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Article

Theorizing for Maintenance Management Improvements: Using Case Studies from the Icelandic Geothermal Sector

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Abstract: As renewable energy sectors evolve and grow within a country, the need for expertise to maintain its infrastructure grows. Such expertise is often provided by foreign industries. It is in the global interest to facilitate expertise to grow domestically, eventually leading to widespread clusters of industries around a renewable energy sector and a global growth of expertise. This ultimately fast tracks the development in the renewable energy sector since more players become active in developing solutions. In this article the factors influencing domestic development are identified from previous studies conducted within the Icelandic geothermal sector. The cause and effect relationships between the identified factors are then mapped. A system dynamics causal loop diagram based on Icelandic case studies is presented to visualise how the formation of industrial clusters in the renewable energy sector can be initiated. This visualisation, based on the Icelandic geothermal sector, can be of use for other industries in the renewable energy sector who are attempting to conduct their maintenance procedures domestically and increase the rate of innovation within a country.

Keywords: cluster theory; renewable energy; innovation; geothermal; maintenance

1. Introduction

It is estimated that easily reachable oil and gas will be depleted within the next fifty years. It is further anticipated that easily reachable coal will be depleted within the next century or so [1]. Fossil fuel energy sources have driven industrial processes and the ever increasing quality of life amongst the western nations over the past century. They have allowed for previously unknown levels of consumption and wealth relative to pre-industrial times. The depletion of these sources is of increasing concern because the effect of their depletion on human societies is virtually unknown. It is also known that on-going consumption of these sources is accompanied by severe environmental impacts [2]. One way to mitigate the effects of climate change and adapt to the ever increasing scarcity of non-renewable energy sources is to increase the use of renewable energy. The current development in the renewable energy sector is, however, not fast enough for renewable energy to compensate for a significant amount of fossil fuel use. British Petroleum (BP) expects global primary energy demand to increase by 41% before the year 2035, most of which will happen within the non-OECD (Organisation for Economic Co-operation and Development) countries [3]. By 2035, BP anticipates that renewable energy sources will grow from their current level of 2% to contribute about 8% of the world's energy supply [3]. An increase in the share of renewable energy sources can contribute to social and economic development, and can also accelerate energy access (especially in the developing world). It can increase energy supply security and some renewables can contribute to reduced greenhouse gas (GHG) emissions [4]. With this in mind, it should be of great importance to increase the rate of innovation and increase efficiency in the global renewable sector. These developments could potentially contribute to the benefits that were previously mentioned. Even though economic crisis is sometimes considered to have a negative impact on innovation, research, and development [5], crisis is also often seen to be the source of innovation. For example, the oil crisis in the 1970s pushed Icelandic society towards geothermal energy utilisation because domestic oil heating became very expensive.

During the 2008 global financial crisis, the cost of maintaining the Icelandic geothermal power plants grew immensely. This can be attributed directly to the devaluation of the Icelandic Krona, rising oil prices, and the relationship between power plant maintenance and energy prices. Even though some power plant maintenance had previously been conducted domestically, this crisis pushed many Icelandic energy companies to begin attempting to solve problems domestically that had previously been outsourced. This was mostly focused on expensive machinery such as turbines, that required costly, specialised, knowledge. Conducting this maintenance domestically required a build up of skills and knowledge within Iceland, since it had either not been present or was in shortage. This knowledge and skill transfer (KAST), originating to some extent in the 2008 global financial crisis, has resulted in a growth of expertise within the country. Icelandic industries are now almost fully capable of servicing the geothermal sector themselves. The knowledge and skills to conduct specialised, costly maintenance were previously sought internationally from a dispersed group of specialised industries. As the Icelandic geothermal companies began to seek solutions domestically, Icelandic industries, such as machine shops, began to address and solve problems that had previously been solved internationally. The KAST can also be regarded as an industrial cluster formation because the Icelandic industries who were beginning, or improving, their domestic services for the geothermal energy companies were all located within the same geographic region. It is simply a matter of time until these Icelandic industries enter global markets, providing domestically developed solutions.

During a time of crisis, problems may become to large to ignore. This was the case for the Icelandic geothermal industry, whose major maintenance activities that had previously been outsourced became simply to expensive. A method to facilitate this innovation without having an initial crisis would, however, be preferred in every case because a crisis may often lead to significant financial loss and cannot be controlled as desired. Even though various methods and tools are available to improve the rate of innovation, it is the intent of this article to show how the Icelandic geothermal sector managed to move major and expensive maintenance activities to Iceland. As a method to visualise the process of this cluster formation, a system dynamics causal loop diagram is presented, which is based on the Icelandic geothermal industry as it moved its major maintenance procedures to Iceland after the 2008 global financial crisis. The model provided was generated using a series of case studies within the geothermal industry, which were conducted by the authors and published in the scientific literature. The contents of this article are investigated in the context of cluster theory, where the theory is used to describe the concentration of industries around the renewable energy sector, in particular the Icelandic geothermal sector.

1.1. Cluster Theory

Industrial clusters can be defined as "geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions in a particular field that compete but also cooperate [6]".

