end. From here, we can cross-check whether the input and the output match with the algorithm to determine the majority in each voting case.

Another important part of voting procedure is the voting for board member. The verification of this procedure is done by tracking the print out output from “voteboard.list” to the “majority”. Then check whether the agent in the majority changes the value of “board” variable into 1.

6.1.2. Single-Agent Testing

In order to properly explore the behaviour of agents, there are two fundamental tests that can be done [11]: (1) Theoretical predictions and sanity checks, and (2) Break the agent and extreme value test. Here, both tests will be performed towards the model.

Theoretical Predictions and Sanity Checks

The investment

- Invest if the agent has the willingness to participate more than the investment threshold. **Confirmed**
- Invest privately if the agent has enough balance to afford it, and store the output in “decisions” list. **Confirmed**
- Invest collectively if the agent has enough balance to afford it, and store the output in “collect.aspiration” list. **Confirmed**

Out from supplier

- Go out from supplier if the reduced.bill higher than the reduced.bill threshold. **Confirmed**

The attendance of general assembly

- The agent will attend the general assembly if the time availability more than the threshold, and the willingness to participate more than the threshold. **Confirmed**

Candidature

- The candidate is the one who satisfy the hard constraints which are the time availability, willingness to participate and number of connection, more than the threshold. Additionally, the need to be the one that has enough skill and investment in cooperatives. **Confirmed**

Break The Agent and Extreme Value Test

The investment

- The agent will not invest if they have 0 balance. **Confirmed**
- The agent will always invest individually and collectively if they have unlimited balance and the willingness to participate is above investment threshold. **Confirmed**

Energy Consumption

- If the energy consumption is 0, then the agent will keep be motivated to invest, as long as the willingness to participate is above investment threshold. **Error**: division by 0 in the calculation of benefit. **Fixed,confirmed**

- If the energy consumption is extremely high, then the agent will keep be motivated to invest as long as they have balance and the willingness to participate is above investment threshold. **Confirmed**

Number of connection

- The agent calculates the perceived outcome discrepancy from 10% of other agents in the connection list. **Error**: zero agent-set in connection.list, means the number of connection 0 . **Fixed, confirmed**: add condition if the connection.list is not zero and adjust the calculation of community trust based on this condition.

6.1.3. Interaction Testing in a Minimal Environment

Define what-to-vote

- If the board member has enough balance and willingness to participate, the agent will opt to propose new investment. **Confirmed**
- If the board member has perceived reduced bill more than the threshold, the agent will opt to propose to go out from energy supplier. **Confirmed**
- The resulting what-to-vote-case is the majority decision of the board. **Confirmed**

Define individual aspiration

- The agent will only consider the case that is given by the board (what-to-vote-case) with correct mapping.**Confirmed**

Share Aspirations

- The agent copies the aspiration of another agent in their connection.list that has the more influence compare to himself and others in his connection.list. **Error:** it returns to zero agent-set. Fixed by change "self" into "myself" in the code. **Confirmed**

Creating new connection

- The agent that attends the general assembly creates 1 new connection every tick with a random agent that has more number of connection and add that particular agent to the connection list and vice versa.**Confirmed**

Voting for the leader

- If there are less than 3 candidate and the agent has enough balance to afford salary of the board, the he will opt to give salary to the board by putting "3" to the collect.aspiration list. **Confirmed**
- The agent choose the candidate that has the same aspiration or in their connection.list and has education more than 2. **Confirmed**
- The candidate choose himself. **Confirmed**
- If there is no candidate that has the same aspiration or in their connection.list and has education more than 2, then the agent will pick random agent from the candidate.list. **Confirmed**
- The agent that become the board is the one that the majority vote for. **Error:** the length of majority.list is less than 3. Fixed by adding additional code if the majority.list less than 3. **Confirmed**
- The non-candidate has board value = 0. **Confirmed**
- The chosen board increase its size **Confirmed**

General assembly vote

- If the quorum is satisfied, it will run vote.case0, otherwise run vote.case1 **Confirmed**

- If the general assembly choose to implement decision ”2”, then the work.hour, no.supplier, tariff and member discount value will be changed and supplier dies. **Confirmed**
- If the general assembly choose to implement decision ”3”, then the salary value will be changed. **Confirmed**
- The assembly.decision is sorted from smallest to largest. **Confirmed**

III

Model Simulation

7
Experimentation

Once the model is implemented and verified, it is time to do the experiment for answering the problem defined before. To do that, the experiment needs to be designed appropriately. There are three main steps, the experiment design, the experiment strategy, and the experiment result, which will be described in following sections.

7.1. Experiment Design

The experimental design starts with determining the model hypothesis, then choosing the time frame, and determining the scenario space [11].

7.1.1. Model Hypothesis

The conceptualisation of the core definition has provided several hypotheses that can be tested (see section 5.3. In summary, those hypotheses are:

1. The iron law of **oligarchy**: the oligarchy will always emerge at least a point of time during the simulation in every experiment
2. The **heterogeneity in population** affect the oligarchy positively
3. The oligarchy correlates with the **community cohesiveness** positively
4. There is a positive correlation between **the fairness and the health of the community**

The core definitions mentioned before has to be formalised in the model to test those hypotheses. The formalisation from the concept to the model is summarised in Table 7.1

7.1.2. Scenario Space

The input parameter contains many parameters with uncertain value (e.g. the thresholds). Consequently, the parameter sweep experiment with a large number of experimental model runs to vary the combination of parameters is needed.

Firstly, we have to define the parameter of interest that need to be swept. In this case, the threshold in the model become one of the parameters of interest, with a quite predefined parameter space (standardized from 0 to 1). Table 7.2 shows the parameter and the parameter space of interest.

Definition	Concept	Formalisation
The Elected	a group of agent who has ever elected as a board	minority.group = cooperatives with [size > 0.5]
Reelected	how often the minority.group are elected	[size] of minority.group / 0,5
Number of minority group	number of minority group with different aspiration	length remove-duplicates [collect.aspiration] of minority.group
Domination	the moment when an agent copy aspiration from the minority.group	+1 if the conditions are true
Oligarchy	Stable * Domination	oligarchy = reelected * (1/numb.min.group) * domination
Adaptability of the oligarch	increasing the coverage of minority group's influence	if oligarchy = 0, then prop.coverage = min (1 prop.coverage + 0.1), update influence of minority.group
Community cohesiveness	decision making, leadership, unified community	if board proposal results on assembly decision, then cohesion +1
Community mindedness	willing to invest and active participation	mean [collect.invest] of cooperatives + mean [attendance] of cooperatives
The health of the community		health = community.cohesiveness + community.mindedness
The fairness of the community		fairness = community.trust

Table 7.1: The formalisation of core concept.

No.	Parameters	Parameters space	Indicator
1.	attendance.thres	1 - 5	attribute of community
2.	investment.thres	0 - 0.8	attribute of community
3.	reduced.bill.thres	0.001 - 0.01	attribute of community
4.	withdrawal.thres	0 - 0.5	attribute of community
5.	subsidy	0 - 0.1	biophysical world
6.	discrepancy.thres	0 - 1	attribute of community
7.	coverage	0.1 - 1	rules
8.	mean.initial.conn	5 - 30	biophysical world
9.	initial.balance.std	500 - 2000	heterogeneity of endowment
10.	c.income.std	100 - 500	heterogeneity of endowments
11.	std.econsumption	100 - 500	heterogeneity of endowments
12.	std.time.avail	1 - 10	heterogeneity of endowments
13.	std.education	1 - 2	heterogeneity of endowments

Table 7.2: Parameter Sweep

7.2. Experiment Strategy

The strategy design is about choosing a good balance between the number experiment, the repetition, and the time frame. It is a trade-off problem between the accuracy of the result and the computational cost.

First, it can be seen that now we have to deal with large parameter space that makes the full-factorial experiment impossible. Thus, **we need to sample the input parameter**.

There are many sampling techniques, such as random sampling, Monte Carlo, and Latin Hypercube Sampling. Since we deal with large parameter spaces with an unknown probability distribution, choosing the random sampling or the Monte Carlo method could lead to non-granular sample distribution.

Latin Hypercube Sampling is a way to deal with too large parameter spaces and still have a good granularity [61]. It is a statistical technique that allows us to ask: If we can afford X experiments in a Y dimensional parameter, where in the parameter space should we perform those experiments while guaranteeing uniform sampling of this space? [62].

Here, we have to determine how many experiments that we can afford. There are no firm rules found to determine this. However, there are some suggestions found. For example McKay et al. [63] suggest X = 2Y rule, while Manache et al. [64] suggest X = 3Y rule. Since this model includes many parameters with parameter space, large number experiment is needed.

Second, the golden rule of agent-based simulation is to **"never trust the outcome of a single run"** because every single run could be unrepresentative outlier [11]. Indeed the more repetition, the better, but the number of repetition has to be balanced with the practicability to finish the experiment.

Third, the next question is how long the run time needed to enable the emergence to appear. Since the one tick is equal to 1 year (**with assumption that the general assembly is held once per year**), **30 ticks** for one simulation run is long enough to explore the emergence of oligarchy

The process

Since the time frame is defined (*30 ticks*), we have to balance between reliable large sample (*number of experiment*) and reasonably long experiment (*repetition*). The simulation of the model takes 5 minutes for 100 runs. Thus, we will follow this following strategy, depicted in Figure 7.1, which is also suggested by van Dam et al. [11]

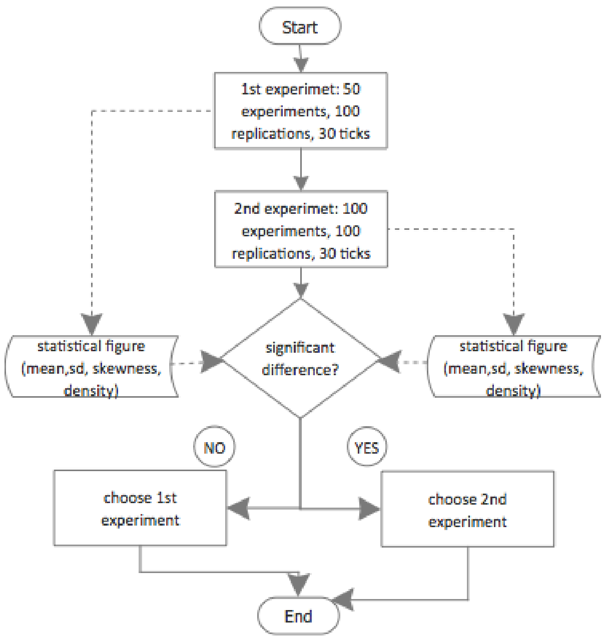

Figure 7.1: The process flow chart

First, we will start with a small number of experiments (**50 experiments**) sampled using LHS and **100 repetitions** for each experiment and perform a descriptive statistic on the oligarchy result.

