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An assessment of the performance and potential of OTEC innovation clusters worldwide

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Preface

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Management of Technology at Delft University of Technology. This research presents the performance and potential of ocean thermal energy conversion innovation clusters and is aimed at the ocean thermal energy conversion industry, policy makers and scientists in the field of renewable energy innovation.

I would like to thank my graduation committee for their guidance during this research. Jaco Quist found this appealing research topic and was always available for feedback and support when I needed it. His extensive knowledge on innovation systems helped to shape the research into what it is today. Roland Ortt always provided useful feedback, his distinct perspective on the study helped to increase the quality of this research. Kornelis Blok gave very constructive feedback based on his extensive knowledge on energy systems.

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Finally, I would like to express my thanks to my family and friends who supported me, with lots and lots of coffee breaks in the library, Friday afternoon drinks and all the encouraging words. Renate, thank you for the needed distraction, recreation, patience and endless support.

Kevin Salz
Delft, April 2018

Abstract

Ocean Thermal Energy Conversion (OTEC) technology development is currently in the gap between academia and commercialization. To bridge this gap, all stakeholders that influence the development must perform optimally. This thesis presents the performance of OTEC developing stakeholder groups (‘clusters’) in Japan, the Netherlands, France, USA and Malaysia and recommendations for improvement. Interviews with the main OTEC developing organizations gave input for a technological innovation system analysis which is used to determine the performance of each cluster. Four structural elements are used to define the current state of OTEC in each innovation system and seven functional elements are used to systematically study activities and events that influence the technology development and commercialization. A cross-case analysis is used to find industry-wide trends.

The cluster around Naval Energies and Akuo Energy in France and the cluster of OTE Corporation and Makai Ocean Engineering both perform well on most of the investigated elements. The performance of the Dutch cluster suffers somewhat from the small scale of its main OTEC developing actor, Bluerise. The Japanese cluster performs very well on research related aspects although limited commercialization efforts can negatively influence further technology diffusion. Malaysia lacks essential actors for technology development and should therefore not be defined as an OTEC cluster.

Two influences external from the industry were found to affect OTEC development negatively. Firstly, current support mechanisms for emerging (renewable energy) technologies are not suitable for technologies that require high upfront investments due to focus on production subsidies instead of upfront grants or guarantees. Secondly, OTEC is not included in renewable energy development plans from governments, which negatively influences the confidence in the technology of industry and investors and creates uncertainty in the market.

Contents

Explanation of acronyms

CAF	Latin American development bank
CAPEX	CAPital EXpenditures (upfront investments into a project)
CC-OTEC	Closed Cycle Ocean Thermal Energy Conversion
DMEC	Dutch Marine Energy Centre
EPC	Engineering Procurement and Construction
EPCI	Engineering Procurement Construction and installation
FIS	Functions of Innovation Systems
IEA	International Energy Agency
IOES	Institute of Ocean Energy Saga University
IRENA	International REnewable ENergy Agency
KRISO	Korea Research Institute of Ships and Ocean Engineering
LCOE	Levelized Cost of Electricity
NELHA	National Energy Laboratory of Hawaii Authority
NEMO	New Energy for Martinique and Overseas (OTEC plant project)
NOAA	National Oceanic and Atmospheric Administration
OC-OTEC	Open Cycle Ocean Thermal Energy Conversion
OES	Ocean Energy Systems (part of IEA)
OPEX	OPerational EXpenditures (maintenance and operational costs)
OTEC	Ocean Thermal Energy Conversion
OTE Corp.	Ocean Thermal Energy Corporation
RET	Renewable Energy Technology
SIDS	Small Island Developing States
PV	PhotoVoltaics
SWAC	Seawater Air Conditioning
TIS	Technological Innovation Systems
UTM OTEC	Universiti Teknologi Malaysia Ocean Thermal Energy Centre

1 Introduction

The time that many policy makers thought of climate change as a fantasy of a handful of scientists is over. A large majority of people, from politicians to experts in the field, are now thoroughly convinced that if energy and environmental policy continues on the current path, the world's climate will eventually be changed beyond recognition. This is one of the main reasons that the investments in renewable energy have been increasing in the last ten to fifteen years.

Among the most successful technologies are wind turbines and solar photovoltaic panels (solar PV). However, to enable grid balancing in case of higher shares of renewable energy sources in the energy mix, more stable base load power sources and/or energy storage are required due to the intermittent character of wind and sun (Velzen, 2017). Ocean Thermal Energy Conversion (OTEC) is one of the few renewable energy technologies that can deliver this. OTEC is a renewable energy technology (RET) that uses the natural temperature difference between equatorial surface seawater and deep seawater to produce clean, reliable electricity, day and night, year-round. This creates the potential to increase renewable energy shares for a reasonable price and limited amount of used space compared to using solar PV and wind energy only.

1.1 Problem statement

Despite that the concept of OTEC has been around since 1881 (Vega, 2012) and a previous period of increased innovation activity in the '70s and '80s, the technology is still in a pre-commercial phase. Now demand for renewable energy technologies such as OTEC is rising and pilot plants are starting to show its true potential, it is time for further commercialization where OTEC plants should be scaled up, projects should become less dependent on subsidies and commercial parties should invest more. Nevertheless, high upfront costs and the fact that the technology has never been tested on a large scale make OTEC a risky investment (IRENA, 2014). Worldwide, only a limited set of leading organizations is currently developing OTEC. These companies work together with other stakeholders in a 'cluster' to enable OTEC technology development and diffusion. When the stakeholders of a cluster do not perform optimally, OTEC might get stuck in the 'valley of death' (the moment between R&D and commercialization) and fail to reach commercialization. To bridge the valley of death, it must be clear what the current performance is and how it can be optimized.

1.2 Objective and research questions

The objective of this thesis is to present an overview of the current performance and potential of OTEC clusters worldwide, and to give recommendations on how the performance can be optimized by both private organizations and governments.

To achieve the research objective and make a significant contribution to knowledge in the field of OTEC and renewable energy innovation clusters, a main research question and three sub-questions are formulated, and the relevance and purpose of each question is clarified. Following the research questions, an overview is given regarding the required data to answer the questions which will be used for further elaboration of the research methodology in the next section.

What is the performance and potential of Ocean Thermal Energy Conversion innovation clusters worldwide?

1. What structural factors (actors, institutions, networks and technology) influence the viability and speed of innovation and diffusion of Ocean Thermal Energy Conversion?
2. What functional factors (e.g. knowledge exchange, market formation) influence the viability and speed of innovation and diffusion of Ocean Thermal Energy Conversion?

3. How can the growth of the identified Ocean Thermal Energy Conversion innovation clusters be further stimulated and facilitated?

1.3 Summarized methodology

The first step of this research is a literature study that identifies all innovation clusters and map the important stakeholders and available literature for each cluster (Chapter 2). The methodology in chapter 3 discusses the chosen research framework, technological innovation systems, which is used for analysis of the innovation clusters to identify systemic problems that form a barrier for innovation and technology commercialization. An explorative structural and functional analysis of the clusters gives an overview of the current state of the clusters in chapter 4. The information required for these analyses are ascertained from literature and interviews with experts from the OTEC clusters. The information gathered from these individual cluster analyses is then used for a cross-case analysis to determine the relative performance of the clusters and to produce recommendations for each cluster to further optimize their performance.

Chapter	Method and approach	Result
1. Introduction		Research aim Scientific relevance
2. Literature	Literature study	Overview of existing literature on OTEC, structures of clusters and innovation theory
3. Methodology and framework		Explanation of research methods used and their implementation
4. Cluster analysis	Interviews, Framework Wieczorek & Hekkert (2012)	Cluster-specific information from interviews. Analysis of structure and activities of each cluster
5. Cluster performance: cross-case analysis and discussion	Framework Wieczorek & Hekkert (2012)	Analysis of cluster performances and creation of recommendations. Discussion of results.
6. Conclusions		Conclusions Recommendations for future work

Figure 1.1: Research structure and thesis outline

1.4 Relevance

1.4.1 Scientific relevance

Thorough research has been done on the workings of the technology (Soto & Vergara, 2014; Uehara, Dilao, & Nakaoka, 1988; Vega & Michaelis, 2010; Yeh, Su, & Yang, 2005), the ecological effects (overview in (Boehlert & Gill, 2010)), and case studies (Banerjee, Duckers, & Blanchard, 2015; Osorio et al., 2016) have been done on potential implementation of the technology and implementation at specific sites. The research described in this thesis focuses on giving an international overview of the different OTEC innovation clusters, the stakeholders that are involved, and their performance and potential. This is scientifically relevant due to the insight it gives in the conditions that are required for successful innovation of renewable energy technologies. Furthermore, it adds to the technological innovation systems theory by using it on several clusters worldwide for a cross-case analysis on their performance.

1.4.2 Practical relevance

The produced information regarding innovation cluster performance and recommendations may serve as guidance for the actors in the OTEC clusters. Technology providers, project developers, regulatory bodies and other OTEC oriented stakeholders can use the results of this thesis to improve the performance of the cluster and facilitate commercialization.

2 Literature

To answer the research questions posed in the previous chapter, information is required on several subjects. Firstly, the properties and preconditions of the OTEC technology and the previous research are discussed. Secondly, the worldwide OTEC clusters are identified. Lastly, the Functions of Innovation Systems theory is described. How this theory will be applied for this research is further elaborated in chapter 3.

2.1 OTEC history and technology

In the same year that the first underground railway in the world started operating in London and people in the Netherlands determined that the death penalty should be abolished, Jules Verne wrote about a technology that used difference in temperature in different depths of the ocean to power Captain Nemo's submarine in "Twenty Thousand Leagues Under the Sea". This conceptualization created interest in the scientific world and eleven years later, in 1881, a formal proposal was written by an academic called D'Arsonval (Vega, 2012).

Although a new type of OTEC had been developed in the meantime which enabled production of desalinated water from seawater, it took almost a century before the technology was again seriously considered as a method of power generation due to, amongst others, cheap fossil fuels in the early 20th century and the 1970s energy crisis. In 1979, the concept was demonstrated for the first time on a small scale in Hawaii with a net power output of 18kW. However, when the energy crisis ended, so did the interest in most renewable energy technologies. It wasn't until early 2000s that OTEC research and development increased again. Since then, research has been done on the individual elements required for OTEC facilities, and pilot plants have been built (see Figure 2.2 for an overview) to gain more insight in the practical functioning of the technology and for testing new technologies.