Players within a cluster include providers of specialised products and services, infrastructure providers, governmental institutions, think tanks, and trade associations who provide technical support that benefits or contribute to a specific sector. Clusters are an important competitive advantage because other factors that were previously important, such as access to non-scarce resources, are becoming less important as global logistics serve the need for resource transportation. For example, aluminium smelters are located in Iceland but the country lacks any bauxite resources. In addition, deploying sophisticated technology is not a factor because industries can freely use modern technology in their production. In pre-modern times, the technology that was available in one region was not so easily transferred or available to another region, today this is not the case. It then becomes clear that infrastructure, the legal environment, and the services that are located in geographic proximity to a particular industry have become a significant factor in how competitive the industry eventually becomes [7,8]. Being a part of a cluster increases productivity as access to inputs, information, technology and relevant institutions improves. As a cluster forms, the formation becomes self-reinforcing. This is further increased when the public sector is supportive and competition is present [7]. In cluster theory, the role of the government is to remove obstacles to industrial growth and achieve macroeconomic and political stability. It should, according to cluster theory, improve general microeconomic capacity "through improving the quality and efficiency of general-purpose inputs to business and the institutions that provide them" [6]. Regardless of the effectiveness of public policy, it has been shown that a cluster takes a decade or more to develop a competitive advantage [7].

A cluster's absorptive capacity is the "capacity of firms to establish intra- and extra- cluster knowledge linkages" [9]. This is the capacity of a cluster to gather knowledge from the outside and effectively distribute this knowledge on the inside. However, when digging deeper into cluster theory, it can be seen that the knowledge flow is not equally distributed between firms within a cluster. In fact, clustering may isolate some firms while others increase their collaboration. In addition, even though business flows are frequent between firms within a cluster, knowledge flow does not necessarily follow. This has been observed when wine clusters have been studied in Italy and Chile [10]. A sectoral system is in essence the same as a cluster. The players within such a system interact through cooperation, competition, exchange, and communication [8]. Clusters, or sectoral systems, are also a dynamic phenomena that is constantly changing [8]. This happens because firms who seek new markets tend to modify their business behavior or begin interacting with other components of a cluster in a different manner. It has furthermore been stated that a firm's value cannot only be seen from the patents issued, staff, and machines owned, but should also be seen in its participation and involvement within a cluster [11].

The literature is rich with information on the effects of cluster cooperation and how innovations are more likely to grow out of such environments [6,12,13]. Benefits have been shown to be partly due to the close geographic proximity of relevant industries, information, complementary relationships, and competitive pressure [14]. An example of this can be found in the technology industry in Silicon Valley, California. Industrial clusters are, however, not bound to be based on a single geographical location for each industry. A sector possibly benefits from having multiple clusters that are spread globally. If multiple clusters are operating around the same sector, an improved rate of innovation and development may possibly be experienced. The structure of a cluster is dependent on the "characteristics of technologies used, social norms and institutional factors that outline the rules followed" within the clusters [11]. Industrial clusters are a key factor in a nation's innovative capacity [13], it is therefore of great importance to facilitate clusters within a nation where the foundations for such a collaboration are sound. This importance is amplified when the need for faster development within a sector is desperately needed, such as within the renewable energy sector. Cluster formations, rather than the dispersion of industries, could potentially serve as the catalyst needed for the renewable sector to have the significant impact it needs to have within the global energy use portfolio. An impact that increases the access to renewable energy globally.

Even though the literature is rich with information about the benefits of cluster cooperation, it suffers from a lack of methods to initiate clusters where they do not currently operate. It has been attempted to fill this gap, with some success [14]. By conceiving a non-simulated system dynamics model, it has been shown how an industrial cluster effect may be achieved [14]. The previously proposed model is, however, based on a literature review rather than on case studies that are conducted by the authors. Others have attempted to simulate the agglomeration of industries within a region and show how knowledge and proximity effect the behaviour of a technology district [15]. These studies have, however, not shown how a cluster can be formed but rather the benefits of the proximity of players within an industrial cluster. The benefits of using a system dynamics causal loop diagram have been shown to be a convenient way of depicting a cluster behaviour [14,15]. Behaviours of industries within sectors, and the sectors themselves are not static. Industries evolve, compete, collaborate, perish and flourish. One way to describe a swift change in behaviour is to look at unforeseen, catastrophic, unwanted or any events forcing a change in behaviour for industries. Such events are often called disruptive events, leading to a so called quantum shift.

1.2. Quantum Shifts

Disruptive events often lead to a shift in behaviour, this is well known in natural evolution as well as in the corporate sector. Disruptive events are non-controllable events that force industries to modify their operational behaviour. Disruptive events can be felt in various forms for different industries, such as increased competition, modification in the legal or policy environment, or even ecological change, such as climate change. As mentioned, this process also happens in nature, but the focus of this article is on business. Disruptive events leading to adaptation are called quantum shifts or punctuated equilibria [16,17]. For industries to survive after a disruptive event, they must radically improve competitive innovation, new value creation, and create and distribute knowledge [16]. A graph depicting a business development before, during, and after a quantum shift can be seen in Figure 1. This graph, however, assumes that the industry has survived the disruptive event and continues to operate after the quantum shift. This is not necessarily correct because many businesses cease to exist after a disruptive event. A disruptive event can also be felt in the form of competition, such as an introduction of a service or a product on the marketplace by a competitor. However, a quantum shift does not necessarily lead to an elevated performance in the same business or operational direction prior to the disruptive event initiating the shift. Indeed, corporations may need, or see potentials, in shifting their direction of operation. This may include new market opportunities or introducing a new emphasis in their operations.

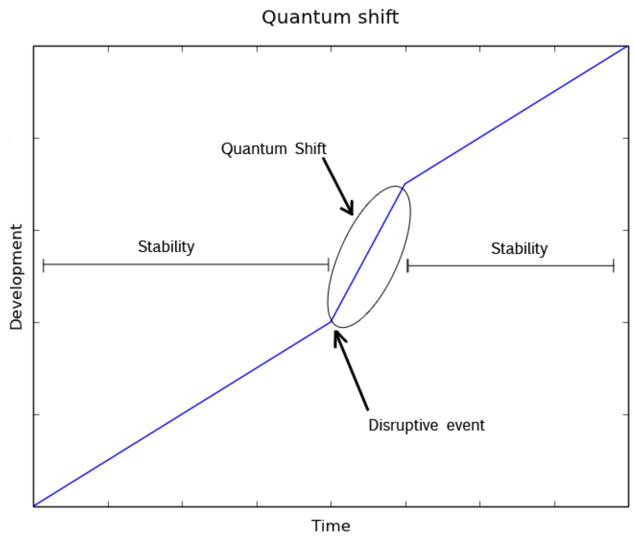

Figure 1. The effects of disruptive events on the operation and development of corporations.