Second, we aim to increase the accuracy. The choice is between increasing the sample size or the repetition. Here, since we deal with big parameter space, we choose to increase the number experiments. Moreover, 100 repetitions is a rule of thumb that arguably enough to handle the randomness in the model [11]. Thus, we design the experiment with **100 number experiments** sampled using LHS, **100 repetitions**, and **30 ticks** time frame and perform the same descriptive statistic on the oligarchy result.

The distribution of LHS sample for each experiment process is shown in Figure 7.2 and Figure 7.3. The complete documentation of it, including the LHS sample used in the model, is shown on Appendix C.

After the both experiment results are obtained, then we compare the result. If there is no significant difference in the statistical figure, then we choose the first experiment since it is more efficient in computational cost and analysis. If there is a significant difference, then we choose the second experiment data-set to be analysed further.

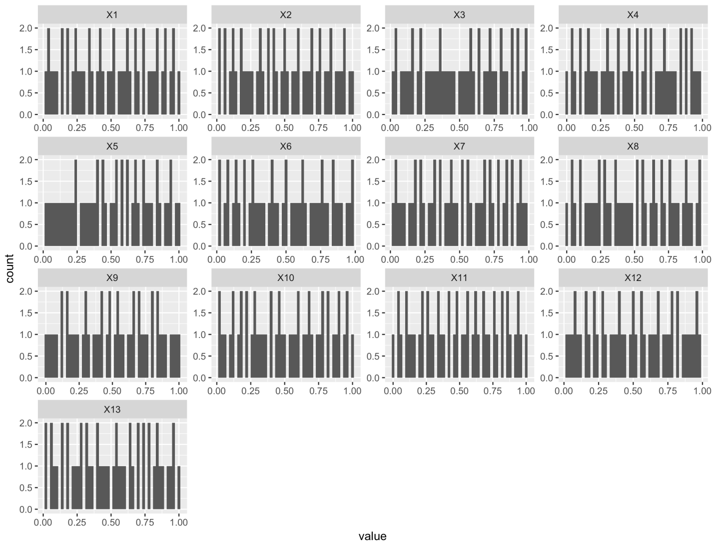

Figure 7.2: Distribution of 100 LHS Sample

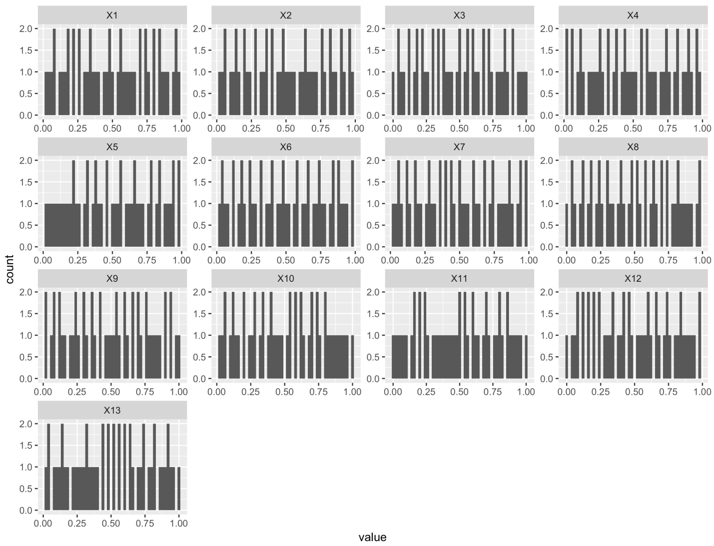

Figure 7.3: Distribution of 50 LHS Sample

7.3. Experiment Result

After both experiments are performed, several statistical figures are documented and compared. Table 7.3 shows the statistical figure comparison towards the oligarchy result from both experiments. Moreover, the comparison of output distribution is shown in Figure 7.3

Oligarchy.level	**First experiment**	**Second experiment**
Mean	6693.72	6791.171
Sd	6578.071	6506.31
Skewness	1.7	1.65

Table 7.3: Experiment Result

It can be seen that the statistical figure and the output distribution have no significant difference. Therefore, we will use the first experiment setting to simulate the model, and its result will be analysed further to test the hypotheses and answer the research questions.

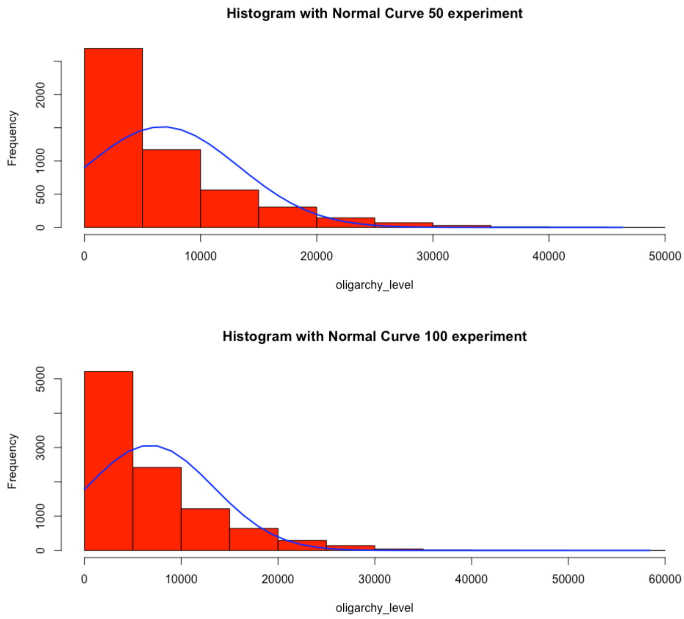

Figure 7.4: Output distribution comparison of oligarchy.level at the end of ticks (tick 30)

8

Data Analysis

This chapter discusses and analyses the output of the experiment so that the model hypothesis can be accepted or rejected, and the main research question mentioned before can be answered. This chapter starts with the analysis of the oligarchy. Section 8.1 will discuss the oligarchy level result and analyse the significant factor that influences it.

Then, Section 8.2 will discuss the influence of this oligarchy situation to the health of the community. After that, Section 8.3 will explore to what extent the fairness in the community can be affected by this situation.

Data analysis will be performed in R. The choice to use R is because this free software gives all the functionality that is needed to perform the analysis, which are data manipulation, data visualisation, and statistical analysis. The complete R code for the data analysis is shown on Script Analysis file in Appendix B.

8.1. Oligarchy Analysis

The aim of this section is to present the oligarchy result across 50 experiments sampled with Latin Hypercube Sampling. As aforementioned, oligarchy is defined as the result of a stable dominion of the minority group. The higher of this value resulted from the particular experiment indicates, the stronger oligarchy situation exists.

First, the oligarchy result from each experiment will be presented and compared. From this overview, it is possible to see which experiments lead to high oligarchy situation and which are not. Thus, it enables comparison and analysis for the next sections.

Second, the regression model will be performed to see the significance of parameter setting to the value of oligarchy level. This regression model facilitates the analysis of factors that significantly contribute to the oligarchy situation and how they affect it.

8.1.1. Experiment Result Overview

The oligarchy level is defined as the sum of oligarchy value from tick 0 to tick 30. The oligarchy level from each experiment is shown in Figure 8.1. It can be seen that experiment number **2, 6, and 36** produce **low** mean of oligarchy level and experiment number **18,28,37** produce **high** mean of oligarchy level.

Furthermore, the dynamic of oligarchy value during the time frame is plotted. It can be seen that even though the low oligarchy produces low mean in total, but **the oligarchy will still exist during the time frame**. Thus, the first hypothesis regarding **the iron law of oligarchy can be accepted.**

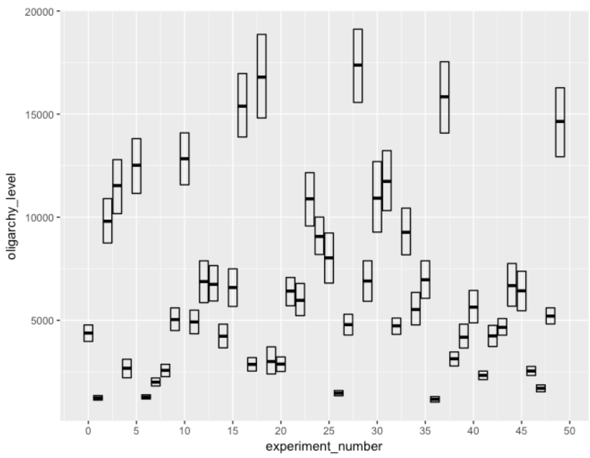

Figure 8.1: Oligarchy level result. The graphs represent three statistical summary variables: the mean and the upper and lower confidence limit without assuming normality

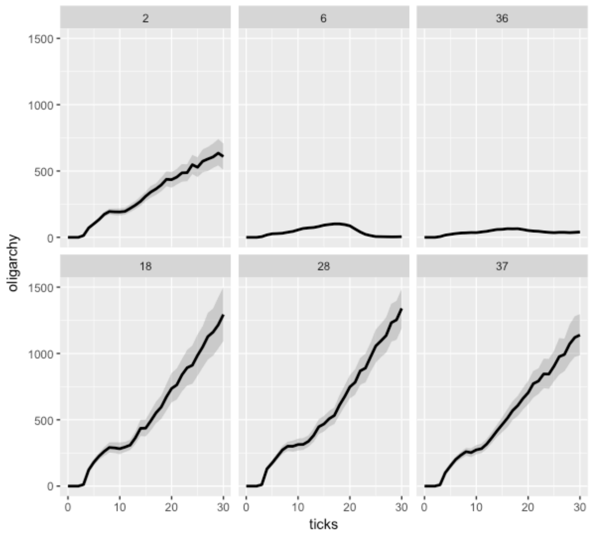

Figure 8.2: Oligarchy per case. Top = low oligarchy case. Down = high oligarchy case

8.1.2. OLS Regression Result

Checking Linear Regression Assumption

To see which parameters have the significant affect to the oligarchy level, the ordinary least square (OLS) regression model is performed. The OLS regression model is chosen because it is the simplest regression model that can indicate the significant parameters towards the oligarchy level.