To generate energy, most power plants use a method of turning kinetic energy into electricity. For example, a windmill uses the rotation of its blades and fossil fuel plants and nuclear plants use heat to evaporate a fluid, after which the vapor is led through a turbine whose rotational movement is translated into electricity. Closed Cycle OTEC (CC-OTEC) is most comparable with the latter. To produce electricity and possibly desalinated water, the Rankine thermodynamic cycle is used. The cycle begins with a working fluid with low boiling point (such as ammonia) being vaporized with warm sea water from the surface of the ocean, after which the vapor is led through a turbine, then the vapor is condensed with cool deep-sea water and pumped back to be vaporized again. Therefore, the whole cycle of the working fluid is closed and only heat is exchanged with the seat water (International Renewable Energy Agency, 2014).

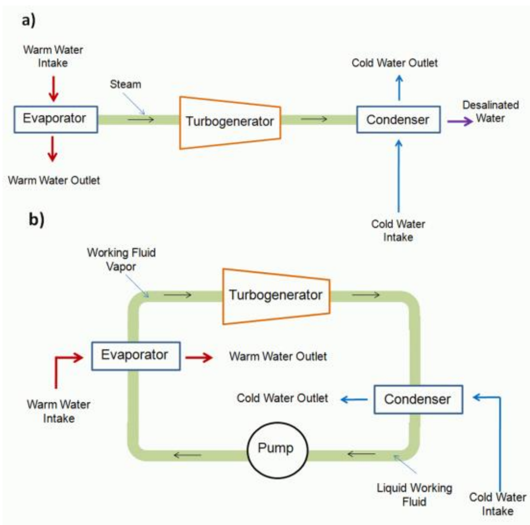

Figure 2.1: a) Open Cycle OTEC, b) Closed Cycle OTEC

With Open Cycle OTEC (OC-OTEC), warm seawater is used as a working fluid. It is partly vaporized, after which the vapor is led through a turbine to generate power, while the water that is not vaporized is led back into the ocean. After the vapor has been through the generator, it is condensed using cold seawater and what remains is desalinated water which can be used as drinking water. Despite the advantage of producing desalinated water, the electricity generating efficiency is much lower than with CC-OTEC (International Renewable Energy Agency, 2014).

Hybrid OTEC combines the benefits of both cycles. First electricity is generated with CC-OTEC, after which an OC-OTEC cycle uses the warm and cold water discharges of the CC-OTEC to produce desalinated water (International Renewable Energy Agency, 2014).

To be able to effectively vaporize and condense a working fluid and therefore make the Rankine cycle possible, a temperature difference of at least 20°C between surface and deep ocean water is required. This means that deep ocean water should be close to 5°C and surface water should be >25°C. This hot surface layer is only reliably available around the equator, while for cold water cold ocean currents have to be intercepted which in these regions are only available at great depths (approximately 1,000m). Figure 2.2 shows a rough map of places where OTEC is technically possible with temperature differences from yellow (20°C) to red (>25°C).

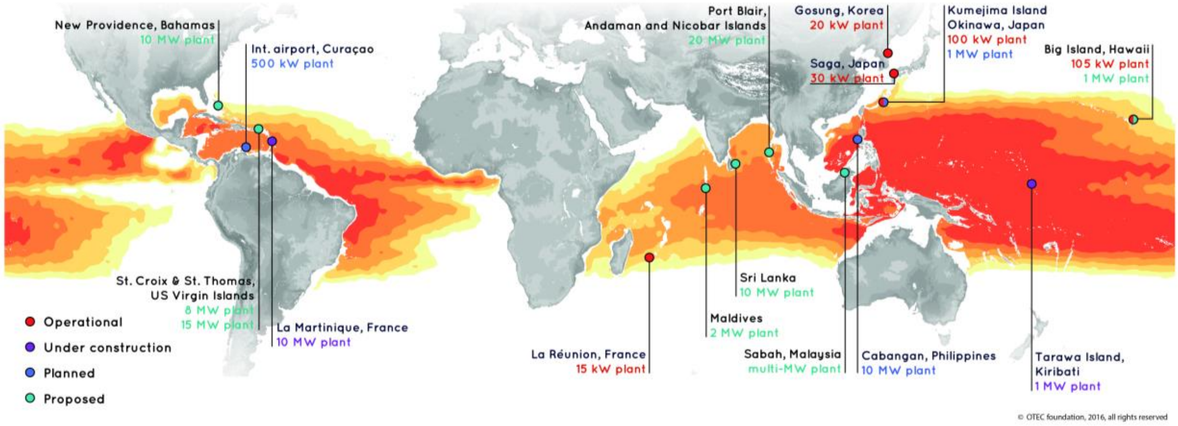

Figure 2.2: Worldwide operational, planned and proposed OTEC plants and its potential (temperature differential: yellow >20°C, red >25°C) (OTEC Foundation, 2016b)

Aside from the technical viability, there are factors that have influence on the economic feasibility. For example, Guyana has very warm water at its shores, however due to its geographical location the required depth of 1,000m can only be found 60km from shore. This increases lifetime cost due to more difficult construction and maintenance and higher power losses in cables between the power plant and shore (Magesh, 2010).

Small Island Developing States (SIDS) have particularly ambitious energy goals due to their isolated nature and the corresponding dependence on imported fossil fuels for energy generation (Dornan, 2015). Secondly, these islands are exceptionally vulnerable in the case of sea level increases. This ambition causes SIDS to reach high shares of renewable energy earlier and therefore require solutions such as OTEC. Due to the dependence on fossil fuel imports electricity is relatively expensive, making new technologies economically viable in an earlier development stage. Therefore, these SIDS attractive locations for early OTEC (Dornan, 2015; OTEC Foundation, 2016b).

2.2 Previous OTEC research

Due to the immaturity of the technology, not very much research has yet been done in comparison to renewable energy technologies such as wind or solar PV. This especially noticeable when the scope of research is observed. Literature has three main topics: technological development (Soto & Vergara, 2014; Uehara et al., 1988; Vega & Michaelis, 2010; Yeh et al., 2005), ecological effects (overview in (Boehlert & Gill, 2010)), and feasibility studies (Banerjee et al., 2015; Osorio et al., 2016). Innovation studies have not yet been carried out and overviews of important actors for OTEC are not available. Therefore, this overview has been created and is presented in the next section.

2.3 Overview of OTEC clusters: their developers and projects

The aim of this research is to give an overview and analysis of OTEC clusters globally. Due to the inherent time constraints for a master thesis, the choice was made to analyse only the most relevant innovation clusters. To make a well-balanced decision on which clusters should be represented in this research, first an overview of all OTEC projects and associated organisations is given. Then OTEC clusters are determined according to that overview. While the actual choice of clusters is made in the Methodology chapter, one precondition is already introduced here to simplify the identification of important organisations; The cluster must be actively working with an operational OTEC facility, or has one proposed, planned or under construction.

2.3.1 Cluster identification

Table 2.1 shows a list of all current OTEC projects, accompanied with the corresponding main technology developers and/or other important firms/institutes. For insight in OTEC installations per country an overview is made in Appendix B: OTEC projects by country, as of March 2017.

*Table 2.1: Current OTEC projects (*Bold: main developer(s))* (OTEC news, n.d.-b)

Project	**Power rating (MW)**	**Organisation 1***	**Organisation 2***
		Operational	
La Réunion 15kW	0,015	**DCNS**	University of Reunion, STX
Hawaii 105kW	0,105	**Makai**	NELHA
Japan Saga 30kW	0,03	**Xenesys**	**Saga university**
Japan Okinawa 100kW	0,1	**Xenesys**	**Saga university**
South Korea 20kW	0,02	**KRISO**	
Total	**0,27 MW**		**Average: 0,05 MW**
		Under construction	
La Martinique 10MW	10	**DCNS**	**Akuo Energy**
Kiribati 1MW	1	**KRISO**	
Total	**11 MW**		**Average: 5,5 MW**
		Planned	
Curacao 500kW	0,5	**Bluerise**	
Japan 1MW	1	**Xenesys**	**Saga university**
Philippines 10MW	10	**Bell Pirie Power Corp**	**Energy Island Bell Pirie**
Total	**11,5 MW**		**Average: 3,83 MW**
		Proposed	
Bahamas 10MW	10	**OTE Corp.**	
Hawaii 1MW	1	**Makai**	
US Virgin Islands 8MW	8	**OTE Corp.**	
US Virgin Islands 15MW	15	**OTE Corp.**	
India	20	**DCNS**	
Malaysia	Multi	**UTM OTEC**	**DCNS**
Maldives	2	**Bardot Ocean**	
Sri Lanka	10	**Bluerise**	
Total	**66 MW**		**Average: 9,43 MW**

This overview shows that there is a limited number of key industry players actively pursuing OTEC development and implementation. As previously explained, an innovation cluster is defined as one or more central players, around which other facilitating actors, such as e.g. contractors, knowledge developers, financial players, have clustered to enable a project. From the table above, nine companies can be identified that form the centre of a cluster.

1. Bardot Ocean (France)
2. Bell Pirie Power Corp. (Philippines)
3. Bluerise (Netherlands)
4. DCNS (France)
5. UTM OTEC (Malaysia)
6. KRISO (Korea)
7. Makai (Hawaii)
8. OTE Corporation (USA)
9. Xenesys/Saga University (Japan)

Five of these clusters were thoroughly studied. How the choice for this subgroup was made is explained in section 3.2.

2.4 Technological innovation systems

The framework of technological innovation systems (TIS) is used as the basis of the analysis of the thesis research due to its focus on the dynamics of technological change and the performance of these dynamics. Furthermore, the innovation system framework comprehends economic, social, political, organisational and other factors that influence the development, diffusion and use of technology (van Alphen, Hekkert, & van Sark, 2008). If the performance of these factors is known, policy advice can be created for the actors in the cluster and therefore improving the chances for successful OTEC innovation.

The Technological Innovation System and Functional Innovation System (FIS) approach (Bergek et al., 2015; Bergek, Hekkert, & Jacobsson, 2008; M.P. Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007; Markard & Truffer, 2008; Weber & Truffer, 2017) is used for analysis of OTEC innovation clusters. The FIS theory uses innovation systems to explain technological change and the resulting innovations. This innovation system theory focuses on the analysis of all structures such as actors, networks, and institutions that support or hamper the diffusion of the innovation while the functions of innovation systems theory adds the activities that create this structure to the analysis (such as entrepreneurial activity, market creation, etc.). This analysis determines the potential systemic problems within the innovation system, or in this case the different OTEC clusters. Based on the formulated strengths and weaknesses public and commercial policy advice is developed to further facilitate innovation.