Figure 2 depicts a quantum shift when the operational direction is subsequently altered. A disruptive event, such as a financial crisis, may facilitate a quantum shift for a whole industrial sector of a country rather than individual companies. In Iceland for example, the 2008 global financial crisis served as a disruptive event that forced the geothermal sector as a whole to face new challenges. As the Icelandic currency devalued dramatically, oil prices rose as did the price of spare parts for the power plants, since the price of oil and spare parts is linked. The value of Iceland's debts also rose because they were issued in foreign currency. This all lead to increased costs in the operation and maintenance of Icelandic power plants. The challenges faced were addressed effectively and this has led to further domestic collaboration that continues to thrive. To gain a good understanding of the Icelandic geothermal sector, one must understand who the main players are within the sector. The following section aims to provide such understanding.

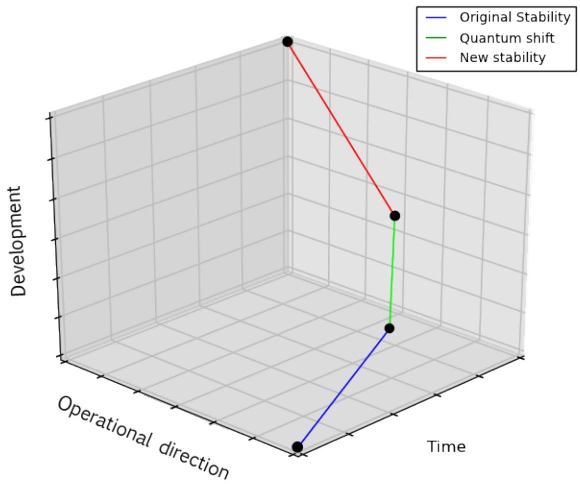

Figure 2. A quantum shift that includes a possible change in operational direction.

2. Key Facts about the Icelandic Geothermal Sector

In this chapter the Icelandic geothermal power plants and the industrial cluster environment that they engage in are described.

2.1. Icelandic Geothermal Power Plants

Six geothermal power plants operate within Iceland. In 2008, the accumulated production amounted to 4.038 GWh (Gigawatt hours) of electricity [18]. The plants are Bjarnarflag (3.2 MWe (Megawatt electrical)), Hellisheidarvirkjun (303 MWe), Krafla (60 MWe), Nesjavallavirkjun (120 MWe), Reykjanesvirkjun (100 MWe), and Svartsengi (76.4 MWe) [18]. Staff from all of the energy companies operating these power plants participated in this research. Icelandic power plants manage to keep a small amount of staff on site while keeping the plants operating without major problems. At Svartsengi and Reykjanesvirkjun (both operated by HS Energy), a staff of approximately 20 people are responsible for the plant maintenance and operations. This staff consists of mechanical and electrical engineers, and earth and environmental scientists. The employees attend to 12 turbines (five steam and seven Organic Rankine Cycle), 36 cooling fans, 17 geothermal wells, wellheads, 70 control valves, 100 pumps, 20 km of pipelines, and a vast amount of valves that all need regular maintenance [19]. A similar situation can be found in the other Icelandic plants, such as Nesjavellir and Hellisheidi, who operate with a total of only 26 employees in each plant [20]. The engineers operate the plant and conduct maintenance. The head of the plant engineering department answers directly under the plant manager. The company CEO is in all cases in direct contact with the plant managers. The plant engineers conduct a great amount of maintenance on site, in collaboration with domestic workshops. It has been stated publicly that the largest geothermal utilisers in Iceland are attempting to fully transfer all of their maintenance activities to Iceland. According to the plant manager at Nesjavellir, the efficient management of the power plants can be attributed to a great extent to the experience that their engineers acquired when working as marine engineers on fishing vessels [21]. Marine engineering education in Iceland is also more detailed than international standards require. At sea, marine engineers can only rely on themselves for repairs, regardless of the prevailing weather conditions, which requires them to adapt a certain mentality, this is especially true for the chief engineer. This mentality is much appreciated by the power plant chief engineers and it includes the notion of unity at site and resourcefulness in order to keep the vessel (in this case the plant) running at all costs. Consequently, the energy companies tend to prefer marine engineers that have worked as chief engineers.

2.2. Domestic Collaboration

Corporations in general tend to outsource more of their non-core activities than they have previously done [22]. This allows companies to focus on other important issues, such as differentiation in the market place or cost leadership [12]. However, industries may depend on non-core activities for successful operations. Non-core activities may become a financial burden that the corporation can solve with lower costs. Outsourcing can also lead to failures because the customer's expectations are not met. Outsourcing also creates dependency on the contractor. Not outsourcing allows the corporation to build knowledge and potential value; however, this is followed by an increase in other costs. Therefore, an industry must analyse the potentials fully before deciding to conduct previously outsourced procedures themselves. Furthermore, by not outsourcing. the corporation becomes independent and frees it from relying on a contractor for its operations. However, a balance is needed between outsourced services and those addressed by the organisation itself.