However, using OLS regression model means that the model has to confirm the assumption of linear regression. Several assumptions have to be proven:

1. Linear relationship
2. No autocorrelation
3. Normality of residuals
4. Homoscedasticity: homogeneity of residual error's variance

R provides diagnostic plot to check whether the model holds those assumptions. Therefore, first, the simple OLS model will be built using the equation 8.1, whereas y_i represents the oligarchy level and x_i represents each parameter, ε_i represents the error term. Then, the diagnostic plot for the first model is produced, shown in Figure 8.3.

$$y_i = \alpha + \beta x_i + \varepsilon_i. \tag{8.1}$$

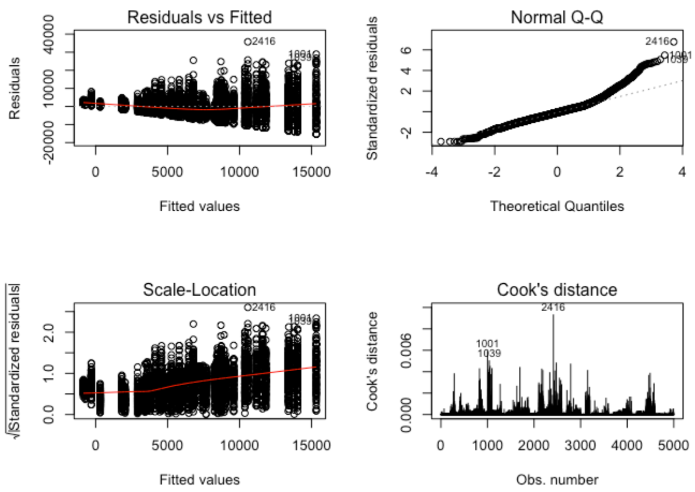

Figure 8.3: Diagnostic plot ols model 1

It can be seen from the normal Q-Q plot that the residuals of OLS model 1 are not normally distributed, thus assumptions number 4 is violated. Moreover, the residual vs. fitted plot shows that the residuals are not spread equally along a horizontal line, indicating that there might be a nonlinear relationship (assumption one is not satisfied). Also, the assumption of homoscedasticity is not met since the scale-location plot presents non-horizontal line and a steep angle. Therefore, the model has to be modified for further analysis.

One of the way to modify it is to transform the y_i into log form ($log(y_i)$). The equation 9.2 shows the OLS model 2 formula. The diagnostic plot for the second model is shown in Figure 8.4.

$$log(y_i) = \alpha + \beta x_i + \varepsilon_i. \tag{8.2}$$

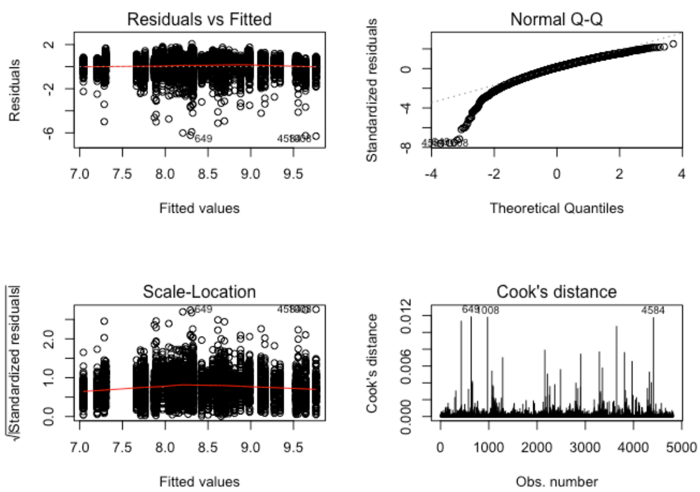

Figure 8.4: Diagnostic plot ols model 2

Through this modification, the residuals on residual vs. fitted plot show more equally spread residual along the horizontal line. Also, the scale-location plot presents horizontal line with equally spread points. Moreover, the Durbin-Watson test is also performed to test whether the autocorrelation among residuals exists. It results on p-value = 0.3514. It means the null hypothesis is accepted, which is there is no autocorrelation in among residuals

However, the Q-Q plot still results on not-normally distributed residuals of OLS model 2. This assumption can be violated since we know that the input has not always followed the normal distribution, for example, the number of connection is distributed using exponential distribution. Thus, we can not assume the normality of the residual.

Moreover, the violation of the normality is arguably not contributing to the bias or inefficiency in the regression model. It has a significant effect on significance testing only when the sample size is very small (<200) [65]. **Therefore, the ols model 2 will be used**.

Regression Result

After the assumption of linear regression is satisfied by the model, it is time to analyse the result of the model. Here, the aim is to analyse parameters that have the significant effect on the oligarchy level value. Table 8.1 shows the OLS model 2 result on the oligarchy level at the end of the simulation. It can be seen that most of the parameters except subsidy, coverage, initial balance standard deviation, and time availability standard deviation have the significant effect on the oligarchy level. As a consequence, the OLS model 2 will be used.

	Estimate	Std.error	t-value	Pr(>|t|)
(Intercept)	7.624e+00	1.117e-01	68.268	0 ***
attendance.thres	-1.551e-02	1.041e-02	-1.490	0.136265
investment.thres	-3.446e-01	5.206e-02	-6.619	0 ***
reduced.bill.thres	-2.173e+00	4.603e+00	-0.472	0.636942
withdrawal.thres	8.898e-02	8.306e-02	1.071	0.284126
subsidy	8.125e-01	4.152e-01	1.957	0.050405 .
discrepancy.thres	1.551e+00	4.135e-02	37.514	0 ***
coverage	1.587e+00	4.571e-02	34.723	0 ***
std.econsumption	-3.639e-04	1.033e-04	-3.522	0 ***
mean.initial.conn	-6.790e-03	1.388e-03	-4.893	0 ***
initial.balance.std	2.288e-05	2.748e-05	0.833	0.404969
c.income.std	3.206e-04	1.041e-04	3.081	0.002077 **
std.education	-3.425e-01	4.162e-02	-8.230	0 ***
std.time.avail	-1.972e-02	4.632e-03	-4.257	0 ***
R-square	0.3696			
p-value	0			

Table 8.1: OLS on the oligarchy level at the end of the simulation

As mentioned before, the thresholds are indicators of the attribute of the community. Here, we want to see which attribute of community that has significant effect to the oligarchy.

In this case, discrepancy threshold and investment threshold affect the oligarchy level positively. **The discrepancy threshold shows how tolerant the community with the unequal distribution of the outcome**. Here, the more tolerant the community, the more oligarchy situation more likely emerges. Moreover, the investment threshold indicates the barrier to invest in the energy generation technology. **The less barrier to invest, the more oligarchy situation becomes apparent.**

The coverage value represents the information spread-ability rules, which this information are the outcome and the individual aspiration. It results that the coverage value has positive influence to the oligarchy. The **more spreadable** the information in the community makes the **oligarchy becomes more apparent**.

Furthermore, the mean initial connection represents the initial connectivity in the community. This value has a positive effect on the oligarchy level. This expresses that **the high connectivity** in the community **ease the minority to spread the dominance**, thus establishes the more stable dominion.

As aforementioned, there is a hypothesis that the heterogeneity in the population become the main variable that may provoke the oligarchy situation. Several indicators of heterogeneity of endowment have proven to be significant, which are the standard deviation of energy consumption, education, time availability and income. **The higher value of standard deviation represents the more diversity or heterogeneity** of a particular endowment in the population. However, the effects are different for each variable.

It is shown that heterogeneity of energy consumption has a negative effect on the oligarchy. The **more heterogeneous the population in energy consumption, the less oligarchy situation exist**.

This negative effect is also applied on the education level and time availability. **The more homogeneous education level and time availability** in the community corresponds with **the higher the oligarchy level**. On the other hand, the more heterogeneous the yearly income in the population positively affect the higher oligarchy level.

8.2. Health Analysis

As mentioned before, there are only two factors that will be analysed as the representative of the healthy community's factor, the cohesion and community mindedness. This section aims to analyse to what extend the oligarchy situation may affect the health of the community by looking into those factors.

8.2.1. Community Cohesion

Community cohesion can be obtained by measuring what-to-vote value and general assembly decision value. However, the value of those metrics resulted in character data type in R. It has to be converted into numerical value. Then, if the value between those variable match, the cohesion value become 1 and vice versa. The complete step of this data manipulation can be found on Script Analysis file in Appendix B.

It can be seen from Figure 8.5 that the total cohesion value resulted from the high oligarchy case is higher than the low oligarchy case. Furthermore, to test the hypothesis that the oligarchy correlates with the community cohesiveness positively (hypothesis no. 3), Kendall's tau correlation is performed.

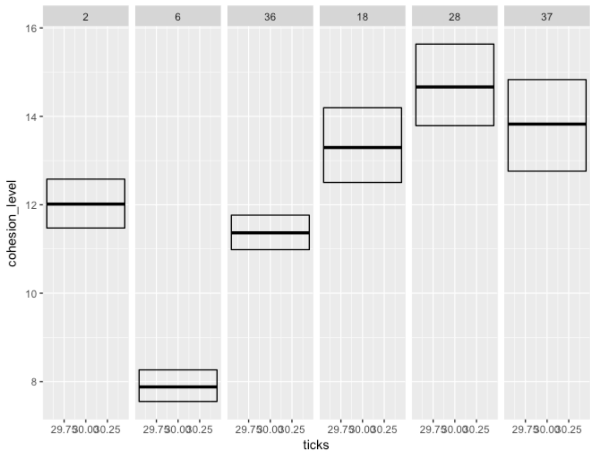

Figure 8.5: Cohesiveness level = sum of cohesion value from tick 0 to tick 30. Each graphs presents three things: the average cohesion level, the upper and lower confidence limit without assuming normality. Left to right = low to high case

The result of this test is shown in Table 8.2. It shows that **there is a statistically significant positive correlation between oligarchy level and cohesion level**. Therefore, the hypothesis by Hogg et al. [31] that the exercise of power by the leader is more likely to emerge when the group is more cohesive and homogeneous can be accepted (hypothesis no. 3 is accepted)

	tau	p-value	remarks
cohesion.level	0.270	< 2.2e-16	significant

Table 8.2: Kendall's tau correlation test on the cohesion level to the oligarchy level

8.2.2. Community Mindedness

Community mindedness is defined as the willingness to invest and have active participation, which has been formalised in Table 7.1. Figure 8.5 shows that in high oligarchy experiment, the community mindedness appears to be higher than in the low oligarchy experiment.

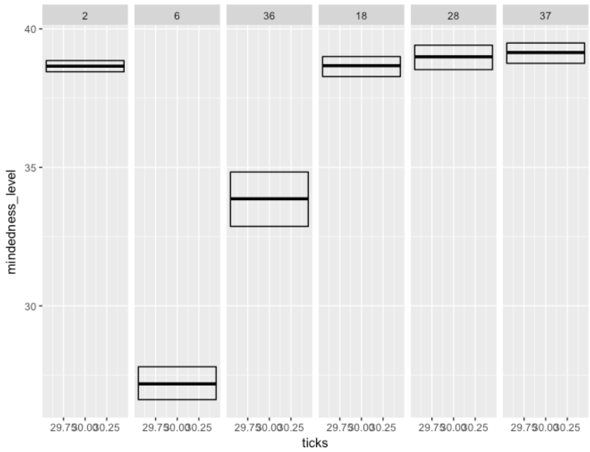

Figure 8.6: Mindedness level = sum of mindedness value from tick 0 to tick 30. Each graphs presents three things: the average mindedness level, the upper and lower confidence limit without assuming normality. Left to right = low to high case

Furthermore, to ensure the positive correlation between those two variables, Kendall's tau test is performed. The result shows that there is a positive, strong significant correlation between those variables. It means that there is strong tendency that in high oligarchy situation, the community mindedness is preserved.

	tau	p-value	remarks
mindedness.level	0.338	< 2.2e-16	significant

Table 8.3: Kendall's tau correlation test on the mindedness level to the oligarchy level

8.2.3. Health of CES

Community cohesion and community mindedness are the factors that contribute to the health of community [6]. Thus, the health of the community is equal to the combined effect of the community cohesion and the community mindedness.