The goal of this thesis is to determine the performance of the OTEC industry and what the potential and possibilities are for improving this performance, including policy advice not only on government level but for businesses in the industry as well. The TIS theory has been widely used to generate government policy advice by analysis of innovation systems and therefore it is a legitimate question why one would use this theory for a general innovation analysis of a technology, while its main aim is much broader than just government policy. However, “The purpose of analysing a Technological Innovation System is to analyse and evaluate the development of a particular technological field in terms of the structures and processes that support or hamper it.” (M. Hekkert, Negro, Heimeriks, & Harmsen, 2011, p. 3). Exactly this, defining the structures and processes that support or hamper technology innovation, is what can answer the research questions which implies that the TIS framework is not only viable for public policy analysis but for general innovation analysis as well. That is why this framework will be applied for the research executed for this thesis.

Multiple types of innovation systems have been defined over time. National innovation system, regional innovation systems can be used when geographical boundaries are a unit of analysis. A sectoral innovation system (Malerba, 2002) focuses on a specific sector and can therefore cross geographical borders (Schrempf, Kaplan, & Schroeder, 2013). Finally, in case of a technological innovation system, the technology is the unit of analysis and while it can span across geographical borders and sectors, it is more specific than the previously mentioned innovation systems due to the focus on one specific technology. Because the focus of the thesis is purely on OTEC and not bound by geography or sectors, only TIS will be used.

A technological innovation system can be defined as: “a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology” (Carlsson & Stankiewicz, 1991, p. 111). To obtain a complete image of an innovation system, one requires an understanding of two main parts of the system; Wieczorek & Hekkert (2012) argue that structure and dynamics influence each other and that therefore both should be combined when studying an innovation system. The structure comprises the components that are relatively stable over time, and the dynamics are the activities undertaken to create the required structures of a technological innovation system in the early stages of technology diffusion (Bergek, 2002). These two subjects are further elaborated below.

2.4.1 System structure

The structure of an innovation system consists of components that are part of the technology innovation and are relatively stable over time. Due to its early stage of market diffusion, the structure of the OTEC technological innovation system is clearly not yet complete. A structural analysis can be used to identify the missing aspects in the system and is done via a method stated in TIS literature.

Over time there has been discussion on what the main components of a TIS structure are. The choice of structural elements for a research seem to be dependent on both the preference of the researcher and the characteristics of the specific case. Therefore, a choice must be made for this research as well. Table 2.2 shows three lists of elements used in frequently cited TIS publications.

Table 2.2: Comparison of structural elements in literature

Actors Networks Institutions Technological factors	Actors Networks Institutions	Actors Institutions Interactions Infrastructure
(M. Hekkert et al., 2011; R. A.A. Suurs, 2009)	(Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Jacobsson & Bergek, 2004)	(Wieczorek & Hekkert, 2012)

Actors

General consensus in innovation system research is that actors play a major role (Wieczorek & Hekkert, 2012). These include all organisations that contribute in the push towards technology diffusion in any way, such as developers and adopters of the technology, financers, regulators, universities and industry groups. Opposing organisations and groups are relevant actors in an IS as well. Therefore, the range of potentially relevant actors in an innovation system is enormous (R. A.A. Suurs, 2009).

The question if actors are part of a TIS is dependent on the perception of these specific actors themselves (do they feel to be part of a community?) and the perception of other actors in the TIS (do other actors feel that this specific actor is part of the community?). The influence of the perception of the researcher deserves a separate clarification as the researcher can choose to classify an actor to be part of a TIS while both the actor in question as well as actors in the TIS do not (yet) agree. An immature TIS can be loosely structured and fragmented and is therefore strictly speaking not a system yet.

However, “as a concept it may then still serve as a powerful heuristic tool to guide the analysis and evaluation of the formative TIS” (R. A.A. Suurs, 2009, p. 44).

Networks/Interactions

Actors in a TIS are connected with each other through their interactions. These interactions can be more formal in the form of standardization associations, technology platform consortia or user-supplier networks, while others can be more informal such as university-industry links (Bergek, Jacobsson, et al., 2008). These interactions can occur within networks but can and do occur outside networks as well, especially in the early stages of product development, when the network structure is underdeveloped. Therefore one can make the distinction between interactions in a network and in an individual context (Wieczorek & Hekkert, 2012). Due to this distinction the term ‘interactions’ is better suitable to this structural element than the term ‘networks’ in cases of technology in the early stages of emergence.

Institutions

There are both soft institutions (culture, habits and routines) as well as hard institutions (rules, norms, strategies) that influence technology diffusion. Because soft institutions are very difficult to map systematically, TIS research usually takes hard institutions into account while (largely) omitting the soft institutions (M. Hekkert et al., 2011). The institutions that are taken into account are the ones that are likely to influence the development of the technology at hand. When researching a technology on the international market, the influence of institutions can be a complex and elaborate task, therefore one can choose to rely on the input of experts regarding positive and negative aspects of the current institutions to get the essence of the effect that policy has without costing too much time. The aim of technology proponents should be to achieve institutional alignment, meaning that the institutions are such that they facilitate the technology (Bergek, Jacobsson, et al., 2008).

Technological factors

The technological features have not been taken into account in most of the early TIS research, while specific features of the technology at hand can play a crucial role in its diffusion (R. A.A. Suurs, 2009). For example, when an emerging renewable energy technology turns out to have a large environmental impact this may halt the development completely, independent of the state of other structural factors. Due to its independency with regard to other structural factors it might be a crucial factor within TIS research (R. A.A. Suurs, 2009).

Infrastructure

Infrastructure can be dissected into three categories; physical (machines, roads, buildings, etc.) knowledge (knowledge, strategic information, etc.) and financial (subsidies, grants, etc.) (Wieczorek & Hekkert, 2012). However, due to overlap with other elements and varying relevance per case makes this an element that might or might not be useful in a research. Physical infrastructure is required for certain types of technology, while for others it only plays a minor role. Knowledge infrastructure can in some cases be classified under a combination of actors and interactions and financial infrastructure is very similar to institutions.

2.4.2 System dynamics

Especially in the case of emerging technology, when the structure of the innovation system is still being built, it might be equally or even more interesting to look at the activities that are being undertaken to create these structures. Due to the short-term nature of these activities, they can be defined as the system dynamics.

Theory on dynamics of technological innovation systems has been, and still is being established by authors such as A. Bergek (Bergek et al., 2015; Bergek, Hekkert, et al., 2008; Bergek, Jacobsson, et al., 2008), M. Hekkert (Bergek et al., 2015; M.P. Hekkert et al., 2007; Marko P. Hekkert & Negro, 2009; Wieczorek & Hekkert, 2012), S.O. Suurs (Breukers, Hisschemöller, Cuppen, & Suurs, 2014; M.P. Hekkert et al., 2007; R. A.A. Suurs, 2009; Roald A.A. Suurs & Hekkert, 2009), and R.A.A. Negro (M.P. Hekkert et al., 2007; Marko P. Hekkert & Negro, 2009; S.O. Negro, 2007; Simona O. Negro, Hekkert, & Smits, 2007). Each of these authors talk about 'Functions of Innovation Systems' (FIS) as a way to explain and map the system dynamics in an innovation system in a methodical way. Via a list of vital functions, in which activities are grouped, one can investigate whether the current activities in an innovation system are sufficient to enable further creation of structure and technology diffusion or if there are activities that impair the system. Although different authors come up with (slightly) different lists of functions over time, there is a large overlap. Two examples are given in the table below.

Table 2.1: Comparison of two function lists

1.	Entrepreneurial experimentation	Entrepreneurial activities
2.	Knowledge development and diffusion	Knowledge development
3.		Knowledge diffusion through networks
4.	Influence on the direction of search	Guidance of the search
5.	Market formation	Market formation
6.	Resource mobilization	Resource mobilization
7.	Legitimization	Creation of legitimacy
8.	Development of positive externalities	
	Bergek, Jacobsson, et al., 2008	M.P. Hekkert et al., 2007; S.O. Negro, 2007; R. A.A. Suurs, 2009

The comparison above shows that there broadly is a consensus between the main researchers in the field of FIS regarding what functions are relevant. The only slight misfit in this overview is the function 'Development of positive externalities' by Bergek, Jacobsson, et al. (2008), while it might overlap with the functions 'Guidance of the search'/'Influence on the direction of search' and 'Knowledge diffusion (through networks)', and Bergek, Jacobsson, et al. (2008, p. 421) "have not been able to determine how this function influences the other functions" and therefore was not thoroughly discussed in their paper. Most importantly, the functions defined by M.P. Hekkert et al. (2007) have been empirically validated in numerous studies (S.O. Negro, 2007; Simona O. Negro et al., 2007; Reichardt, Rogge, & Negro, 2017; van Alphen et al., 2008) and therefore, these functions will be used to map the key activities for cluster analysis in this thesis.

Definition of system functions

The following interpretation of the seven system functions are based on the definitions stated in M.P. Hekkert et al. (2007) R. A.A. Suurs (2009) and S.O. Negro (2007).

Function 1: Entrepreneurial activities

Entrepreneurs are an essential part of any innovation. They take risks and find opportunities to experiment and commercialize new technology. Entrepreneurs can be both new entrants as well as diversifying incumbents. Activities that are associated with entrepreneurs are e.g. commercial projects and technology demonstrations.

Function 2: Knowledge development

Innovations are dependent on new knowledge. Technological research and R&D are sources of new ideas that can enhance the innovation process. Activities include studies, laboratory tests and pilots.

Function 3: Knowledge diffusion
The exchange of information is essential not only for technological development purposes. It is important for contact with governments and market as well to ensure the alignment of R&D efforts with changing norms and values and policy decisions with the latest technological insights. Events associated with this are, among others, conferences, workshops and alliances.

Function 4: Guidance of the search
Due to the limited nature of resources, either natural or financial, a specific focus of the involved stakeholders is important to enable the development and diffusion of a technology. An inadequate or absent focus might lead to a resource deficiency for innovations. These guidance activities have a positive effect on the clarity of specific stakeholder needs, for example a government setting renewable energy quota. Successes of experiments and resulting (industry, market, government) expectations of the industry can have a guiding effect as well.