Various players within the Icelandic geothermal sector have engaged in a conversation on further collaboration in the operation and management of the Icelandic geothermal power plants [23]. These players include energy companies, utility companies, machine shops, banks, universities, research facilities, engineering consulting firms and others [24]. It has been shown that by domestically conducting the operational and maintenance tasks, sometimes overseen by foreign specialists, domestic know-how and experience could be increased and currency be kept within the country. Such procedures could potentially allow domestic service providers to enter foreign markets. Experiments have been conducted on geothermal steam turbine parts and the possibility for such parts to be produced domestically has been analysed. Such experiments have often proved successful. Some experiments were conducted fully by domestic machine shops but some were also conducted in collaboration with foreign specialists. Collaboration with foreign industries contributes to KAST to Iceland and can, therefore, be seen as beneficial to some extent.

Two mutual platforms have been established to smooth the communication platform between all parties: one platform is business driven, while the other is research driven. The business driven platform is called Iceland Geothermal and the research driven platform is called the Geothermal Research Group

(GEORG). The business driven platform is organised by a private entity, which facilitates lectures and provides a communication platform.

Discussion has been ongoing in both the scientific and popular literature about the possibilities of a domestic cluster that builds on Iceland's knowledge of geothermal energy utilisation. This is expected to be a good way to improve the opportunities for domestic industries to serve the geothermal sector in the coming future [23]. The knowledge created within this cluster is expected to be of value to all participating companies. The Icelandic geothermal cluster has been defined as a business driven cluster. GEORG is also a geothermal cluster but is research driven and funds various geothermal based research [25]. GEORG consists of 22 multi-national research driven partners, ranging from universities and public companies to private partners. A connection, both internally and to private industries within the cluster, can also be considered to be a factor for the efficient operation of these power plants. Given the small scale of the Icelandic economy, relatively few service projects are conducted per year and domestic service providers are forced to use their employees for servicing other industries, such as fishing and aluminium. Together, these industries work together to help to support the buildup of domestic knowledge and expertise. By servicing various industries, Iceland's service providers can keep up the number of projects required to maintain their employees. In addition, solutions developed and implemented for one industry can be adapted to another.

The collaboration described above became increasingly visible after the global financial crash. The Porter report [23] can be viewed as a landmark for the visualisation of its benefits. The cluster and the collaboration were already forming before the 2008 financial crisis. However, the 2008 events pushed the Icelandic geothermal industry towards further developments domestically, especially with regards to the most expensive maintenance procedures, namely the turbines. The benefits after this quantum shift occurred are, however, attractive for industries involved in the renewable energy sector, although the initial seed is not. Theorizing for such developments is partially the focus of this article.

2.3. Article Intent and Content

The aim of this article is to gather vital information from a series of case studies that were conducted by the authors and then present a causal loop diagram depicting how cluster formation may partially be initiated. The introduction provides background information describing the importance of domestic industrial clusters to the global renewable energy sector. Subsequently, the methodologies used in each case study are briefly described. The results from the case studies are then used to form the results chapter. A causal loop diagram is shown to demonstrate the behaviour of the Icelandic geothermal industrial cluster. The limitations of this research, suggestions for future research, and general discussions about the developed diagram are provided in the discussions chapter.

3. Methodologies

This section will discuss theory building and describe how the research was planned, eventually providing a description of how and why each case study was conducted.

3.1. Theorizing and Case Studies

The construction of theory from case studies is a strategy that includes one or several case studies that are used to conceive theories or propositions [26]. Case research has been used as a powerful research tool in the development of new theory [27]. Calls have been made for more field-based research simply to keep up with technological changes in managerial methods within operations managements [28]. By conducting field case research, theory is not merely improved or enriched but, equally or more importantly, the researcher themselves are also enriched [27]. However, case research has various challenges, such as time consumption [29], the need for skilled interviewers, and the care needed to draw conclusions [27]. This is amplified when a series of case research studies are to be conducted in theory building. Case research assists with answering how and why questions and it is also good for theory building. Conducting case based research has several benefits [30]:

- The study is conducted within the natural environment of the phenomena, which allows for an observation of real practice.
- Why, what, and how questions can be answered with a great understanding of the phenomenon.
- Early investigations where variables are unknown and the phenomenon is unclear are suitable for case studies.

Various researchers have defined the methodology for case based theory building in a similar manner [27,31]. The steps are outlined in Table 1. Interestingly, even though case based research is praised by some researchers and calls have been made for such research, only a minority of operations management articles are actually case based. The research model has been defined as having five stages, as follows: (1) define the research question; (2) instrument development; (3) data gathering; (4) data analysis; and (5) dissemination [29,31]. In fact, the case based theory building process that is presented seems to be generally accepted by researchers in operations management [31]. Furthermore, it has been stated that service design is one of the potential areas for future operations management research, which is partially the focus of this article [29].

3.2. This Research in a Theoretical Context

In the context of this research, it was decided to follow the guidelines that are shown in Table 1 [31]. Case studies were conducted to answer the questions posed in each step. The theory building process used in this article is also found to be relevant to other theory building procedures demonstrated in the literature, hence its validity [32].

The results of each step were published in the scientific literature for approval, either in journals or peer reviewed conference proceedings.

Even though the methodology to fully construct a theory has been described [31,32], because the proposed model has not been tested, it is not our intent to fully form a theory in this article but rather to theorize. This includes the first three steps in Table 1. This article is a step on the way towards a theory.

Table 1. The theory building process as presented in the literature [31].