The overall health community during the time frame is analysed, illustrated in Figure 8.7. It shows that in the high oligarchy case, the health level is higher than in the low oligarchy case.

To analyse how the oligarchy effects the health of the community, the simple OLS model is built using the equation 9.1, whereas y_i represents the health level and x_i represents the oligarchy, ε_i represents the error term. The result is presented in Table 8.4. It can be concluded that **the oligarchy affect the health of the community positively.**

	Estimate	Std.error	t-value	Pr(>|t|)
(Intercept)	4.529e+01	1.269e-01	356.80	0 ***
oligarchy.level	4.201e-04	1.353e-05	31.06	0 ***
R-square	0.1646			
p-value	0			

Table 8.4: OLS on the health level

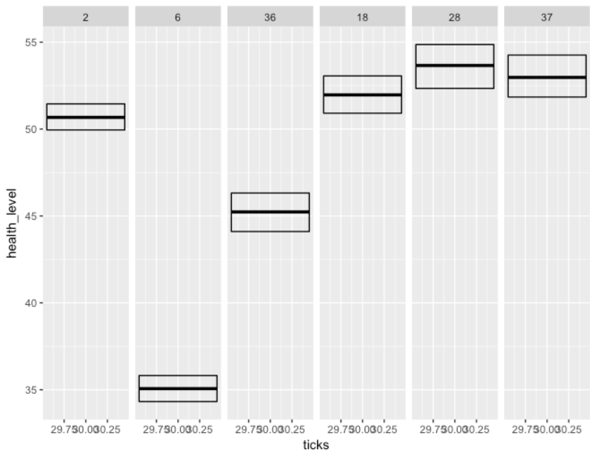

Figure 8.7: Health level = sum of health value from tick 0 to tick 30. Each graphs presents three things: the average health level, the upper and lower confidence limit without assuming normality. Left to right = low to high case

8.3. Fairness Analysis

The analysis on how the oligarchy situation influences the fairness starts by looking into the average community trust value from different experiments. Figure 8.8 shows that in high oligarchy situation, the perceived fairness is higher than in the low oligarchy ones.

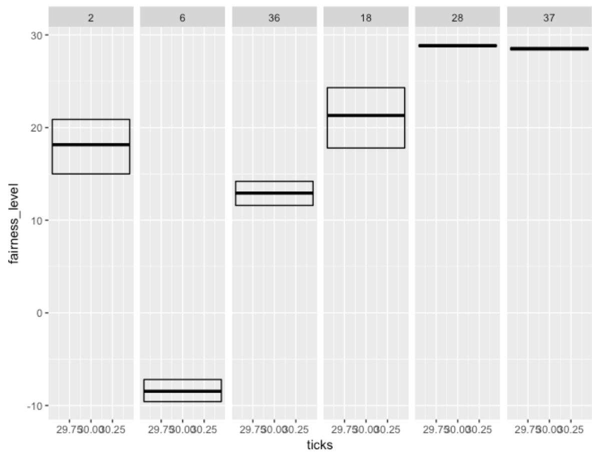

Figure 8.8: Fairness level = sum of community.trust value from tick 0 to tick 30. Each graphs presents three things: the average fairness, the upper and lower confidence limit without assuming normality. Left to right = low to high case

To analyse to what extent the oligarchy affects the fairness of the community, the simple OLS model is built using the equation 9.1, whereas y_i represents the fairness level and x_i represents the oligarchy, ε_i represents the error term. The result is presented in Table 8.4. It can be concluded that **the oligarchy affect the fairness of the community positively.**

	Estimate	Std.error	t-value	Pr(>|t|)
(Intercept)	1.179e+01	3.445e-01	34.24	0 ***
oligarchy.level	7.541e-04	3.671e-05	20.55	0 ***
R-square	0.097			
p-value	0			

Table 8.5: OLS on the fairness level

Then, the question is how the fairness can be higher in high oligarchy situation. It is becaus the oligarchy is stronger in high tolerance community, makes the perceived fairness in high oligarchy situation is easier to be maintained.

Furthermore, there is a hypothesis that the fairness and the health of the community have a positive correlation (hypothesis no.4). The correlation test is performed using Kendall's tau. Table 8.6 shows that the hypothesis can be accepted since **there is positive correlation between the health and the fairness in the community [58].**

	tau	p-value	remarks
health.level	0.244	< 2.2e-16	significant

Table 8.6: Kendall's tau correlation test on the fairness level to the health level

8.4. Adaptability Analysis

8.4.1. The Hypothesis

Figure 8.1 conveys that there is a tendency that the experiment that produces the higher mean of oligarchy has a higher deviation in value and vice versa. It means that, when the structure of action arena produces the low oligarchy value, the value most likely stick around for most of the repetition of the experiment.

The question is why. It seems like the oligarchy value has a positive correlation with the adaptability of the system. Therefore, when the less oligarchy value produces by the system, the system most likely has less adaptability. As a consequence, the system produces stable low oligarchy value in most of the experiment run (the system becomes so rigid in low value).

Thus, the hypothesis is constructed that ***the oligarchy has a positive correlation with the adaptability of the system***.

8.4.2. The Shock

The adaptability is visible when the system is in shock (the oligarchy value drops to 0). Therefore, Figure 8. shows the prop.value as an indicator of adaptive response when the shock happens.

It can be seen that in most of the cases, **the shock happens on around tick 10 and tick 20**. The difference is that in low oligarchy case (especially experiment no 6 and 36), the shock keeps going on.

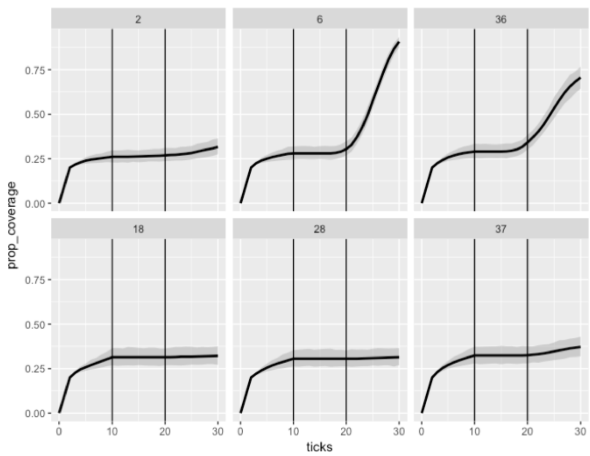

Figure 8.9: Propaganda coverage value over 30 ticks. Top: low oligarchy case. Bottom: high oligarchy case

8.4.3. The System Adaptability

To define the adaptability of the system, we have to look it from two different perspectives: **(1) the minority group perspective, and (2) the cooperatives perspective.**

From the minority group perspective, there are two main factors that can contribute to the loss of adaptability, (1) the presence of many contenders, (2) the withdrawal of the individuals in minority group from the community. Those two conditions could lead to the loss of stable domination of the minority, even though the adaptive response is performed.

From the cooperatives perspective, the adaptability is lost when the member loses its willingness to participate in the community. The combined effect of those can be an indicator of the adaptability of the system.

Adaptability = (1 / contender) * count.minority.group * will.participate.cooperatives

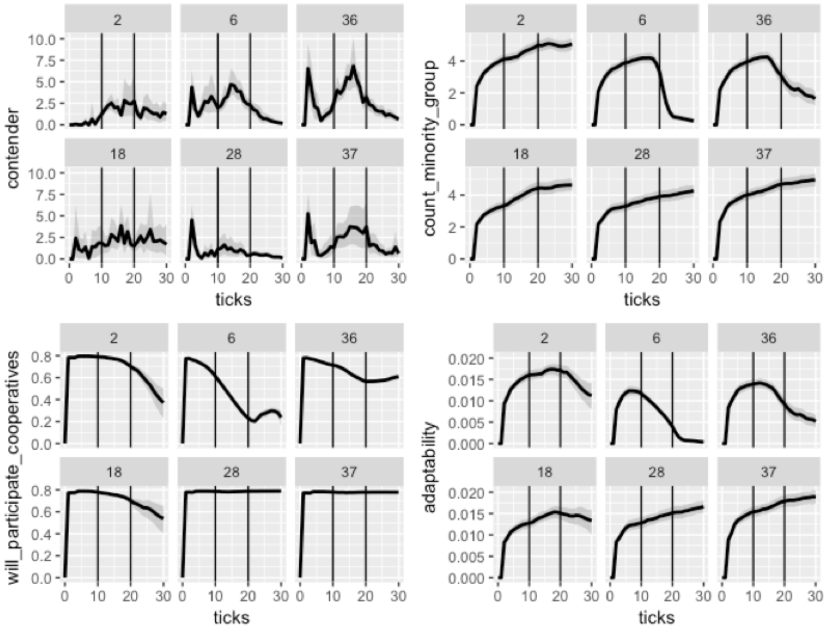

Figure 8.10: The number of contender, The number of minority group, The average willingness to participate of the cooperative, The adaptability. Top: low oligarchy case. Bottom: high oligarchy case

It can be seen from the figure above that the adaptability of the system decreases rapidly in low oligarchy situation. From the visualisation, **the most contributing factor that leads to the loss of adaptability is the decreasing willingness to participate of cooperatives and the number of minority group after shock**.

It can be seen that **the shock is a bifurcation point that leads the system into two different paths**. One path leads to the major withdrawal of the individuals in the minority group and rapid decrements of willingness to participate. The others lead to more stable domination of the minority group and stable willingness to participate of the cooperatives.

8.4.4. The Correlation

Then, the correlation test is performed to test the hypothesis. It shows that there is a strong positive correlation between the oligarchy and adaptability of the system. It means that when **the structure of community enables the stable domination by the leader, the community most likely becomes more adaptive when the shock happens.**

	tau	p-value	remarks
adaptability.level	0.296	< 2.2e-16	significant

Table 8.7: Kendall's tau correlation test on the oligarchy level to the adaptability level

8.5. Leadership Analysis

The previous analysis has explored several conditions that significantly affect the oligarchy situation, and to what extent it affects the health and fairness of the community. Since the leadership is the central point of oligarchy, it is a virtue to analyse the leader characteristic under different oligarchy case.