Function 5: Market formation
Emerging technologies often lack the competitive edge against embedded technologies in both performance and cost. The formation of (niche) market for these emerging technologies can be facilitated to overcome these issues. Both governments and industry play a role in this. Governments can regulate the market by subsidies, tax exemptions or other policies, while industry can try to find other applications for their technology until benefits of scale are starting to reduce cost and increase performance.

Function 6: Resource mobilization
Financial, human and physical resources are required for an innovation system development. Any limitation can be a cause of failure in an innovation system. Activities that in this category can include applying for/receiving subsidies or investments and cooperation with organisations with more human resources.

Function 7: Creation of legitimacy
Parties that are in any way invested in the incumbent technology will often oppose an emerging technology due to the cost associated with change and the diminishing value of their investment. Therefore, to let the emerging technology become part of the incumbent regime, or even overthrow it, actors need to put their technology on the political agenda to counteract resistance and support innovation. Possible activities are lobbies and success stories.

Indicators

An issue with the functions as defined above, is that they are too broad to use directly as a guideline for information gathering in the research as they are broad terms and encompass a great number of smaller details. Therefore, indicators are defined for each function to easily identify important bits of information and to be able to couple them to the right function. Using events as indicators is common in TIS research and has advantages because they are often clearly defined in history and it eventually might be possible to create a narrative of what events caused certain results and get a coherent storyline (R. A.A. Suurs, 2009). Indicators are very case-specific and therefore need to be determined for each case specifically. By literature analysis of FIS research regarding other renewable energy technologies the following indicators in Table 2.3 were determined to be applicable to OTEC.

Table 2.3: Functions and their indicators of an innovation systems. Based on publications of M.P. Hekkert et al. (2007) and Vasseur et al. (2013).

Function	Indicator
Entrepreneurial activities	Organizations or companies entering/leaving the market
	Diversification activities by incumbents
	Research and technological projects
	Demonstration and pilot projects
Knowledge development	Number of patents
	Number of scientific publications
	Research diffusion/convergence
Knowledge exchange	Intra-cluster knowledge exchange (workshops, conferences, research publications etc.)
	Inter-cluster knowledge exchange
	Co-authorship of scientific publications
Guidance of the search	Targets set by industry
	Targets set by regulatory bodies
	Expectations and opinions of experts
Market formation	Market size
	Efforts made to enable market formation
Resource mobilization	Financial resources
	Human resources
	Physical resources
Creation of legitimacy	Extent to which the technology is promoted by organizations, government
	Lobby activities for/against the technology

Due to the method used for coding the used data (see section 3.6 for more details) adaptations on this list were possible during data analysis. Therefore, the list of indicators that was used to obtain the final results, shown in section 3.4.2, is slightly different to what is proposed here.

3 Methodology and framework

This chapter describes the qualitative analysis that is carried out for this thesis. The research is explorative of nature due to the lack of publicly available information on the industry, innovation practices and potential barriers and drivers of the innovation process.

3.1 Research steps

The goal of the research is to determine the performance and create actionable advice for the researched OTEC clusters. The following sections give a more in-depth overview of how this research is set up, starting with how the choice was made on what clusters should be researched.

The goal of the research is to gain insight in what clusters are currently doing to enable technology diffusion, (their functional performance), and what they should do to increase effectiveness of their activities (recommendations). To do this, there first must be insight in the current status of the structure of the different OTEC clusters. This helps to put the subsequent results into context. In section 3 of this chapter the main focal points (the structural elements as discussed in section 2.4.1) for the structural analysis (sub-research question 1) for this specific research are determined.

Due to the target of this thesis, performance and facilitating recommendations, the primary in-depth focal point of the research is the functional (sub-research question 2) analysis. This analysis aims to gather information on what actors in clusters are doing to further diffuse their technology and build structure, based on the seven innovation system functions as defined by M.P. Hekkert et al. (2007). To find information for these rather broadly defined functions, more focused indicators are defined.

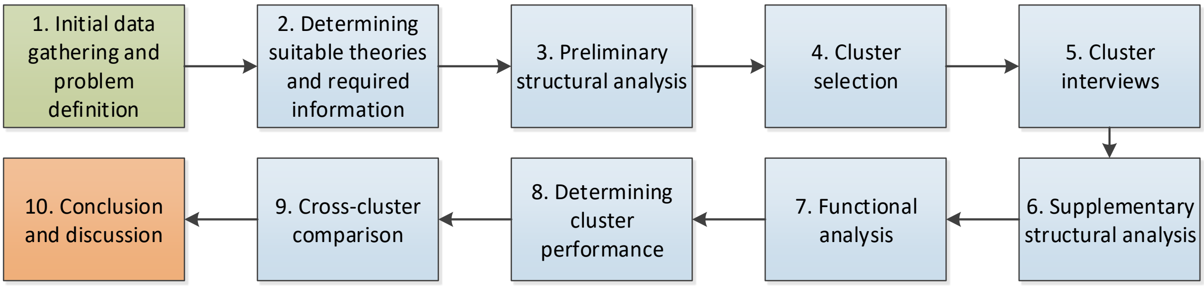

Figure 3.1: Research steps

The approach to data gathering for the aforementioned analyses via semi-structured interviews is then evaluated. Finally, the method for a cross-cluster comparison is given. Figure 3.1 shows the research steps linearly, however, the research does involve a certain amount of iteration. Step 1, 2 and 4 are dealt with in this and the previous chapters. The method of step 5 is defined in this chapter while the data that was gathered in the interviews is used in the following chapters. Step 3, 6, 7 and 8 are discussed in chapter 4. Step 9 and the discussion from step 10 can be found in chapter 5 and the conclusion in chapter 6.

3.2 Determining most relevant clusters

In section 2.3.1, nine clusters of OTEC developing organizations were defined to be relevant for this research. Due to the relatively large number of often small OTEC clusters worldwide and the law of diminishing returns, the choice was made to only analyse the most relevant clusters in-depth. Therefore, a choice of clusters had been made using the data regarding the actors active in the OTEC industry. A cluster is relevant first and foremost because of their high level of current activity on OTEC projects while access to information is required as well to enable proper research. Therefore, the interviewees were chosen on the following criteria:

1. The cluster currently has an OTEC plant operational or under construction, and;
2. In the case of a planned OTEC plant, there have been press publications on this project since 2016, and;
3. At least one main actor from the cluster is willing participate in an interview regarding this research.

However, when contacting the main organizations of each cluster, it unfortunately became apparent that not all were willing to participate in this research. Therefore, the choice was made to try to interview all relevant organizations of the remaining five clusters:

1. Bardot Ocean (France)
2. Bell Pirie Power Corp. (Philippines)
3. Bluerise (Netherlands)
4. DCNS (France)
5. UTM OTEC (Malaysia)
6. KRISO (Korea)
7. Makai (Hawaii)
8. OTE Corporation (USA)
9. Xenesys/Saga University (Japan)

The assumption was made that this choice of clusters would be a good representation of the OTEC industry as a whole due to similarities between the clusters that were studied in-depth and those that were not and that this limitation does not affect the validity of the research.

3.3 Structural analysis

The structural analysis is useful for this research for two reasons. Firstly, a preliminary structural research gives a high-level insight in the industry and its state of development, which is useful for determining the research focus and problem definition. Secondly, the preliminary structural analysis combined with the supplementary structural insight from data that is gathered further on into the research gives contextual understanding of the results from the functional analysis. That is also why structural analysis is split up in two separate steps, as shown in Figure 3.1. This section first defines what information is required to do the analysis by establishing which structural elements will be explored, after which the practical execution is discussed.

3.3.1 Structural elements

As was discussed in section 2.4.1, the structural analysis consists of several elements, the application of which depends on the specific research objective and researcher in previous research. Literature mentions six different elements, namely *actors*, *networks and interactions*, *institutions*, *technological factors* and *infrastructure*. This is due to differences in interpretation and relevance for specific researches. The interpretations of the structural elements have been discussed earlier in section 2.4.1. Which elements are relevant for this research is dependent on the type of innovation (e.g. is the technology diffusion highly dependent on technological progress? Is it dependent on infrastructure?).

Actors

The element 'actors' is used consequently in literature. Just like in all previous research, in this case actors are a fixed requirement to do anything, including innovation and technology diffusion. The structural analysis will therefore include the mapping of all known actors in each OTEC cluster's innovation system. The innovation system does not yet contain a full value chain due to the early stage of development and diffusion of OTEC, however this still creates a good oversight of actors that are active in the sector and/or influence the technology.

A first overview of actors has been made through literature study. Relevant actors connected to clusters are found by examination of publications regarding OTEC plants and plans while additional actors that could not be clearly linked to clusters via literature are determined through interview data.

Networks and interactions
As was stated in the literature study, the terms ‘networks’ and ‘interactions’ have a large overlap. However, the difference between the two is that a network requires multiple actors to be connected to each other for longer periods of time while interactions are less formal and might only consist of a single sale or short-term cooperation. Due to the premature state of technology development and diffusion in the OTEC industry, many interactions are too informal or of too short duration to really be able to call these parts of a network. Therefore, the term ‘interactions’ is more suitable to this case.

There are several reasons why interactions are relevant to investigate. The OTEC technology is created from a combination of all kinds of existing technologies and therefore interactions should be mapped that occur between organisations with general OTEC expertise and organisations with expertise on a specific technology that is used for OTEC. Furthermore, governments are important due to their roles as both potential financial enabler and potential project client. Therefore, interactions will be included in the structural analysis. Apart from the interactions themselves, one of the focal points will be the (in)existence of intermediary organisations that might influence the interactions. The interactions between actors are determined by looking at co-authorship of scientific papers, press publications of activities around OTEC plants and through what is told in interviews.

Institutions
Due to the international nature of the renewable energy market, which is even more so in the case of OTEC due to the geographical restrictions (see section 2.1), a general conclusion is not possible regarding institutions. Every cluster can be affected by different institutions and even within the one cluster, two projects on different locations can fall under different jurisdiction. However, institutions still play a major role as enabling or restraining factor for the development of new projects and research.

To get a coherent image of the institutions that affect OTEC, institutions will be mapped per cluster, while making a distinction between different projects in the same cluster if necessary. These institutions include (national, international, project based) research structures and specific policies that influence the development and/or diffusion of OTEC, such as subsidies, tax exempts and renewable energy policies.