Purpose	Research Question	Research Structure	Examples of Data Collection Techniques	Examples of Data Analysis Procedures
1a. Discovery * Uncover areas for research and theory development	* What is going on here? * Is there something interesting enough to justify research	* In-depth case studies * Unfocused, longitudinal field study	* Observation * Interviews * Documents * Elite interviewing	* Insight * Categorization * Expert opinion * Descrptions
1b. Description * Explore territory	* What is there? * What are the key issues? * What is happening?	* In-depth case studies * Unfocused, longitudinal field study	* Observation interviews * Documents * Elite interviewing * Critical incident * Technique	* Insight * Categorization * Expert opinion * Descriptions * Content analysis
2. Mapping * Identify/describe key variables * Draw maps of the territory	* What are the key variables? * What are the salient/critical themes, patterns, categories?	* Few focused case studies * In-depth field studies * Multi-site case studies * Best-in-class case studies	* Observation * In-depth interviews * Diaries survey questionnaires * History * Unobtrusive measures	* Verbal protocol * Analysis * Cognitive mapping * Repertory grid technique * Effects matrix * Content analysis
3. Relationship building * Improve maps by identifying the linkages between variables * Identify the "why" underlying these relationships	* What are the patterns or links between variables? * Can an order in the relationship be identified? * Why should these relationship exist?	* Few focused case studies * In-depth field studies * Multi-site case studies * Best-in-class case studies	* Observation * In-depth interviews * Diaries survey questionnaires * History * Unobtrusive measures	* Verbal protocol * Analysis * Cognitive mapping * Repertory grid technique * Effects matrix * Content analysis * Factor analysis * Multidimensional * Scaling * Correlation analysis * Nonparametric analysis
4. Theory validation * Test the theories developed in the previous stages * Predict future outcomes	* Are the theories we have generated able to survive the test of empirical data? * Did we get the behavior that was predicted by the theory?	* Experiment * Quasi-experiment * Large scale sample of population	* Structured interviews * Documents * Open and closed-ended questionnaires * Lab experiments * Field experiments * Quasi experiments * Surveys	* Triangulation * Analysis of variance * Regression * Analysis * Path analysis * Survival analysis * Multiple comparison procedures * Nonparametric statistics
5. Theory extension/Refinement * Expand the map of the theory * Better structure the theories in light of the observed results	* How widely applicable/ genera-lizable are the theories developed? * Where do the theories apply? * Where do they not apply?	* Experiment * Quasi experiment * Large scale sample of population	* Structured interviews * Documents * Open and closed-ended questionnaires * Lab experiments * Field experiments * Quasi experiments * Surveys * Documentation * Archival research	* Triangulation * Analysis of variance * Regression * Analysis * Path analysis * Survival analysis * Multiple comparison procedures * Nonparametric statistics * Meta analysis

3.3. Case Studies Conducted

The cluster formation will be visualised using a qualitative method. A system dynamics approach is used without simulation because it is not our intent to simulate the rate of formation of a cluster but rather to visualise which factors may initiate such formation.

To visualise the connection between different players within the Icelandic geothermal industry and to create a systems dynamics model, case studies were carried out that focused on various themes. The themes were selected after multiple meetings with chief maintenance engineers at the power plants and machine shops, and meeting with the staff at innovation and cluster centers. The themes that we studied required us to answer some questions that fitted within the theory building process as described in the literature [31].

- Domestic service providers in the geothermal industry.

  This part describes how domestic industries are currently addressing major maintenance issues with regards to geothermal steam turbines in Iceland. It will examine how they collaborate and which products are being manufactured domestically [33,34]. When critical failures occurred, the repair process was visualised and the communication chain was identified. It was seen that domestic repairs were conducted in a more economical and faster way. This resulted in shorter down-time of the turbine and a subsequent lower loss of output. It was also shown that knowledge was building up within the machine shops and the energy company. During one study, where the current turbine operations and maintenance procedures were examined, it was seen that the operations and frequency of overhauls on geothermal turbines is changing as the staff becomes more experienced. Problems are analysed in collaboration with the Icelandic innovation center and also with the machine shops. If a solution is viable when looking at performance, then it was developed further. In this case, a faulty setting on a valve lead to the breakdown of the labyrinth packing. The problem was analysed and a repair, with an improved version of the labyrinth packing, was conducted on-site in collaboration with a domestic machine shop.

- Corporate culture with regard to innovation.

  The development of a geothermal control valve was examined: first, from the corporate viewpoint of how the development process occurred within the company; and secondly, from the technical side of how the valve operates, is manufactured, and tested [35,36]. This allowed for a clear visualisation of a successful innovation process within the geothermal industry. A willingness to try the development of a solution posed by a staff member was observed because of a lack of solutions available to the problem observed and also because of the possible financial viability of the solution since it was to be produced domestically. It was shown that the CEO of the energy company allowed the staff member a certain degree of freedom to develop the proposed valve solution. This included funds for prototyping, and specialised consulting and testing. The valve became the standard for control valves within that particular company. A machine shop was included in the development process, allowing for the knowledge about the manufacturing side of the valve to be located in a geographic proximity to its final use. The valve is currently fully manufactured and used domestically.

- The effects of the operation engineer's previous experience.

  This research also outlined the Icelandic geothermal cluster, and described who the main players are and how they are interconnected. It was seen that maintenance engineers operating within the energy companies possess a certain characteristic, perhaps because of their naval experience. The mentality brought to the geothermal power plants by naval engineers was statistically examined [24]. The engineers were found to be less considerate and less likely to seek supervisory opinion than regular workers on the market. It was noted that the naval engineers need to repair any failures on board while on the ocean. The same was seen with maintenance engineers in the geothermal power plants, who are very confident and willing to try developing domestic solutions.

- The effects of operational experience

  The way that operational experience effects planning was visualised with regards to the wellheads at Hellisheidi geothermal power plants. Real data was gathered and statistically analysed [37]. This study was conducted to analyse how a maintenance pattern evolves with time as operational experience is gathered among staff. By using a Weibull survival distribution for the analysis, it was shown that the frequency of maintenance does in fact change with time, diverting from the original recommendations made by engineering consulting firms. This is also in line with the previous observations of the engineers' characteristics.