The oligarchy is defined as a stable domination of the minority group over the member. The domination is the ability of the agent to influence the others as a manifestation of the exercise of power. Thus, when the high influential leader emerges, the stronger oligarchy most likely emerges. Therefore, the hypothesis is that **the existence of strong influential leader correlates with the more powerful oligarchy situation.**

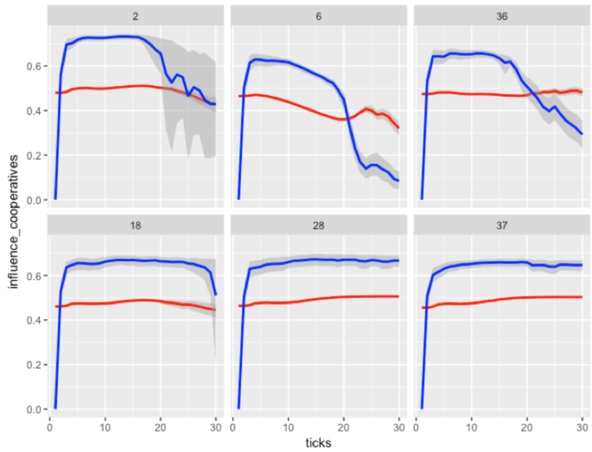

Figure 8.11: Blue: The average influence of the minority group. Red: The average influence of cooperatives. Top: low oligarchy case. Bottom: high oligarchy case

	tau	p-value	remarks
influence of minority.level	0.4554182	< 2.2e-16	significant

Table 8.8: Kendall's tau correlation test on the oligarchy level to the influence of minority

Now, we know that the presence of strong leader correlates with the stronger oligarchy situation. Then, the intriguing question is **whether the leaders perceive their outcome better than the average the community member in the strong oligarchy case**. Though it sounds reasonable, figure 8.12 shows that in high oligarchy case, the minority group most likely perceives the outcome a bit less than the average community member.

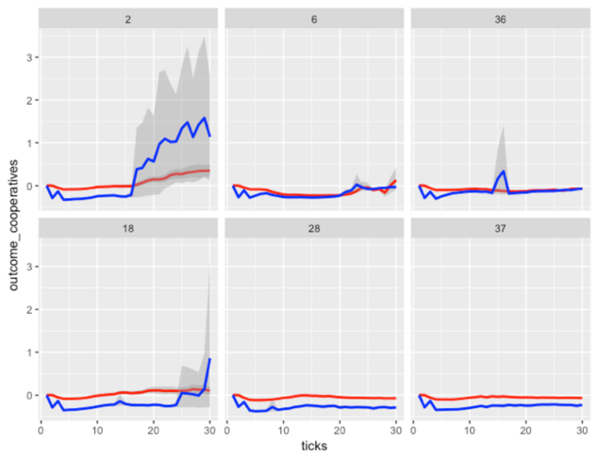

Figure 8.12: Blue: The average outcome of the minority group. Red: The average outcome of cooperatives. Top: low oligarchy case. Bottom: high oligarchy case

This is an important point to be noted that makes the oligarchy in CES is different with the political parties or other commercial organisations. **The underlying motivation to join CES is not like the motivation to join political parties, which are to establish power or gain economic benefit.**

The motivations that underlie the participation in CES is mostly environmental concern, sustainability, and trust to the community they live in. The trust highly depends on the perceived fairness of the individuals as a result of their day-to-day interaction. The nature of the membership and leadership is purely voluntary, and the member most likely knows each other since they live in the same neighbourhood, so the perceived fairness plays an important role here, more than in political parties and commercial organisation.

This fact makes the better outcome is not a proper incentive to increase the motivation to participate in CES. Thus, even though the leaders perceive their outcome better, their perception of the fairness in the community might decrease as they sense illegitimate outcome (high outcome discrepancy) or illegitimate process (the attendance drops or quorum is not meet).

As a result, their willingness to participate and influence the community as a leader is decreasing. It is shown in Figure 8.13, that in high oligarchy situation, the community trust between the minority group and the average member is quite aligned and stable during the time frame.

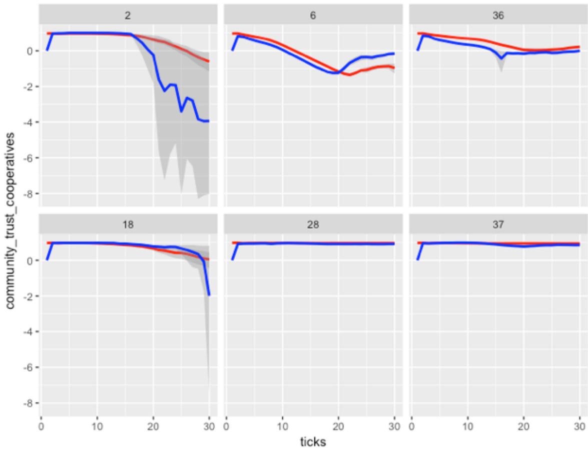

Figure 8.13: Blue: The average community.trust of the minority group. Red: The average community.trust of cooperatives. Top: low oligarchy case. Bottom: high oligarchy case

9 Model Validation

This chapter will discuss the validation of the model. While verification aims to ensure that we build the things right, the validation aims to ensure that we build the right things. There are several methods to validate Agent-Based Model, which are the historic replay, expert validation, literature validation, and model replication [11].

9.1. Historic Replay

Historic replay is a useful validation method for the model that can be compared to a real-world situation. Here, the real-world situations are parameterised and translated to the model; then experiments explore whether the emergent patterns from the observed scenario are present in the simulations and if the outcomes and end states of the model resemble the current state of the real system [11].

Although it seems plausible to use this method for this model, that is not the case. In this case, we do not have complete data-set that enable to parameterised the real community energy system, such as all the ”thresholds” parameters, the average social connection, etc.

However, the comparison with the real-world situation might be done by looking back to several case studies of cooperatives in Netherlands. Here, the emergence oligarchy might be seen from the stable leadership position in the history of the cooperatives. Therefore, we look deeper into the leadership history of Texel Enegie, the mature energy cooperatives in Netherlands.

In this case, Brendan de Graaf has become the director of texel from 2008-2014. He resigned to develop the Renewable Energy Union, the service provider for local sustainable energy initiatives. In 2015, the administrative work was handed over to Renewable Energy Union [66]. Last communication with the representative of TexelEnergie on March 2017, Coöperatie Texel Energie sits in a very turbulent period. Their staff decrease to only one employee with no board at that moment.

It can be seen that the way the board keeps being re-elected can become the real indication of the stable dominion the board. Apart from other unknown circumstances that happen inside the cooperatives, the moment Texel Energie loses the board, the organisation itself starts to be in turbulent period.

9.2. Model Replication

Model replication is validation method by creating second ABM model with different decomposition or use different modelling techniques. Due to the time constraint, we are unable to the validation using this method.

9.3. Literature Validation

Literature validation can be performed by studying the academic literature that reached a similar conclusion through both theoretical research and non-agent-based models. If such literature is found, it will increase the confidence in the model outcome.

As aforementioned, Hogg et al. [31] stated that the exercise of power by the leader is more likely to emerge when the group is more cohesive and homogeneous. From the data analysis, it can be concluded that the cohesiveness level positively correlates with oligarchy level, which is aligned with the conclusion from Hogg et al. [31].

However, in the homogeneous part, the model result is different. It results that the more heterogeneous population in money leads to the more oligarchy situation, but the less heterogeneous population in electricity consumption and education leads to the more oligarchy situation.

9.4. Expert Validation

Expert validation is the most common method to validate the agent-based model. Performing an expert validation usually includes structured interviews or workshops with expert [11]. Unfortunately, there is a little time to do that in the context of this thesis. The other method, in this case, is face-validation. Face validation aims to validate the model in the context that the model appears to be reasonable and looks like it is supposed to do.

The face validation is done by presenting the result of our model to Binod Koirala, an expert that has done extensive research in the Integrated Community Energy System (ICES). So far, he deemed that the result of this model appears to be reasonable, and able to answer the problem defined before. He stated that the existence of motivated sub-group is important to sustain the cooperatives. This sub-group of people is usually the ones that initiate several proposals regarding investment, rules, etc. Also, most probably they are the ones that become the board at the end.

He also gave several inputs for improving this model at the later stage, such as make the regulatory condition becomes more dynamic, introducing the merger phenomena from several small cooperatives into LDEB (like what happened in Texel), and simulate under the different size of cooperatives.

10

Discussion and Conclusion

Community Energy System has emerged as a way to facilitate the renewable energy generation. Since this system is built by and for the community member [13], it is usually approached as a self-governed common-pool resource system [2]. In this system, the community members are actively contributed in making and adapting rules that regulate the use of a common-pool resource [3] such as energy generation, distribution, and storage. Those rules are called the self-governing institution.

Meanwhile, there is an iron law of oligarchy, which claims that the complex organisation will always end up in an oligarchy, no matter it was constituted originally. In this situation, the organisation will be dominated by some minority groups. Those minority groups can steer the organisation to stabilise their domination or benefit them more than the others. Therefore, the oligarchy situation can cause the unfairness in the system and deteriorate the health of the system.

This thesis contributes to filling the knowledge gap in CES from the organisational perspective by looking into the emergence of oligarchy. It is analysed whether the iron law of oligarchy happens in CES and how it affects the health and the fairness of the community.

Since the institution is dynamic, and the community has a heterogeneous population, an agent-based model and simulation are built to model the emergence of oligarchy in CES and to enable the analysis of its effect. The input of this model comes from the desk research, which consists of the literature review, the exploration of theoretical background, and the exploration case studies.

This thesis, which consists of the desk research, the model construction, and the model simulation, has able to answer the subquestions and the main-research question mentioned before. This chapter will conclude the answer to each question.

10.1. The Sub-questions

10.1.1. What is the characteristic of community energy as a bottom-up self-governing system?

The characteristic of CES is gained from the exploration of the energy cooperatives in Netherland. Those organisations mostly aim for improving sustainability in their neighbourhood [42], facilitating the investment for renewable energy [43], increasing energy independence for the neighbourhood [49] [51].

Moreover, the survey from Binod et al. [39] also reveals the factors that contribute to the willingness to participate in ICES, which are education, community trust, energy independence, and environmental concern. Furthermore, several kinds of literature also emphasise the importance of the fairness to maintain the community trust of the member [6] and ensure the participation of the member [20] [15].

Those motives make the CES is different from other commercial or political organisations. Those make the incentives to trigger the participation in CES as a self-governing system are different, unlike the commercial and political organisation which is of the economic benefit or power.

Furthermore, as a common-resource system, the technology characteristic makes the CES unique from other "natural" common-resource system. The CES needs the investment of the technology to start exploiting the resource, unlike the natural common-resource system that is ready to be exploited without any investments in technology. This characteristic makes the exploitation right in CES is less tricky. As mentioned in several case studies, the member usually has some shares in energy generation, proportionate with their investment in collective energy generation.