Technological factors
The incorporation of technological factors in a structural analysis is not too common, although it could have benefits to do so in certain cases. They are defined by R. A.A. Suurs (2009, p. 45) as: “Technological factors consist of artefacts and the technological infrastructures – which are themselves artefacts as well – in which they are integrated”. In some cases, technological factors play a larger role than in others. However, in this case these are critical. OTEC promises to be a renewable energy source that can replace fossil fuel-based energy sources and contribute to a stable renewable energy system by providing baseload energy. To fulfil this promise, there are several boundary conditions that must be met. For example, producing energy with OTEC is much more environmentally friendly compared to fossil fuel-based production. Furthermore, the technology should enable OTEC facilities to provide reliable power for a competitive price compared to current sources.

These examples show that it is relevant to research the boundary conditions that exist, how the OTEC technology currently performs with regard to these boundary conditions and, if the information is available, what the differences are between the technologies of the different clusters. The required information is gathered from both literature and interviews.

3.3.2 Conclusion

The structural analysis is used to gain high-level contextual insight in the OTEC industry to better understand the activities of OTEC actors that follow from the functional analysis. The structural analysis consists of four elements; *actors*, *interactions*, *institutions* and *technological factors*.

3.4 Functional analysis

The structure of an innovation system shows the components of the system. However, it is likely that this structure is incomplete in emerging innovation systems, and the structural analysis only shows what structures are missing, not how these missing structures are being or should be created (R. A.A. Suurs, 2009). The fact that the sheer number of more and less relevant activities in an innovation system makes mapping them all unfeasible, resulted in a more simplified method for functions analysis. As explained in section 2.4.2, Hekkert et al. (2007) have defined seven key functions (e.g. entrepreneurial activity, knowledge creation, see Table 3.1 for all functions) to consider when analysing innovations and it has been empirically validated in various innovation system analyses (Simona O. Negro et al., 2007; van Alphen et al., 2008; Vasseur et al., 2013). By investigating the performance of the functions, the performance of the whole innovation system can be established and can give clues to what measures could be useful to improve the innovation process.

3.4.1 Method of inquiry and data availability

Regular FIS research uses a combination of qualitative and quantitative research. The qualitative part's purpose is to create an insight in the TIS and create hypotheses, after which these are validated the with quantitative part of the research. In this case there are two main reasons why the quantitative part of the research is unfeasible and to deviate from the regular method. Firstly, compared to structure the functions are more evaluative of nature due to their focus on innovation system performance which makes quantitative research less feasible. Due to the large diversity of variables in clusters and differences in characteristics of geographical regions in the OTEC industry, it was not possible to make the analysis replicable and comparable when investigating multiple innovation systems at once. Secondly, OTEC is in such an early phase of development and so little research has been done on its innovation processes that limitations in time, lack of information and lack of (access to) experts made a quantitative validation of this research unfeasible.

The whole research is explorative and qualitative of nature. The research of the functioning of the innovation systems was done with extensive input from OTEC and renewable energy experts. By using diagnostic questions based on the indicators above, an assessment is made what effect the activities that are being undertaken for each function have on the performance of the cluster, and if there are barriers for further development of the innovation system. Usually, these diagnostic questions are answered by experts on a Likert scale from 1 to 5 (M. Hekkert et al., 2011). As discussed, the functional analysis in this research is more explorative and therefore fully qualitative of nature. The interview protocol is presented in Appendix A: Interview protocol and discussed in section 3.5.

3.4.2 Functions and indicators

In the literature study, a list of indicators was defined to aid in the search of events and actions in innovation clusters that influence the performance of a specific function and consequently the whole cluster. The list of indicators in Table 3.1 was proposed.

Table 3.1: Functions and their indicators of an innovation systems. Based on publications of M.P. Hekkert et al. (2007) and Vasseur et al. (2013).

Function	Indicator
Entrepreneurial activities	Organizations or companies entering/leaving the market
	Diversification activities by incumbents
	Research and technological projects
	Demonstration and pilot projects
Knowledge development	Number of patents
	Number of scientific publications
	Research diffusion/convergence
Knowledge exchange	Intra-cluster knowledge exchange (workshops, conferences, research publications etc.)
	Inter-cluster knowledge exchange
	Co-authorship of scientific publications
Guidance of the search	Targets set by industry
	Targets set by regulatory bodies
	Expectations and opinions of experts
Market formation	Market size
	Efforts made to enable market formation
Resource mobilization	Financial resources
	Human resources
	Physical resources
Creation of legitimacy	Extent to which the technology is promoted by organizations, government
	Lobby activities for/against the technology

During the research new insights were gained concerning the properties of the industry and availability of information. No data was available on several of these indicators while other information could not be classified in the list of indicators. Therefore, an iterative method (Friese, 2011) was used when processing the gathered research data, using the list above as a starting point, to achieve a comprehensive set of indicators that is able to describe the innovation system. The list presented in Table 3.2 is the final set of indicators that was used to code all data.

A complicating factor in the analysis of the functioning of innovation systems is that for emerging technologies, not yet all structures are fully in place, and certain functions of the innovation system are not equally valuable for every phase of development. Therefore, the phase of development should be determined to establish which structures and functions are found to be currently essential. M. Hekkert et al. (2011) have established four phases of development, three of which are relevant for OTEC. In the *pre-development phase* a prototype shows that the new technology works. In the *development phase* the first commercial application of the technology occurs, the technology enters the market without subsidy. The *take-off phase* covers the period when large scale diffusion starts to occur. Worldwide there are multiple OTEC prototypes in use. A first commercial application is under construction by DCNS in Martinique, although it is still dependent on subsidies such as NER 300. Therefore, OTEC worldwide can be placed in the development phase (M. Hekkert et al., 2011). This influences which functions are (most) relevant in the functional analysis. OTEC development is currently in the development phase, where it is expected that *entrepreneurial experimentation* is the most important function due to testing with prototypes. All other functions relevant as well due to the delicate state an innovation system is in in this stage. Therefore, all functions influence the system either positively or negatively and all functions need to be analysed.

Table 3.2: Functions with final indicators

Function	Indicator
Entrepreneurial activities	Commercial projects
	Formation of supply chain
	Demonstration and pilot projects
Knowledge development	Learning by doing
	Learning by using
	Learning by searching
	Research diffusion/convergence
Knowledge exchange	Learning by interacting
	Co-authorship of scientific publications
Guidance of the search	Targets set by industry
	Targets set by regulatory bodies
	Expectations and opinions of experts
Market formation	Introduction of niche markets
	Efforts made to enable market formation
Resource mobilization	Financial resources
	Human resources
	Physical resources
Creation of legitimacy	Aid for/resistance against projects
	Lobbying activities for/against the technology
	Technology promotion

3.5 Semi-structured interview

Due to the only recently renewed interest of the academic community in OTEC, which is mainly focused on technology, there is little recently published information that can be used to describe OTEC clusters. Therefore, data for the analyses in this thesis are mainly sourced from primary expert interviews. The interview is semi-structured to enable both comparability between clusters and give it an explorative nature, which is required due to the aforementioned limited availability of literature. The main focus of the interview is the functioning of the innovation clusters, although some questions allow some overlap with the structure. From each cluster of which an in-depth analysis is made, at least one expert is interviewed, principally using the same questions for each interview. Relevant information from previous interviews is incorporated in following interviews to maximize relevance, and the two versions of the interview can be found in Appendix A: Interview protocol. Except the first, all interviews were done via audio or video calls. All interviews have been transcribed and coded in Atlas.TI.

3.5.1 Interview questions

The questions in the interview are based on the indicators of the innovation system functions. Open-ended questions were formed to give the interviewee the freedom to interpret and answer the question in a way they seem fit.

3.5.2 Interviewees

The interviewed experts were required to have a relevant function in an important organisation in the OTEC industry, either commercial or public. To gain insight regarding the different actors in the OTEC industry an analysis was made in section 2.2. These organisations have been contacted directly to enquire about their willingness to participate in this research. Several interviewees gave recommendations on potential other experts that could be of value. This led to a total of seven OTEC experts of seven different organisations and one interview with an ocean energy expert. All OTEC experts had thorough knowledge of the OTEC industry. Table 3.3 shows an overview of the interviewees. The interviews took between one hour and one and a half hours and were guided by a list of questions that was made available to the interviewees in advance.

Table 3.3: Interviewee organizations and functions

Organization	Function/expertise
Saga University (Japan)	Assistant professor of Institute of Ocean Energy researching OTEC plant design
Xenesys (Japan)	Facility manager of 100kW OTEC demonstration plant in Kumejima
Bluerise (Netherlands)	Chief technology officer
Dutch Marine Energy Centre (Netherlands)	Head of operations
Akuo Energy (France)	Project Manager NEMO (10MW offshore OTEC project)
Naval Energies (France)	Senior business development manager
Ocean Thermal Energy Corporation (USA)	Chief science advisor
Universiti Teknologi Malaysia (Malaysia)	Director of the UTM Ocean Thermal Energy Centre

3.5.3 Interview structure

Two different versions of interviews have been conducted, the first one had a structural and a functional part while seven interviews were purely functionally orientated. This first interview was more comprehensive to quickly gain more information on the OTEC clusters' structure and to be able to validate literature.

The interview that was done first has only been carried out with Bluerise and was split in two parts; a general part which deals with some personal questions and questions about the global OTEC industry and a second part regarding the specific OTEC cluster and/or organisation. To maximize interview effectiveness a funnel structure was used for ordering questions, starting with broad and general questions, followed up by more specific questions. In the second part questions were ordered by function to ensure coherence of consecutive questions. The general questions were meant to get a better understanding of the structure of the whole OTEC industry, while questions regarding cluster-specific innovation system functions are based on the function indicators and used to obtain a more in-depth analysis of the performance and potential of the Dutch OTEC cluster. This approach of using a different interview for Bluerise compared to the others was chosen to maximise the information gathered from a source that is easily accessible and maximise the focus of the other interviews. Furthermore, the first interview was used as control for the questions as well. The other interviewees have gotten a condensed version of the first interview. Some questions were removed or adapted due to the experiences expressed by the Bluerise interviewee.