- Identification of future developments

  A quantitative Kano model was used to identify the solutions sought after by Icelandic geothermal power plant maintenance engineers [38]. This study demonstrated how a model for customer satisfaction can be utilised within the renewable energy sector. When applied to the geothermal sector, it demonstrated which maintenance management tools are wanted by maintenance engineers. The problems to be addressed include the long documentation time and the uncertainty of postponing maintenance, among others. The Kano analysis tool can be used to visualise the needs of domestic industries while the other industries within the cluster can use the results to develop these solutions.

The results from the studies were then analysed and used to form a system dynamics causal loop diagram. The causal loop diagram can be used to visualise the connection between the factors examined. The causal loop diagram was not intended to be simulated but rather to demonstrate the behaviour of the industry before and after a quantum shift has occurred. A previously proposed theory building process was followed, which eventually led to this article. Table 2 outlines the case studies conducted and where they fit in with the theory construction process. The result from this article is essentially step 3, as defined in the theory building process [31]. This step includes relationship building, identifying an order in different relationships previously observed through field and case studies, eventually resulting in cognitive mapping. In this study, case studies have been conducted and the mapping was done using causal loop diagrams.

Table 2. A list of the case studies conducted, the intention of the studies and where they fit within the theory building process.

Case Study	Intention	Stage in Theory Building according to [31]	Research Structure	Method of Data Collection according to [31]
[35]	Explore how staff has influenced innovation within geothermal firms.	1a. Discovery	- Interviews - Observation	- Insight - Expert opinion - Descriptions
[24]	Get an overview of the Icelandic geoth. sector. Who are the players and what are the characteristics of plant maintenance engineers.	1a. Discovery	- In-depth case study	- Description - Insight
[38]	Visualise how operations management can be improved using staff knowledge.	1a. Discovery	- Interviews	- Expert opinion - Insight
[33]	Identify the current benefits of the geothermal cluster collaboration within Iceland. an acute repair of a geoth. turbine was examined	1b. Description	- In-depth case study	- Critical incident - Documents
[36]	Visualise how domestic industries can influence innovation process.	1b. Description	- In-depth field study	- Observation interviews - Documents - Technical specifications
[34]	Get an overview on how maintenance on geoth. turbines is conducted. Who are the main actors and what are the challenges ahead.	2. Mapping	- In-depth field study	- Verbal protocol - Analysis
[37]	Explore how experience influences the operations management in geothermal power plants.	2. Mapping	- In-depth field study	- Analysis

4. Results

In Figure 3, one can see the established causal loop diagram, which is coded with three colours. The initial condition before the quantum shift occurs is coloured in orange. As the quantum shift occurs, a process coded in blue is initiated. Third is the green graph, which has not been visualised throughout the case studies but has been stated to be a goal suitable for the Icelandic geothermal industry [23]. The relationship between the variables is explained in the following sections. Not all of the variables are equally weighed, and some can be regarded as key variables. The variables "willingness to try" and "KAST" are shown to be key variables in the system dynamics model.

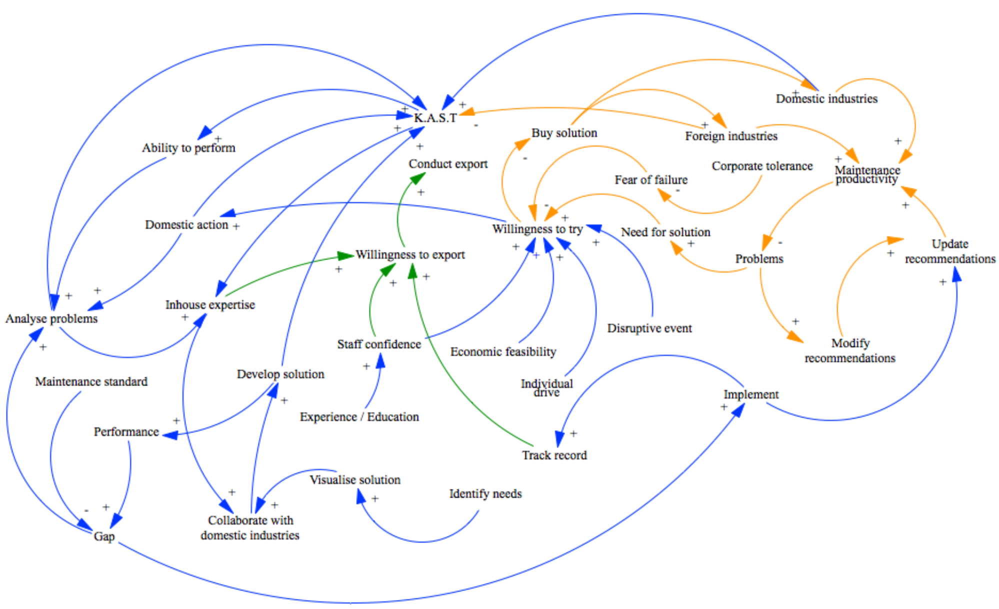

Figure 3. A causal loop diagram describing the behaviour leading to increased domestic development.