From the organisational perspective, the CES consists of the board and the member. The board holds the leadership position and actively manage and initiate the development of CES. The crucial decisions in the cooperatives, such as the governing rules, the investment and the development policies, are decided in member meeting. Here, the member has equally one vote no matter their share in the energy generation technology.

In the Netherlands, the cooperatives are usually bounded by the same neighbourhood due to the government incentives (the poscoderoos). Also, the CES usually has a formal contract with the renewable energy supplier that manages the distribution of the energy generated from and to the cooperatives.

Those characteristics imply the conceptualisation of the model. From a general sense, the model has the general characteristic of the self-govern common-pool resource system, such as the dynamic of the institution, the heterogeneous population, and the boundary-specific resource system. On the other hand, the model will have some particular characteristic that differentiates the CES from others.

10.1.2. How is oligarchy defined in community energy system? To what extent does the oligarchy could happen?

Theoretically, the oligarchy is defined as the stable domination of the elected over the electors. Nevertheless, this definition is used in a political party context. Thus, the oligarchy has to be defined in community energy system context.

The oligarchy is defined as the stable domination of minority group over the member. A minority group is a group of people that has ever been elected to the board in the community. The domination happens when this minority group influences the collective aspiration of the majority. It is stable when the people from that group are keep re-elected as the board.

The result of the model simulation shows that the iron law of oligarchy happens in community energy system. The oligarchy situation always exists at several points of time in the development of CES.

The extent of the oligarchy situation is strongly influenced by attribute of the community and the heterogeneity of the population. The data analysis reveals that the oligarchy situation is more apparent in the community that is more tolerant, has a low barrier to invest, has high ability to spread the information and well-connected concerning social connection.

From the heterogeneity side, it reveals that the more heterogeneous population in the income provokes the stronger oligarchy situation, while the more homogeneous population in education, time availability, and energy consumption have a negative effect on the oligarchy situation.

10.1.3. To what extent does the oligarchy influence the health and the fairness of the community energy system?

The fairness in the community is important because it effects on the legitimacy of the outcomes and the process in which the institution is formed. This perceived fairness is strongly correlated with the community trust of the people in the community. It is because when the people perceived fairness, they are more likely to trust and accept the decisions resulting from the process, and the institution that makes the decisions [6].

Meanwhile, Brown et al. [6] define the health of the community as the ability of a community to adapt to the change and adjust the institutional structure. Several factors that contribute to the health of the community, such as the community cohesion, and community mindedness.

Since the institution is dynamic, the oligarchy can influence the health and the fairness of the community energy system by dominating the process of forming or reforming the institution. Therefore, the focus of the analysis is to the effect of the oligarchy emergent in the action arena, where that institution is made and remade, to the health and the fairness.

The iron law of oligarchy exists in CES with different extent. Thus, the effect on the health and the fairness depends on the extent of the oligarchy situation in the community. The data analysis from the simulation discovers that the oligarchy situation has a positive effect on the health and the fairness of the community. The extent of this effect depends on the strength of the oligarchy situation. The greater the oligarchy presents, the better health and fairness the community has.

Furthermore, since the health is also measured by the adaptability of the community, this adaptability is also measured. The data analysis results on the positive correlation between the oligarchy and the adaptability of the system. This ability is mostly apparent after the shock happens (when the oligarchy value drops to zero). This shock becomes the bifurcation point that leads the system into two different paths because of the different level of the adaptability of the system.

Also, the interesting point made by Syme et al.[58] is that some factors in the health of the community can be seen related to the fairness. The correlation test shows that there is a significant positive correlation between the health and the fairness of the community. Thus, the hypothesis by Syme et al. [58] can be accepted.

10.1.4. In case it does cause failure or unfairness, how can it be prevented or reformed?

The iron law of oligarchy occurs in the CES with different extent. Since the oligarchy situation has a positive effect on the health and the fairness of the system, the strong presence of stable leadership has to be maintained to prevent the failure and the unfairness of the system.

It is because of the leader, in this case, is more of the highly active agent than the autocrat. They usually perceive the outcome even a bit less than the average people in the community, yet they still have high trust to the community. They use their influence to keep the community unite and ensure the legitimate outcome and process for its member. This kind of leader that could make the community sustain.

On the contrary, when the autocrat leader present, the other member will perceive unfairness and more contender will appear. As a consequence, their leadership will be unstable. Then, without the presence of stable leadership, the CES will lose its unity and adaptability, which aggravates the legitimacy of outcome and process even more.

Therefore, to prevent the failure or unfairness, the presence of stable leadership is paramount. As aforementioned, several community attributes can promote the stronger presence of stable leadership. Thus, moving towards a community that is well connected, tolerant, has a low barrier to invest, and has sufficient information distribution can be a way to reform the unfairness and failure in the CES.

10.2. Conclusion

The sub-questions mentioned before have given a direction to answer the main research question below.

How does the oligarchy situation emerge and affect the health and the fairness of the community energy system?

The case study of the cooperatives in the Netherlands shows two observed emergent patterns, which is the emergence of leader and the emergence of the institution. Since the leader holds the leadership and management position, they are usually the initiator of the change of institution.

In that process, the people in the community will interact and influence each other. The domination happens when the minority group can influence the aspiration of the majority. Then, the stability is apparent when the person on that minority group keeps re-elected. In this case, the oligarchy situation emerges.

Several factors contribute to the extent of oligarchy situation, such as the tolerance of the community, the barrier to invest, the spread-ability of the information, the connectivity concerning social connection, and the extent of the heterogeneity in the population.

Apparently, the strong presence of stable leadership is necessary to make CES have the level of fairness and health needed to support its continuity. It gives the adaptability to the system when the shock happens by keeping the cohesiveness, the participation, and the fairness of the community. Thus, the oligarchy affects positively to the health and the fairness of the community energy system.

It is because the typical leader under the strong oligarchy situation is more of the highly active agent than the autocrat. It is shown by the fact that the economic incentive indicators, such as the reduced.bill.threshold, or the subsidy, is not the proper incentives for this system to create the oligarchy. So, the oligarch in this system is not driven by the economic benefit, which makes the emergence of oligarchy in this system is different compared to other commercial or political systems.

Moreover, the community trust plays an important role to make the outcome, and the process is legitimate [6] and make the community unified and active [67]. Therefore, the presence of autocrat leader, who aims better outcome than the others by exercising its power, will induce the unfairness and create many contenders, which make their domination will not survive. Consequently, the community will lose the presence of strong leadership, and it will further affect its health and fairness.

11
Reflection and Further Work

11.1. Reflection

This section intends to give the reflection on this thesis project including some limitations in it.

11.1.1. The Scope

Initially, the scope of this work is to model and simulate the community energy system. However, the concept of community energy system differs per country. Additionally, the available data regarding the willingness-to-participate on community energy system is limited only to Netherlands. Therefore, the scope of case studies used in this project is limited to community energy system in Netherlands, in the form of energy cooperatives.

On the other hand, the literature review is selected based on the most cited literature from mostly the Scopus. The most cited literature give more general description and theory behind community energy system. However, choosing the literature from the most cited ones is prone the risk that the content is not up-to-date with the state-of-the-art knowledge. Also, limiting the search using Scopus constraints the search to mostly the academic literature only.

11.1.2. The Conceptualisation

The conceptualisation starts with the output from the literature review. In this case, the background to build the conceptual model mainly uses the snowball method as the search method. For example, the literature review on the leadership theory is a consequence of a finding of the need for leadership from oligarchy study. The use of IAD framework is a result of the findings that institution is dynamic from the previous literature reviews.

Then, the conceptualisation focuses on type 1 cooperative in Netherlands. By all means, this choice limits the usability of the conceptual model to this kind of cooperatives. In this type cooperatives, the technological part is limited, since the energy supplier manages most of the operational side of distribution and management electricity in the community.

As a consequence, this limits the option of rules that can emerge from board decision or general assembly decision. Indeed, the concept enables the general assembly decision to withdraw from the energy supplier, thus move the cooperatives towards the type 2 cooperative. However, the consequences after the cooperative become type 2 cooperative are restrictively captured by the model.

Moreover, the focus of conceptualising the dynamic structure of the action arena reduces the focus on the complexity of the biophysical world. For example, the electricity market that may affect the cooperatives through the fluctuation of electricity price is not conceptualised in the model. Also, the action that the energy supplier can do is limited.

11.1.3. The Formalisation and Verification

The formalisation begins with determining and assigning the variable value to the agents. During this process, many assumptions are made, and the random variables are assigned, although some of them are based on some literature or case studies found.

The formalisation process requires many iterations. The formalisation that is presented in chapter 7 is the formalisation from the last iteration. It also excludes several dummy variables that are needed for the implementation for the sake of clarity.

The verification always follows the formalisation of each iteration to make the model is implemented right. This sequencing process makes the author sometimes lose the track in the writing of the document. Therefore, the verification presented in this report does not contain many errors since the last model has been through many verification processes before that has not been accurately traced in writing.

11.1.4. The Experiment and Data Analysis

The experiment is designed to test several hypotheses and to answer the research question. Here, the oligarchy, health, and fairness in the community are measured on a systemic level using the definitions from the literature review.

The result of the experiment then is analysed. The analysis is mainly done using graphs and OLS model. The graphs can indicate how parameters' value evolves. The OLS model can give the statistical description between several parameters.

However, the OLS model always assumes linearity, which is not the nature of this system. Some modifications are made to satisfy the assumptions on a limited basis. The main aim of the OLS model is to give statistical description needed for the analysis, such as the significant effect of parameters, or the correlation between parameter, but it is not the best-fit model for the system. Further exploratory data analysis may be needed to create a model algorithm to describe the oligarchy in system level (from a top-down perspective).

Moreover, the health of the community is only assessed through two factors, which are community cohesion and community mindedness. More factors could be incorporated into the model with less time constraint. Also, there might be correlation or causation effect between the health of community factors or between the health of the community and the fairness, which falls outside the scope of this project, but might provide more insight regarding the effect of oligarchy.

11.1.5. The Validation

The validation for the model has limitedly done in this project due to the time limitation. The face validation was only performed with one expert. From this face validation, he deemed that the result of this model appears to be reasonable. Several possible improvements are also given.

11.2. Further work

The reflection on this thesis project has explored several limitations and possible improvements and developments of the project. Those will be summarised into several further works for this model.

Scope-wise, the system description of the model can be developed to incorporate broader case studies of community energy system, not only Netherlands. Also, the model can be designed to enable type 1 cooperatives to evolve towards type 2 cooperative. The use of IAD framework also can be extended adding the dynamic of the institution into the three layer of institutions, which are the operational choice, collective choice, and constitutional choice [4]. Thus, the model can simulate the evolution of community energy better, so the effect of oligarchy can be analysed further.