3.6 Data analysis

All data that could be used for the functional and structural analyses were coded in Atlas.TI according to the indicators below. The method for coding data that is advised by Atlas.TI (Friese, 2011) was applied on all interview data to obtain a comprehensive overview of what is being said by interviewees. Following the guidelines of this method, an initial set of codes was created which was likely to encompass most of the data. These codes are also known as indicators in FIS theory. Subsequently, an iterative process was started where the data is coded and at the same time the initially determined set of codes was updated based on what was found in the text. When certain codes were underused, it was merged with other codes, while overly common codes were split into multiple more specific codes.

4 Cluster analysis

In this chapter the properties and activities of the five analysed clusters will be discussed. The clusters are individually analysed using the structural elements, functions and indicators as defined in chapter 3. The transcripts of the interviews were coded in Atlas.TI, thereby defining what indicator corresponds to each piece of information. This section starts with the analysis of the cluster, first giving a short history of the cluster, after which the structural and functional analyses are presented. The (condensed) cluster analysis of the clusters without interviewees can be found in Appendix C.

Referencing from interviews is done via the coded transcripts that were made with the software Atlas.TI. Each reference consists of the interviewee/document number (eight interview transcripts and one written document) and the quotation number: (<interviewee/document number>:<quotation number>). For example, (1:39) is the 39th marked quotation in the interview transcript of the facility manager working at Xenesys, Japan. Beside the eight interviews, one large document regarding Bluerise was coded in a similar way to the interviews and is shown as document 9 in referencing.

Table 4.1: Interviewee organizations and functions

Interviewee number	Organization and function/expertise	Interview date
1	Xenesys (Japan). Facility manager of 100kW OTEC demonstration plant in Kumejima.	12 September 2017
2	Bluerise (Netherlands). Chief technology officer.	7 July 2017
3	Naval Energies (France) Senior business development manager.	19 September 2017
4	Dutch Marine Energy Centre (Netherlands). Head of operations.	28 August 2017
5	Ocean Thermal Energy Corporation (USA). Chief science advisor.	18 September 2017
6	Saga University (Japan). Assistant professor of Institute of Ocean Energy researching OTEC plant design.	22 August 2017
7	Akuo Energy (France). Project Manager NEMO (10MW offshore OTEC project).	15 September 2017
8	Universiti Teknologi Malaysia (Malaysia). Director of the UTM Ocean Thermal Energy Centre.	3 November 2017

4.1 Japan – Saga University / Xenesys

For the Japanese cluster analysis, two interviews were held. The first interviewee is an Assistant Professor employed by the Institute of Ocean Energy (IOES) of Saga University where he researches OTEC plant design. The second interviewee is the facility manager of the 100kW OTEC demonstration plant in Kumejima.

OTEC research started at Saga University in 1973 with multiple experimental OTEC facilities since 1982. Since the year 2000, deep seawater research is being done on Kumejima island by the Okinawa Deep Seawater Research Institute, focusing on all kinds of applications of deep seawater such as oyster and prawn hatcheries, a sea grape farm, and the farming of winter vegetables in summer (Okinawa Prefecture, n.d.; OTEC Okinawa, n.d.; 1:57). After the nuclear disaster in Fukushima in 2011 the Japanese government set up a renewable energy funding scheme which allowed for the addition of a 100kW OTEC demonstration plant to the deep seawater research facilities, which started operation in 2013 and still delivers steady power to the grid 24/7. The aim of this project is to gain technical knowledge regarding OTEC, as well as promotion of the technology and education. The plant is open to the public five days per week and offers free tours around the facility (OTEC Okinawa, n.d.). This cooperation between different deep seawater users, including electricity generation, food production and water desalination, was first established in Kumejima and therefore is called the Kumejima-model.

A consortium of three Japanese companies was selected by Okinawa Prefecture for the construction of the plant. Xenesys, a small company with expertise on heat exchangers and power generation units, Yokogawa Electric, a large electrical engineering and software company, and IHI Plant Construction, a medium size company specialized in plant design and construction. Since its completion, Xenesys has taken on operation and maintenance and organises guided tours of the plant for visitors for education and demonstration purposes (Xenesys, n.d.).

The deep seawater industry in Kumejima is starting to reach the limits of the current deep seawater supply. Consequently, preparations are being made and funds are being sought for a larger scale cold water intake pipe for the deep seawater industry, combined with a 1MW OTEC plant. The collaboration between OTEC and other deep seawater users makes the development more financially feasible. However, it is expected that this expansion will primarily be funded by the Japanese national government in the form of the ministries of Economy, Trade and Industry as well as Education because private financers are not yet willing to invest in OTEC and for this scale plant the required initial expenditure might be too large to carry for a regional government.

4.1.1 Structural analysis

The structural analysis discusses the actors, interactions, institutions and technological factors in the cluster.

Actors

The largest OTEC research organisation in Japan is the Institute of Ocean Energy of Saga University and focuses mainly on primary research of heat exchange. The OTEC demonstration plant in Kumejima has been built by a consortium of private organisations and is now operated by Xenesys (1:1), which is one of the original members of the OTEC consortium. In Japan OTEC is intertwined with other deep seawater industry which uses the same deep seawater resource (1:40). The Deep Sea Water Research Institute investigates how the deep seawater resource can be used for numerous applications including aquaculture and agriculture and businesses have spawned from this research (1:41). Funding for the OTEC project comes from the Japanese national, regional and local governments (1:1), while their policies influence the viability of the technology.

The Global Ocean reSource and Energy Association is an international organisation with over 50 private, public and academic members that was formed in Japan and aims to promote the research and use of the Kumejima-model (cooperation between all kinds of deep seawater industry including OTEC, aquaculture, agriculture, seawater desalination) worldwide (GOSEA, n.d.). Okinawa has had a clean energy partnership with Hawaii up to 2015 and has now developed into a sister-city partnership between Hawaii County and Kumejima (1:31).

For the overview four types of actors were distinguished; private, public, public-private and research institutes. An overview of actors is shown in Table 4.2.

Table 4.2: Actor overview, main OTEC developers marked in bold

Type	Actor
Private	**Xenesys** (2-10 employees)
	Japan Marine United (1:113)
	Yokogawa Electric (1:113)
	IHI Plant Construction (currently not active in OTEC) (1:51)
	Deep seawater industry (1:40)
	OTEC Consortium – A group of Japanese businesses related to the Kumejima OTEC plant (1:72)
Public	Japanese national government (1:1, 6:15, 6:21): • Ministry of Economy, Trade and Industry • Ministry of Education
	Okinawa Prefecture regional government (OTEC funding) (1:1)
	Kumejima local government
	Okinawa-Hawaii Clean Energy Partnership (1:34)
Public-private	Global Ocean Resource and Energy Association (GOSEA) (1:32, 1:33), consisting of approx. 30 private, seven academic, and 14 public organisations (GOSEA, n.d.). Amongst others: • **Saga University** • Ryukyus University • Okinawa Institute of Science and Technology • **Xenesys** • Kumejima town • Okinawa prefecture • National ministries
Research institute	**Saga University, Institute of Ocean Energy Saga University** (university: approx. 7000 students, 500 research staff)
	Okinawa Institute of Science and Technology

Interactions

None of the found actors has the ability to develop OTEC singlehandedly. To enable their OTEC activities they interact with each other, which have been mentioned in the actor overview of the previous section. Saga University, Xenesys, IHI Plant Construction and Yokogawa Solution Services have cooperated in the development and construction of the 100kW Kumejima OTEC facility in the form of the OTEC consortium. When construction was completed, Xenesys was hired by Okinawa prefecture to operate and maintain the plant and give tours to visitors. Currently, the main interactions in the Japanese cluster are between Saga University and Xenesys, who are currently in contact for further development and testing of new OTEC equipment on the existing plant and for the effort to get designs and funding for a proposed 1MW plant. Saga University and Japan Marine United are doing some research on floating OTEC together (1:113). A graphical overview of all interactions in the cluster is given in Figure 4.1.

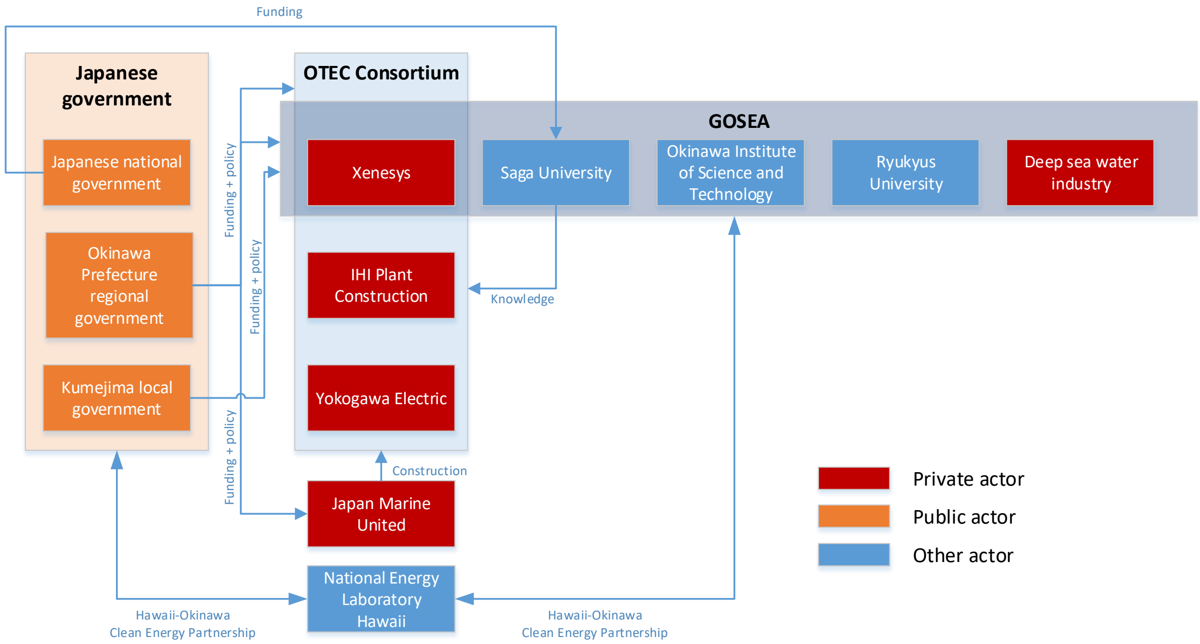

Figure 4.1: Graphical overview of interactions in the Japanese OTEC cluster

There are interactions between the Japanese cluster organisations and the international market through the yearly OTEC symposium and the Netherlands and Japan have signed an agreement for further collaboration on ocean energy research, including OTEC (OTEC news, n.d.-a). Nevertheless, it is not clear how much international collaboration there is and to what degree this adds value to the development of the cluster.