4.1. Initial Behaviour

The variable "maintenance productivity" can be seen as the efficiency (doing things the right way) or effectiveness (doing the right thing) of maintenance procedures within a given industry. The more frequent that the occurrence of an unexpected or unwanted maintenance is, the more problematic it will be. Therefore, maintenance recommendations should be reviewed and modified, and subsequently official recommendations should updated for the staff [34,37]. In many cases, a need to purchase an external service or solution (such as software) is needed. This leads to the "willingness to try" variable in Figure 3. Initially, there is not much willingness to try because the status quo has worked previously or a fear of trying a new method is prevalent. A solution is then purchased from an external company. Initially, this expertise comes from a foreign industry, leaving no build up of expertise or innovation within the country. However, in some cases domestic industries are able to provide the needed solution, especially if the risk / benefit ratio is favourable and tests can be made on site with minimal or acceptable risk. Domestic solutions are not necessarily custom made for the geothermal industry but may be a spinoff from other industries, such as the aluminium industry. When solutions are modified to serve the geothermal industry, the operations are shifted slightly for a certain industry that previously did not serve the geothermal sector. This leads to KAST domestically as previously non-related industries become familiar with problems faced in the geothermal sector and begin to focus on them. However, the fear of failure variable is very sensitive to corporate tolerance and especially top level tolerance. This initial behaviour, coloured in orange in Figure 3, can be seen as the first stability phase, as demonstrated in Figures 1 and 2. The industry has developed a certain behaviour that operates in a sufficient manner but does not initiate or support either cluster formation or knowledge buildup domestically.

4.2. Willingness to Try

When a problem occurs and the "willingness to try" variable in Figure 3 has reached a certain level within the organisation, domestic action will be initiated. The "willingness to try" variable is the willingness within an industry to seek the development or improvement of solutions domestically rather than using the solutions that were used in the past. This variable is mostly relevant among senior maintenance engineers or operations managers within the industry. There are certain ways for the willingness to try to reach high levels. This may either be a disruptive event (such as a financial crisis), individual drive within the organisation, or high confidence of the staff, in this case maintenance engineering staff. Staff confidence has been shown to be influenced by previous experience or education. In the case of the Icelandic geothermal industry, it was seen that marine engineers are preferred to engineers that have no marine experience [24] because of their high problem solving skills, ability to work under pressure, and previous nautical experience. Also, if the need for a solution is great but it is not available internationally, then the willingness to try variable increases greatly, which leads to domestic action [35,36]. There will always be a fear of failure linked to the "willingness to try" variable. "Corporate tolerance" is the only balancing variable influencing the fear of failure, underlining the importance of tolerance with regards to failure and experimentation within an organisation. As the tolerance increases within an organisation with regards to failures, the fear of failures decreases, giving in turn less impact to the willingness to try variable. The tolerance is, however, case by case dependent and is often the subject of a favourable cost / benefit ratio.

4.3. Domestic Action

As can be seen in Figure 3, only one variable ("willingness to try") leads to domestic action. When domestic action is initiated, a given problem is analysed. This increases not only in-house expertise but also KAST. In addition, KAST has been observed when foreign industries are hired to service the domestic geothermal sector but in-house staff are allowed to study the procedures. As more domestic expertise builds up, collaboration with domestic industries increases [24,33,36]. The variable "identify needs" influences the visualisation of solutions and collaboration with domestic industries to create such a solution. This variable was identified as a method to provide cascade industries with a method to visualise which solutions to develop to service the geothermal sector. Solutions are more rapidly developed when more domestic collaboration occurs. The performance of a solution that has been developed domestically is measured and a performance gap is seen between the current maintenance standard and the proposed solution that is developed domestically. If the gap is found to be favourable, then the new solution is implemented and the current recommendations are updated. This also increases the track record of domestic solutions and services. If the gap is found to be non-favourable, then this leads to the problem being analysed further and the cycle repeats itself. "Problem analysis", "domestic action" and "develop solution" are all variables leading to KAST. Furthermore, KAST leads to an increase in the in-house expertise as well as the domestic ability to perform. A need analysis serves as a good tool to take predetermined steps and service the observed sector [38]. Even though a "cluster formation" variable is not defined within the diagram, the environment for a cluster development is essentially facilitated for use when the blue portion of the model is initiated. Although the KAST is a key factor in the cluster formation, it is not the cluster formation itself. One can observe a negative effect on KAST when the cluster has been initiated but a solution is purchased from a foreign industry. This negative impact is observed because no build up of knowledge or skills occurs when foreign expertise is used to solve operational problems without the inclusion of any domestic observers, eventually domestic industries suffer.

4.4. Export

As in-house expertise increases, staff confidence increases and the track record of successful solution implementations grows. The variable "willingness to export" reaches a level where export of new solutions become viable. Although this connection has not been observed in the case studies, it is a logical continuation from previous behavior. As a final product, a cluster around the particular sector has grown domestically, serving global markets. A time delay between the start of the cluster initiative and the ability to start exporting solutions can be expected because domestic products need to be fully tested, their track record needs to be monitored, and expertise needs to built up domestically. A theoretical demonstration of such a delay is depicted in Figure 4.

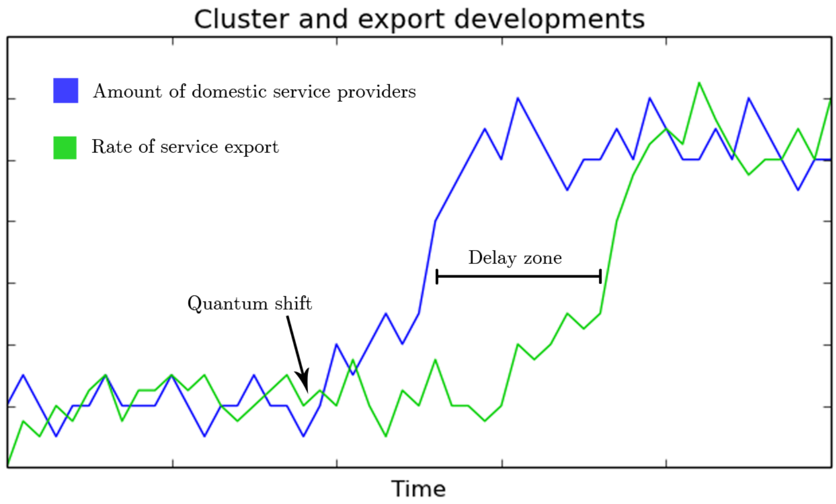

Figure 4. A theoretical relationship between a domestic cluster development and service exports. The delay zone shows a period between the cluster development and service exports.