Moreover, since the work mostly focuses on the organisational and institution part in the community energy systems, more elaborate focus on the technological and the governance outside the community, such as subsidy scheme, several tariff options, or the fluctuation of electricity price, can be a further valuable work.

Also, the more advanced descriptive exploratory data analysis can add valuable features in data analysis. However, to do this, large experiments have to be made, which costs the computational power and time.

For future work, more face validation with the expert is encouraged, which focuses more on the discussion of several assumptions made in the model. Also, historical replay could be done as well if complete data-set that enable to parameterised the real community energy system can be obtained.

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Appendices

A

Pseudo-code

A.1. Model Formalisation

After the identification of what, who is in the model and what they do, model formalisation aims to translate the main narrative into pseudo-code using the concept formalisation described before. The model formalisation consists of two main procedure, which are the setup procedure and the running procedure.

A.1.1. Setup Procedure

The setup procedure includes the creation of the agents and the attributes assignment to those agents. Several assumptions are also made to assign the value for some variables. The full documentation of assumptions is given on Appendix A.

Creation of the cooperatives

- Create number of cooperatives : 200
- Set up the initial variables of cooperatives
  - Give each cooperative random location
  - Give each cooperative dot shape, blue colour, and initial size 0.5
  - Assign balance: the initial balance is drawn from a normal distribution with average 10.000 € and standard deviation of 2000 €
  - Set decision, investment.list and collect aspiration as empty list
  - attendance = 1
  - Set education with random value between 1 to 4. It represent four levels education in demographic data of Netherlands (university degree, higher vocational education, secondary vocational education, and high school) [39].
  - Set env.concern with random value between 0 to 1
  - Set e.independence with random value between 0 to 1
  - Set time.avail: the time availability is drawn from a normal distribution with average 30 and standard deviation 10
  - Assign e.consumption : the energy consumption is assumed from a normal distribution with average 6570 kWh/ year and standard deviation of 500 [60][p. 107].
  - Set outcome.discrepancy 0
  - Set work.hour 6. The value is taken from the actual work hour of the board in De Ramplaan Cooperatives [42].
  - Assign c.income: c. income represents the yearly income of an agent aimed to pay their yearly electricity bill. The value of this variable is assumed from a normal distribution with average 1000 and standard deviation of 200 [60][p. 107]

- Assign add.econsumption: add.econsumption represents the additional electricity consumption of an agent. The additional electricity consumption each tick is distributed normally with mean 0.2 and standard deviation 0.1.
  1. add.econsumption = (random-normal 0.2 0.1) * e.consumption

- Place the cooperatives in social network
  - Assign numb.connection: the initial number of connection has minimum value of 2 and distributed using exponential distribution with average 10.
    - numb.connection = 2 + random-exponential 10
  - Set connection.list as a list that consist of other agent randomly as per numb.connection defined
    - connection.list = other-n-of (numb.connection) of cooperatives
  - Create the link with agent in the connection list
- Define the hub in the social network, the pareto
  - Define connect.list = Sort the numb.connection of the cooperative from the highest to the lowest
    - connect.list = sort-by > [numb.connection] of cooperatives
  - Calculate the cumulative amount from the connect.list
    - cumm.list = item n of connect.list + item (n+ 1) of connect.list
  - Set the pareto list as the division of each item in cumm.list to the total of number connection of cooperatives
    - foreach cumm.list [[x] -> set pareto.list lput precision (x / sum [numb.connection] of cooperatives) 1 pareto.list]
  - Set the pareto as the item on connection.list which is top 20% of the numb.connection of cooperatives
    - Pareto = report item (position 0.2 pareto.list) connect.list
  - Differentiate the visualisation of the hub
    - Set the colour of the hub's link into red

Creation of the neighbours

- Create number of neighbours 100
- Set up the initial variable of neighbours
  - Give each cooperative random location
  - Give each cooperative triangle shape and white colour
  - Assign n.balance : the initial balance is drawn from a normal distribution with average 10.000 € and standard deviation 2000
  - Set n.education with random value between 1 to 4 [39]
  - Set n.env.concern with random value between 0 to 1
  - Set n.e.independence with random value between 0 to 1
  - Set n.time.avail : the time availability is drawn from a normal distribution with average 30 and standard deviation 10

Creation of the neighbours

- Create number of suppliers 1
- Set up the initial balance of supplier 10000000

Set the environments

- Create and assign the anonymous procedure: when the variable is called, the agent will run the specific procedure only
  - Set case.n [[] -> c.case.n]
  - Set case (list case.n case.n+1 case.n+2 case.n+3 case.n+4 case.n+5 ...)
  - Set what-to-vote0 [[] -> d.case.0]
  - Set what-to-vote1 [[] -> d.case.1]
  - Set what.to.vote (list what-to-vote0 what-to-vote1)
- Create global variable
  - Set quorum = 1
  - Set no.supplier = 0
  - Set salary = 0
  - Set tariff 0.1903. This number is drawn from Qurrent energy tariff, which is 0.1903 [59]
  - Set member.discount 17.5. The member discount is assumed to be 17.5 €/ year, drawn from the member discount given by Qurrent to De Ramplaan Cooperatives [41].
  - Set real.market.price 0.035
  - Set subsidy 0.09
  - Set attendance.thres 10
  - Set real.tariff 0.04. The real.tariff represents kale inkooprijs in Qurrent energy tariff [59]
  - Set diff tariff - real.tariff ; the diff is assumed as the other variable cost that than the tariff, which need to be paid no matter they stay with energy supplier or not

A.1.2. Running Procedure

The running procedure consists of six main procedures mentioned in sequence diagram (Figure 3.8) before. The narrative and the pseudo-code for each procedure is described below.

To implement-decisions

1. Run each item in cooperative's decisions list
   - If the decision list is not empty, the run each item in case.list that match with the item in agent's decision list. The procedure for each case will be explained on different sub-section.
   - Case 0 represents the case which the agent invests privately
   - Case 1 represents the case which the agent invests collectively
   - Case 2 represents the case when the general assembly decides to go out from energy supplier
   - Case 3 represents the case when there is no one or less than 3 persons willing to be a candidate of the board
2. Calculate the bill
   - Define e.bill: electricity bill
     - If e.consumption > e.generation, then e.bill = tariff * (e.consumption – e.generation) – subsidy* e.generation – member.discount
     - If e.generation> e.consumption, then e.bill becomes the the additional income for the agent. However, they still need to pay the fixed cost (diff), therefore:
       - If no.supplier = 1, e.bill = - ((e.generation – e.consumption) * (market.price – diff) + (e.generation * subsidy))
       - If no.supplier = 0, e.bill = - (tariff – diff) * (e.generation – e.consumption)) + (subsidy * e.generation))

- Define invest.benefit: Investment benefit is defined as the comparison of the electricity bill with and without investment in e.generation
  - Invest.benefit = ((tariff * e.consumption) – e.bill) / (tariff * e.consumption))
  - max-i.benefit = max [invest.benefit] of cooperatives
  - min-i.benefit = min [invest.benefit] of cooperatives
- Define reduced.bill: it is defined as the evaluation whether it is still profitable to stay with the energy supplier or not. Each of them perceived the market price differently depend on their position as a board member or not. Here, the information asymmetry is introduced in the model
  - If board = 1 and no.supplier = 0 , then market price = (1 + random-normal 0.3 0.1 - random-normal 0.3 0.1) * real.market.price
  - If board = 0, then market.price (1 + random-normal 0.5 0.1 - random-normal 0.5 0.1) * real.market.price
  - Reduced.bill = (tariff – (market.price + diff)) / tariff

3. Calculate the collective investment

- total.investment = total.investment + investment
- min-invest = min [investment] of cooperatives
- max-invest = max [investment] of cooperatives
- avg-invest = mean [investment] of cooperatives

To evaluate-decisions

1. Define perceived.cost

- First, the cost is perceived from internal factor of an agent. Here, the agent evaluates the cost based on how much they invest at particular year towards their income at that year. It is defined by comparing the investment at particular year (this.year) and the current income (c.income). The higher the value means that they perceived the cost is higher
  - ori = this.year / c.income
- Second, the agents will be perceived their cost of investment based on the comparison with their peer. The agent will have imperfect information in this comparison
  - perception-min-invest = min-invest * (1 + random-float 0.05 - random-float 0.05)
  - perception-max-invest = max-invest * (1 + random-float 0.05 - random-float 0.05)
  - invest = max (list 0 (investment - min-invest)) / max (list 1 (max-invest - min-invest))
- Third, depend on their position as one of the board member or not, they will be perceived cost differently
  - If board = 1, then time.cost = work.hour/time.avail, skill.cost = 1
  - If board = 0, then time.cost = 0.2, skill.cost = 0
- Calculate the total.cost. Here, we need to standardise the value, so it lies between 0 and 1
  - perceived.cost = max (list 0 ((ori + invest + time.cost + skill.cost) / 4))

2. Define perceived.benefit

- First, the benefit is perceived from their own investment benefit (invest.benefit)
  - Ori = invest.benefit
- Second, the agent will be perceived the benefit as the comparison with their peer. The agent will have imperfect information in this comparison
  - perception-min-bill = min-bill * (1 + random-float 0.05 - random-float 0.05)
  - perception-max-bill = max-bill * (1 + random-float 0.05 - random-float 0.05)
  - r.bill.benefit = max (list 0 (reduced.bill- min-invest)) / max (list 1 (max-invest - min-invest))

- Third, depend on their decision to invest or not and their position as one of the board member or not, they will perceived benefit differently
  - If salary > 0 and board = 1, salary.benefit = 1, else salary.benefit = 0
  - If decisions != [], then if item 0 of decisions = "0" or item 0 of decisions = "1", then motivation.benefit = 1
- Calculate total.benefit. Here, we need to standardize the value, so it lies between 0 and 1
  - perceived.benefit = max (list 0 ((ori + reduced.bill + r.bill.benefit + motivation.benefit + salary.benefit) / 5))

3. Define the willingness to participate

- First, the trust need to be calculated. It is defined as how much (perceived) outcome discrepancy that they have. This outcome discrepancy is defined as how big the outcome gap between themselves with their peer (% coverage of agent in their connection list).
- Moreover, this trust also depends on the community situation. In this case it depends on whether the quorum was satisfied or not and whether they attend the general meeting or not
  - outcome = outcome + abs (perceived.benefit – perceived.cost)
  - discrepancy = mean [outcome] – (perceived.benefit – perceived.cost) of myself
  - if abs (discrepancy) > 0.5, then outcome.discrepancy outcome.discrepancy – abs (discrepancy)
  - community.trust = (quorum + outcome.discrepancy + attendance) / 3
- Calculate the willingness to participate.
  - will.participate = 0.307 + 0.271 * community.trust + 0.147 * env.concern + 0.158 * e.independence + 0.117 * (education / 4)

4. Define the influence: The influence of each agent is defined based on their willingness to participate, their education, number of connection and the money that they have. The higher the value the more influence that they have.