Institutions

The institutions in Japan have been relatively beneficial for OTEC due to the focus of the government on renewable energy developments as result of the Fukushima nuclear disaster, creating opportunities for a small-scale pilot plant.

There should be institutions that allow for international funding of projects (1:97). Due to governmental restrictions with regard to the funding of international research and project development it is hard to cooperate with OTEC organisations from other countries than Japan.

Technological factors

The Kumejima demonstration plant, a 100kW double Rankine cycle facility (1:38), has shown that the technology works reliably in one of the most corrosive environments in the world and survives multiple typhoons per year without any major maintenance (1:44). Designs for a 1MW plant are advanced (1:55), although they still require an intensive study to be able to realise the plant (1:25). Technical feasibility studies are not yet detailed enough and should be worked on to obtain long term finance more easily (6:10).

The technology theoretically already enables megawatt-scale OTEC (1:4) up to 10MW, although there are no detailed plant designs for this scale yet. One major technical barrier for >10MW OTEC is the cold-water pipe design, to make that large enough affordably is a challenge (6:60). Although the consensus in the Japanese cluster is that the technology is ready and finance is the main barrier, they do understand that the technology in its current state is too expensive and should be made cheaper, which in essence is as much a technical barrier as that it is a financial one (1:10, 6:56, 6:57). Larger scale OTEC of >50MW requires a somewhat different design and is not yet technically feasible (1:11).

4.1.2 Functional analysis

The goal of the functional analysis is to map actions and events in a cluster, that influence the creation of a well-functioning cluster, either positively or negatively. The previously determined indicators are used to find information in the data regarding the seven system functions.

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

Although there is only a limited number of organisations currently active in the OTEC cluster, these organisations have achieved things that many other clusters did not. The Japanese cluster has a 100kW demonstration plant in Kumejima which is connected to the grid and is operational 24/7 (1:2, 1:38). This **demonstration project** consists of R&D being done on the demonstration plant and on a laboratory scale OTEC plant at Saga University (1:2). To make OTEC more feasible, the plant's deep seawater output is not directly discharged in the sea. Deep seawater industry in Kumejima is connected to this output and reuses it for other applications (OTEC Okinawa, n.d.; 1:57). Work is being done to increase deep seawater capacity and therefore enable larger scale OTEC and deep seawater industry in general (1:53).

The Japanese cluster has good connections for future collaborations in commercial, demonstration and/or research projects through Prof. Yasuyuki Ikegami of the Division of Ocean Thermal Energy Conversion of IOES, who has a large network in the offshore world. This network can be utilized when **forming a supply chain** for new projects or commercializing products (1:48). Furthermore, the Kumejima demonstration plant attracts national and international stakeholders (1:50, 1:73).

No evidence has been found that work is currently being done to commercialize the technology in form of **commercial projects** in the short term.

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

Technological developments are achieved by **learning by searching** via primary research projects of Saga University and applied research of private organisations. The research of Saga University comprises components, thermodynamic cycles and other OTEC related technologies (1:37), while for example Japan Marine United did joint research with Saga concerning the conceptual design of an offshore OTEC platform (Japan for Sustainability, 2013) and Xenesys tries to apply current knowledge without doing much more research (1:80). Furthermore, the local government of Kumejima did a feasibility study regarding advanced use of deep seawater by combining OTEC with other applications of the resource, which resulted in the link between the deep seawater industry and the OTEC plant (1:57). By **learning by doing** in the form of construction and **learning by using** in the form of operation and maintenance of the demonstration plant, insight is gained in these processes, which can be used in new, potentially larger scale projects (1:38). By **diverging research** from only OTEC to deep seawater use in general, upfront investments and risks are shared in early development and commercialisation (1:40). In the future, the focus should **converge** again to minimise complexities for early offshore OTEC platforms, while on the long term other uses for the deep seawater could become viable again (1:68).

Nevertheless, to obtain larger scale OTEC much work is still to be done, especially in the case of >10MW. Due to limited funding, only small steps can be taken which slows down the knowledge development and commercialization of OTEC.

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

The actors in the Japanese cluster are very willing to cooperate both nationally and internationally. **Learning by interacting** happens nationally and internationally between private organisations and universities and Saga University cooperates with several universities globally. OTEC is discussed nationally by related organisations at multiple Japanese symposia, such as Techno Ocean (1:79; 1:80, 6:58). Internationally, the yearly OTEC symposium is seen as an important event for knowledge exchange (1:30), as well as international OTEC workshops that bring people together (1:6). Saga University researches heat exchangers together with Xenesys (6:4) and offshore OTEC with Japan Marine United (Japan for Sustainability, 2013). Kumejima, the town where the demonstration OTEC plant is located, has a sister-city agreement with Hawaii county, which includes knowledge exchange regarding renewable energy (1:107) and yearly workshops and symposiums (1:31). This resulted from the Okinawa-Hawaii Clean Energy Partnership between 2010 and 2014 (1:107). One of the results is a signed Memorandum of Understanding to develop a 1MW OTEC facility between the National Energy Laboratory of Hawaii Authority (NELHA), Hawaiian OTEC company Makai, and several Japanese organisations, including Xenesys, Saga University, Japan Marine United (Barbour, 2015).

Due to the use of the same resource, OTEC organisations and deep seawater industry (passively) share knowledge on handling and use of deep seawater. The low temperature difference between the warm and cold stream makes the Rankine heat cycle of OTEC very similar to that of other technologies that are currently in development and in use in Japan, such as those that use industrial waste heat or geothermal heat sources. The experience of that development and use helps OTEC development as well (6:33).

Co-authorship of scientific publications was very limited. In SCOPUS 18 journal articles and conference proceedings were found that were co-authored by other 15 organizations between 1984 and 2017 (search query: TITLE-ABS-KEY (otec) AND AFFIL ("Saga university")). Therefore, no evidence for extensive knowledge exchange could be found from this indicator.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

Japanese **regulatory bodies have set targets** in the form of roadmaps regarding renewable energy that were created by both the national and regional governments. The Japanese government funded all kinds of ocean energy due to the Fukushima nuclear disaster (6:14) and has set OTEC targets of 100kW in 2013, 1MW in 2020 and 10MW in 2030 (1:82). Okinawa is aiming to have a completely renewable energy supply in the 2040s (6:41). The Japanese government was even the most important factor in the emergence and continuation of OTEC development in Japan (1:19). Especially several local governments see OTEC as a solution to their problems, their motivation to support OTEC is not financial, it is practical (6:22).

This focus should give technology developers the certainty that they will have funding in the future and should reduce the regulatory burden. However, due to the broad focus OTEC did not get enough funding for commercialisation (1:14; 6:41). While there still is political interest (1:14), the Japanese national government is currently showing signs of decreasing interest in renewable energy, partly due to many negative results of previously funded renewable energy research and development (6:41). This increases uncertainty, while a clear vision and policy of the government is critical to achieve finance for the next step in development (6:28). Policy creation is hindered by technological uncertainties as well (1:16). Despite increasing global consensus that action is required against climate change, there are no unified international targets yet that might reduce risk for the industry (1:92)

The **industry targets** focus on the domestic market in the short term, taking small steps in plant power output to decrease the initial investment required for the next generation OTEC plant and create track record to reduce risk (1:22; 1:94). Taking smaller steps should make the technology transition to that required for large scale plants smoother as well (1:12). The next step should be the increase of deep seawater capacity in Kumejima from 10,000 tons to 100,000 tons per day (1:53), in combination with the construction of an OTEC plant with 1MW net power output in winter and larger scale deep seawater industry (1:43; 1:53; 6:30). After the 1MW plant, the Japanese OTEC industry should be able to support itself and not be dependent on government subsidies anymore (6:30). Subsequently the focus is set on achieving 10MW with an internationally oriented project in both development and funding (1:85). By cooperating internationally, each actor in this project can focus on their strengths and no one needs to reinvent the wheel (1:62, 1:108). Saga University however, is focusing their research on large scale offshore floating OTEC (6:16) as an important technology for baseload energy in sustainable society (6:38). This focus on offshore OTEC might mean that applied and primary research are not perfectly aligned due to the short-term focus of companies on onshore OTEC, which in turn can negatively influence the speed of development of OTEC in the early stages. Furthermore, the cold-water intake riser is seen as the main technological hurdle, especially for large scale offshore OTEC (1:87; 6:40), which does not receive much attention of any actor in Japan due to the onshore development (1:115).

Expectations of experts in the Japanese cluster are that OTEC will develop in small steps. The first step will be the first-of-a-kind commercial-size OTEC plant (1:23; 6:39). Innovation can then be driven by creating a market for relatively small onshore OTEC plants (1:63). These early OTEC plants need to be developed carefully because any failures can have seriously negative effects on the whole industry (1:26).

Instead of the baseload characteristic of OTEC which is often seen as the major benefit, the deep seawater resource is at least, or even more beneficial to the technology. By reusing it after it has gone through the OTEC facility, the technology becomes much more competitive compared to other (baseload) renewable energy technologies (1:28; 1:53). Nevertheless, OTEC will remain a niche technology due to the geographical limitations of the resource, although in the long term it can be used to produce hydrogen even for countries without access to the OTEC resource (1:86).

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

As was already stated in *entrepreneurial activity*, **niche markets are introduced** that use output water from the OTEC plant for other applications, such as seawater desalination, agriculture and aquaculture. With the cold-water intake pipe being the largest expense of an OTEC project, sharing these costs greatly reduces the electricity price (1:59; 1:66). When this deep seawater industry grows, it can induce the demand for larger OTEC and vice versa (1:41). As stated in *knowledge development*, this is a good strategy for onshore OTEC and mature offshore OTEC but not so much for early offshore OTEC, when the added complexities could hinder development and commercialisation.

Market formation is possible domestically for the Japanese cluster due to the availability of the resource around the southern islands of the country. The Japanese cluster is currently focusing completely on the domestic market. By focusing on the additional possibilities of the cold-water resource, a larger market is potentially created (1:41). Currently OTEC still requires large government investments and is not yet commercially viable, although the high electricity price on the Japanese islands can help OTEC reach financial viability relatively early.

Aside from this, there are no real plans or ideas yet on how to commercialize OTEC yet. The focus seems to really be on development instead of commercialization.