4.5. Balancing Variables

Balancing (or negative) variables are likely to be important factors in the formation of industrial clusters. The "fear of failure" variable behaves as a balancing variable on the "willingness to try" because staff are less likely to try or develop new solutions if "corporate tolerance" is low. "Maintenance productivity" also serves as a balancing variable on the "problem" variable because fewer problems will be observed as the industry becomes more productive. The use of foreign industries influences the KAST variable in a negative way because foreign industries did not contribute towards KAST in Iceland. The variable "maintenance standard" balances the "gap" variable because a lower gap between previous solutions and developed solutions is going to be observed if the previous maintenance standard is high, thereby decreasing the possibility of new solutions being implemented.

5. Discussion

As demonstrated, three variables had a positive impact on the willingness to try variable. However, one of those variables, the disruptive event, is preferably avoided. Excluding the disruptive event puts an increased emphasis on the other two, staff confidence and individual drive. Individual drive can be impacted by an array of motivations, financial being only one of these. As has been shown, staff confidence is highly dependant on previous experience and education. It was found in Iceland that marine engineers are good candidates to oversee and conduct geothermal power plant maintenance. It is, however, not given that marine engineers possess the same qualities elsewhere as in Iceland. It is also not given that marine engineers are able to serve other renewable energy industries as efficiently. This may be contributed to by the use of steam turbines in geothermal power plants. Marine engineers might, therefore, have little knowledge about the operation and maintenance of solar or other types of power plants. Which characteristics are needed by the maintenance engineers to serve a given technology need to be identified. Although marine engineers are perhaps well suited to serve other industries, this needs to be researched in more depth. The "fear of failure" variable had a negative impact on the willingness to try. According to this model, fear of failure can only be minimised and does never increase the willingness to try. It is, therefore, in the role of corporate leaders to minimise this fear to minimise the impact on the willingness to try variable. This is especially true when the disruptive event is to be avoided. Methods to minimise the fear of failure can include improved prototyping and testing facilities, innovation seminars leading to organisational skill development, learning and growth [39].

A delay can be expected from when the cluster collaboration is initiated until exportation begins. This delay happens because products and services need to be developed and tested domestically until the track record, staff confidence and in-house expertise is sufficient and the willingness to export is enough for it to be conducted. This delay can be visualised in Figure 4. Given that the Icelandic geothermal sector has experienced a disruptive event, gone through, or is going through a quantum shift but has yet to enter global markets with products and services, it can be estimated that the Icelandic geothermal sector is currently located within the delay zone in Figure 4.

If the willingness to try variable reaches a significant level within different countries and domestic action is initiated, one can see that the resulting development increases the knowledge and skill within an industry in that particular country. However, it cannot be overlooked that by increasing the share of maintenance conducted domestically, the contractors that were previously used are no longer conducting those particular jobs. Under certain circumstances, foreign contractors keep consulting the domestic industry after the procedure has been transferred to a domestic industry. However, this consultation is merely marginal compared to previous procedures. This may have a negative effect in other regions as businesses are reduced. This could be observed as a disruptive event by international industries, pushing other industries to develop further because of the increased competition. The question also arises about how spread out clusters can actually become global before becoming a disoriented spread of small groups of companies with little connection to each other.

Building domestic clusters of adequate size, while not causing permanent harm to other clusters but rather increasing global competition, should be pursued by policymakers. These developments can potentially assist global society to develop renewable energy solutions at a faster pace, minimising the carbon footprint in energy generation and increasing the share of renewable energy technologies in the global energy portfolio.

6. Conclusions

This article uses the evidence from the case studies to demonstrate that the willingness to try domestic development within industries may be of importance when initiating industrial cluster development. If external factors will cause little willingness, then the particular industry will not participate in or initiate domestic developments but will rather continue using previous methods. The willingness to try variable needs to be triggered without a disruptive event. This may be initiated by a relevant corporate strategy (therefore minimising fear of failure within the industry), increasing the numbers of source staff with relevant experience (and therefore confidence), and facilitating individual drive. The economic benefits for the industry in question should also lead to an increased willingness to try domestic developments. Laying this groundwork should lead to domestic developments and assist with the formation of an industrial cluster around the sector in question. The model put forward, backed by case studies, shows the possible benefits of cluster collaboration for industries. Knowing the variables that influence the "willingness to try" variable may help leaders of industries to facilitate domestic development and innovation.

Future Work

It would benefit the literature if models such as the one presented in this article are quantified. This would make a practical tool available for policy makers who wish to facilitate the formation of domestic industrial clusters in the renewable energy sector. The model provided in this article demonstrates an idea, a framework, based on multiple observations, but it does not predict the rate of industrial cluster formations. Even though the role of government has been stated in the literature, governmental interventions are avoided in this article because governmental actions (such as incentives) have not been studied by the authors. It would benefit the model to include governmental actions because the importance of policy is likely to influence an industrial cluster formation.

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Author Contributions

Reynir S. Atlason conducted field observations, majority of analysis and the composition of the article. Gudmundur O. Valsson contributed to the design of the article, the theoretical background structure, analysis of data and model construction. Runar Unnthorsson contributed to the design of the article, oversaw the project and assisted with the data analysis and model building.

Conflicts of Interest

The authors declare no conflict of interests.

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