- max.connection = max [numb.connection] of cooperatives
- min.connection = min [numb.connection] of cooperatives
- conn = (numb.connection - min.connection) / max (list 1 (max.connection - min.connection))
- money = (investment - min-balance) / max (list 1 (max-balance - min-balance))
- influence =(will.participate + (education / 4) + conn + money) / 4

To what-to-vote

1. Set the list to empty list
   - board.choice = []
   - what-to-vote-case = []
2. Ask each board member to determine the what-to-vote in general assembly
3. "0" represents the case which the board choose to ask the cooperatives to consider new collective investment
4. "1" represents the case which the board choose to ask the cooperatives to consider withdrawal from the energy suppliers
   - if balance > 0 and will.participate >= investment.threshold, then board.choice = fput "0" board.choice
   - if reduced.bill > reduced.bill.thres, then set board.choice = fput "1" board.choice
5. Set what-to-vote-case = modes board.choice

To define-aspirations

1. Set the list to empty list
   - Decisions = []
   - Collect.aspiration = []
2. Run each item in what-to-vote-case list
3. If "0" is in the list, then define whether the agent want to invest or not, and whether it will be private investment or collective investment
   - If will.participate >= investment.threshold, if balance > 20000, then decisions = fput "0" decisions, if balance > 325 then collect.aspiration = fput "1" collect.aspiration
4. If "1" is in the list, then define whether the agent want to change some rules or not
   - If reduced.bill > reduced.bill.threshold, then collect.aspiration = fput "2" collect.aspiration
5. Sort the decision, and collect.aspiration in ascending order
   - decisions = sort decisions
   - collect.aspirations = sort collect.aspirations

To vote

1. Before the voting happen in general assembly, based the cooperative will proceed the withdrawal of membership and they share their aspiration in the social-network. When the member withdraw their membership, they cannot be a member again in the future.
   - Foreach cooperatives (x) -> ask x ()
   - If will.participate <= withdrawal.threshold and (perceived.benefit – perceived.cost) < 0, then die
   - If any? connection.list with [influence > [influence] of self and distance myself <= coverage * 40] and [influence] of myself < mean [influence] of cooperatives with [board = 1], then collect.aspiration = collect.aspiration of the one who has the most influence and distance myself <= coverage * 40 in the connection list
2. Set several lists into empty list
   - assembly.decision = []
   - candidate.list = []
   - voteboard.list = []
   - my.choice = []
3. The voting procedure starts with the decision whether the agent wants to attend general assembly or not.
   - Foreach cooperatives (x) -> ask x()
   - If board = 1, then set attendance 1
   - Ifelse board = 0 and time.avail <= attendance.threshold or will.participate <= withdrawal.thres, then attendance = 0, else attendance = 1
4. Candidature process is a process to determine the potential leader. Here, the potential leader is the one that has time, skill, connection, willingness to participate and invest above average of the agent in the cooperative.
   - Foreach cooperative with [time.avail >= work.hour and investment >= avg-invest and education > 2 and will.participate >= avg.participate and numb.connection >= pareto], candidature = 1

- If length (list cooperative with [candidature = 1] < 3, then foreach (list cooperatives with [time.avail >= work.hour and will.participate >= 0.8 and numb.connection >= pareto]), candidature = 1
- candidate.list = list cooperatives with [candidature = 1]

5. Voting for the board
   - If length candidate.list < 3, then if balance > (salary * number of board) / number of cooperatives, then collect.aspiration = fput "3" collect.aspiration
   - Else, foreach cooperative with [attendance = 1], my.choice = candidate that has education > 2 or at least they have same aspiration with myself
   - voteboard.list = my.choice + voteboard.list
   - majority = three highest vote from voteboard.list
   - majority = n-of (min (list 3 length modes voteboard.list)) modes voteboard.list
   - foreach (list cooperatives with [candidature = 1]), if item 0 majority = [who] of self or item 1 majority = [who] of self or item 2 majority = [who] of self, board = 1
6. Voting for the change of rules
   - Check whether the quorum is satisfied. If count cooperatives with [attendance = 1] >= 2/3 * count cooperatives, then run vote.case.0, quorum = 1
   - Else, run vote.case.1, quorum = 0
   - Vote.case.0 is the case which the decision is valid when at least 50% + 1 of attendance vote for it
   - Vote.case.1 is the case which the decision is valid when at least 2/3 of attendance vote for it
   - The detail procedure for each case will be described later

To eoy

1. Update decisions and balance for each agent
   - decisions = assembly.decision + decisions
   - sort decisions
   - balance = balance + c.income – e.bill
   - add.econsumption = random-normal mean.addeconsumption std.addeconsumption
   - e.consumption e.consumption + add.econsumption
2. Update income of suppliers
   - income = max (list 0 (real.tariff * (total-e.consumption - total-e.generation))) - max (list 0 (real.market.price * (total-e.consumption - total-e.generation))) + max (list 0 (real.market.price * (total-e.generation - total-e.consumption))) - count cooperatives * member.discount
   - balance.supp = balance + income
   - if income <= 0 and balance.supp > 0 , member.discount = max (list 0 ((1 - random-float 1) * member.discount
   - if income <= 0, increase = real.market.price * random-float 0.5, real.tariff = real.market.price * (1 + increase), tariff = tariff * (1 + increase)
3. Creating new connection
   - Foreach cooperative with attendance = 1
   - new.partner = one-of cooperatives with [attendance = 1 and numb.connection > [numb.connection] of myself]

- if new.partner != nobody, create-link-with new-partner, numb.connection = numb.connection + 1, connection.list = connection.list + new.partner
- ask new-partner, numb.connection = numb.connection + 1, connection.list = connection.list + new.partner

4. Update the Pareto

   - Pareto = pareto
   - foreach (list cooperatives with [numb.connection >= pareto]) [[x] -> ask x [ask my-links [set color red]]]

5. Add new member

   - Ask 5 neighbours
   - surround.benefit = surround.benefit + perceived.benefit of neighbors
   - surround.cost = surround.cost + perceived.cost of neighbors
   - if surround.benefit > surround.cost and n.will.participate > withdrawal.threshold , hatch-cooperative 1, run new-member procedure

A.1.3. Additional Procedure

To new-member

- set shape "dot"
- set color blue
- set size 0.5
- set balance [n.balance] of myself
- set decisions []
- set decisions sentence assembly.decision decisions
- set collect.aspiration []
- set attendance 1
- set education [n.education] of myself
- set time.avail [n.time.avail] of myself
- set env.concern [n.env.concern] of myself
- set e.independence [n.e.independence] of myself
- set investment.list []
- set e.consumption random-normal 8000 500
- set outcome.discrepancy 1
- set numb.connection 5
- set connection.list other n-of numb.connection cooperatives
- set c.income random-normal 1000 200
- foreach (list connection.list) [[x] -> ask x [create-link-with myself [set color grey]]]

To case.0

This is the case which the agent decides to invest privately. This procedure is called from implement-decisions procedure, that originally comes from the decisions list of the agent. When this procedure is called, it will update several variables of the agent.

- e.generation = e.generation + 5600
- investment = investment + 20000
- balance = balance – 20000
- investment.list = investment.list + 1
- this.year = this.year + 20000

To case.1

This is the case which the general assembly decides to invest collectively. This procedure is called from implement-decisions procedure, that originally comes from the decisions list of the agent. When this procedure is called, it will update several variables of the agent.

- If balance > 325, then
- e.generation = e.generation + 225
- investment = investment + 325
- balance = balance – 325
- investment.list = investment.list + 2
- this.year = this.year + 20000

To case.2

This is the case which the general assembly decides to go out from energy supplier. This procedure is called from implement-decisions procedure, that originally comes from the decisions list of the agent. When this procedure is called, it will update several variables of the agent and global variable.

- Since there is no supplier anymore, the board will have better information about the market price
- market.price real.market.price

To case.3

This is the case when there is no agent or less than 3 agents wants to be board member. In this case, it is assumed that the cooperative will give the board salary to increase the attractiveness to be a board member.

- balance = balance - (2000 * number of board / (count cooperatives))
- if board = 1, the balance = balance + salary

To vote.case0

In case that the quorum for general assembly is satisfied, the "to vote" procedure will run this additional procedure.

- rule.vote = []
- rule.vote = collect.aspiration + rule.vote
- attendance.list = count cooperatives with [attendance = 1]
- if length filter [i -> i = "1"] rule.vote > 0.5 * attendance.list, assembly.decision = fput "1" assembly.decision

- if length filter [i -> i = ”2”] rule.vote > 0.5 * attendance.list, then
  1. assembly.decision = fput ”2” assembly.decision
  2. work.hour = work.hour + 6
  3. no.supplier = 1
  4. tariff = diff
  5. member.discount = 0
  6. ask suppliers [die]
- if length filter [i -> i = ”3”] rule.vote > 0.5 * attendance.list, then
  1. assembly.decision = fput ”3” assembly.decision
  2. salary salary + 2000
- set assembly.decision sort assembly.decision

To vote.case1

In case that the quorum for general assembly is not satisfied, the “to vote” procedure will run this additional procedure.

- rule.vote = []
- rule.vote = collect.aspiration + rule.vote
- attendance.list = count cooperatives with [attendance = 1]
- if length filter [i -> i = ”1”] rule.vote > 2/3 * attendance.list, assembly.decision = fput ”1” assembly.decision
- if length filter [i -> i = ”2”] rule.vote > 2/3 * attendance.list, then
  1. assembly.decision = fput ”2” assembly.decision
  2. work.hour = work.hour + 6
  3. no.supplier = 1
  4. tariff = diff
  5. member.discount = 0
  6. ask suppliers [die]
- if length filter [i -> i = ”3”] rule.vote > 2/3 * attendance.list, then
  1. assembly.decision = fput ”3” assembly.decision
  2. salary salary + 2000
- set assembly.decision sort assembly.decision

B

The Model

The verification and final model can be found in this drive https://drive.google.com/open?id=0B3n9a3Zi03owRm1WZ1k0S2ZhZ2M

- final model = EP1.22
- verification model = EP1.22 (verification)
- the result = EP1.22 parameter sweep0-29 ,EP1.22 parameter sweep30-59, EP1.22 parameter sweep60-99
- the R script for data analysis = Data.Analysis.R

C

Latin Hypercube Sampling (LHS)

The R files for experiment design using Latin Hypercube Sampling and the LHS data-set for the experiment can be downloaded using this link
https://drive.google.com/open?id=0B3n9a3Zi03owRm1WZ1k0S2ZhZ2M.

- the R script for creating LHS sample = Experiment.Design.LHS (1).R
- the result = lhs50.csv & lhs100.csv