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

The whole Japanese OTEC operation is currently dependent on government funding for its **financial resources** (1:20), with the Ministry of Economy and Trade and Industry having funded the development and construction of the demonstration plant and the Ministry of Education that funds the primary research of universities. The plant has been built using an ocean energy fund that Japan set up after the nuclear disaster in Fukushima in 2011. It is operated and maintained on a budget of the regional government of Okinawa. The downside of this is that OTEC development in Japan is completely dependent on government initiative and funding, which affects the ability to upscale the technology. Private financers are not yet interested in risking their investment in OTEC. A 1MW plant already requires such an upfront investment that it cannot be carried by one regional government (6:19), while >10MW OTEC projects probably requires funding of an international set of governments and/or private investors to carry the risk (1:81). Therefore, the main hurdle for OTEC development in general is the lack of financial resources (1:5; 6:10; 6:43; 6:56).

By doing feasibility studies (6:10), developing and building OTEC step by step (1:14; 6:64; 1:69) and combining it with other (deep seawater) industry branches (1:42; 1:59), the cluster can build a track record (1:91), reduce cost and potentially generate some revenue while doing it. By focusing on the domestic market first, the OTEC case can be highlighted more easily (1:56). All these things make it either easier and cheaper to obtain financial resources, either from the government or private financing, due to reduced risk.

Other resources are not yet limiting OTEC development. **Human resources** are sufficiently available when funding is available (1:98; 6:6) and lacking knowledge within the cluster can be solved via the large network of specialist organisations that is available through Prof. Ikegami (1:48). The only issue regarding human resources is that the Japanese language makes it difficult for international people to join Japanese research (6:44).

Physical resources are currently not an issue (1:105).

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

One of the main supporters of OTEC research and development in Japan is the national government. The **aid for projects** of the government does help, although the unreliability of its support undermines this to a certain degree (1:15). An issue that creates resistance is that a small 100kW plant can still be an unconvincing demonstration of a technology that aims to eventually produce many times that amount of energy, one needs at least 1MW for a convincing case (6:61).

By allowing visitors into the OTEC demonstration plant freely, the **technology is promoted**, negative prejudices that exist about OTEC (OTEC is too expensive, environmental issues (OTEC Foundation, 2016a), OTEC plants are extremely large(6:11)) are dealt with and the technological viability, safety and reliability are shown (1:39; 1:45; 1:50; 1:109; 1:110; 1:111; 6:48; 6:49). Further developments are being done very carefully to prevent failures and keep up the good track record, due to the seriously negative consequences that failures can bring for the whole industry (1:26). The good track record helps back up hypotheses and therefore legitimizes the technology further (1:24). The GOSEA association is a collaboration between private, public and academic organisations with the goal to promote OTEC (1:32), while Prof. Yasuyuki Ikegami, the main OTEC researcher in Japan, travels the world to engage and educate the international community (1:47).

The director of the Okinawa Deep Sea Water Research Institute in which the demonstration plant is placed is a coral expert. His support of the OTEC technology does away with many ecological concerns regarding the effects of deep seawater discharge in shallow water (1:112) and already promotes the technology with his presence alone. Deep seawater is now even being applied to nurse corals that have been weakened due to increasing ocean temperatures (6:54). Nevertheless, there are still both positive and negative remarks being made regarding the environmental impact, which has convinced actors in the Japanese cluster that more research on this topic should be done to promote it further (6:12).

The demonstration plant is used as a tool to **lobby for the technology** as well. Many policy makers and other stakeholders have visited the plant, which helps spread information regarding the state-of-the-art and get OTEC on the political agenda (1:39; 6:48). Other work is being done as well to let OTEC stand out against other renewable technologies to get funding for further development from the government (1:49).

Summary

The following table is a summary of the more detailed table presented in Appendix A, which is the source of information of the analysis. Here the aspects that affect the functional performance are split into positive and negative aspects.

4.2 Netherlands - Bluerise

For the Dutch cluster analysis, two interviews were held with people from Bluerise and one with the head of operations of the Dutch Marine Energy Centre (DMEC). The first interview with Bluerise was unstructured and aimed to give an overview of the fundamentals of the global OTEC industry. The second interview was similar to the interviews held with other clusters, focusing on the structural and functional aspects of their cluster. Additional information regarding the current activities and performance of Bluerise was found in their recent crowd funding pitch (Bluerise BV, 2017a).

This cluster originates from Bluerise, a company founded in 2010 by two TU Delft alumni whose goal is to successfully commercialize OTEC. Bluerise and TU Delft cooperate in research and development of OTEC technology, including the construction, operation of and experimentation with a laboratory scale OTEC facility. This has led to increased performance of their OTEC technology.

Figure 4.2: OTEC research prototype (TU Delft, n.d.).

Cooperation is viewed as an important aspect for the technology's success. Therefore, Bluerise signed an MoU with TU Delft and the Japanese Saga University and Xenesys to increase joint research and development. An MoU is underway for Bluerise and the University of Curacao. Local parties are contracted for international developments.

Until recently all revenue was generated through consultancy activities, including OTEC related feasibility studies and deep seawater resource mapping. Currently SWAC and OTEC projects are starting to become more and more important, with a contract for the development and construction of an 'Ocean Ecopark' in Curacao, including SWAC, small-scale OTEC and other applications of the deep seawater and potential projects in Colombia, Sri Lanka and Jamaica.

4.2.1 Structural analysis

The structural analysis discusses the more or less static aspects of an innovation system, i.e. actors, interactions, institutions and technological factors in the cluster.

Actors

Bluerise is the main actor in this cluster, it is a small enterprise with approximately 20 employees. This company is the driving force behind all research, development and marketing of OTEC. For research they do cooperate with several parties, such as Delft University of Technology and parties in the (mainly Dutch) offshore and marine industry. For international research and development, for example in the case of international feasibility studies and/or projects, Bluerise might collaborate with the local university. Examples are Curacao and Colombia. Furthermore, due to different expertise in different locations, international cooperation in research has started between Bluerise, TU Delft, and Japanese Saga University (does much OTEC research) and Xenesys (OTEC developing company).

Table 4.3: Actor overview, main OTEC developer marked in bold

Type	Actor
Private	**Bluerise** (approx. 20 employees)
	Offshore industry
	Marine industry
	DMEC
	Xenesys (Japan)
	Ecopower Lanka Engineering Services (Sri Lanka)
	New Leaf Power (Jamaica)
Public	The Netherlands Ministry of Economy
	European Union
Public-private	Topsector Water
	Topsector Energie
	Nederlands Water Partnership
Research institute	Delft University of Technology
	Institute of Ocean Energy, Saga University (Japan)
	University of Curacao
	National University of Colombia

For project development, Bluerise uses local parties for activities that require knowledge of the local market and policy circumstances. It has partnered up with New Leaf Power and Ecopower Lanka Engineering Services in Jamaica and Sri Lanka respectively. There is a relatively complete supply chain for small scale projects (2:10), although these parties do not yet have the capacity to realise larger scale plants (2:11)

Several national and international private-public industry groups are utilised to get OTEC on the political agenda internationally. In the Netherlands, examples of these are Topsector Water, Topsector Energie, and Nederlands Water Partnership who help water and energy related companies to connect with governments, research institutions and relevant companies (2:13). Internationally there are organisations such as the International Energy Agency: Ocean Energy Systems (IEA: OES) and the

International Renewable Energy Agency (IRENA) (2:12). There are some private non-profit organisations that have similar aims as well, such as Dutch Marine Energy Centre (DMEC), who provides consultancy services regarding ocean energy testing and networking and the OTEC Foundation (founded by a board member of Bluerise), whose aim it is to independently educate external parties about OTEC technology.

Funding of the company comes from private investors and subsidies from the EU and the Netherlands Ministry of Economy, aside from the revenue generated by the company itself.

Interactions

Several interactions have already been discussed when considering the actors. The main company in this cluster, Bluerise, interacts with several universities, marine and offshore industries and several other private organisations for research. To get access to expert companies and get OTEC on the policy agenda, there is contact with several private and public-private partnership organisations. The Netherlands Ministry of Economy and the European Union have granted subsidies to the company.

Institutions

Institutions for OTEC in this cluster have been mostly comparable to the institutions of other early development phase renewable energy technologies (2:81). It is crucial that this support remains for the further development and diffusion of the technology (2:79). Nevertheless, clear government vision and focus towards a specific goal is lacking, which increases risk for project and company financers and makes it very difficult to get land/sea plots and permits to execute projects (2:63).

Technological factors

The technology to build an OTEC plant is available at Bluerise (9:59). they claim to have a technological advantage compared with their competitors (9:58), which has been tested by using their laboratory-scale OTEC demonstration system that was constructed together with the TU Delft (9:59). Nevertheless, one will need the expertise of other industries to grow towards large-scale OTEC plants (2:92).

4.2.2 Functional analysis

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

Bluerise started its projects early in its existence with a laboratory-scale OTEC demonstration system. This **demonstration project** was conducted in collaboration with TU Delft to test their technological developments (9:20).

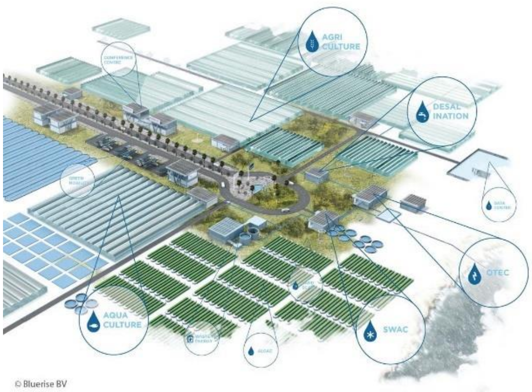

Figure 4.3: Ocean Ecopark Curacao (Bluerise BV, n.d.).

Besides other commercial activities, such as paid feasibility studies and consultancy services (9:12), Bluerise has been working on their first **commercial project;** Ocean Ecopark Curacao, which should be operational in 2019 (2:30). The main part of this project is Deep Seawater District Cooling of 10MWt, which will cool the Curacao airport terminal and several other buildings and will be combined with a 500kW OTEC plant (9:30). The deep seawater output will be used for cooling the soil to produce temperate crops (crops that cannot grow in hot climates, such as tomatoes), aquaculture, algae production and some small-scale other applications (Bluerise BV, 2017b). Furthermore, Bluerise has signed agreements to build the largest deep seawater district cooling system in Jamaica with local partner New Leaf Power (9:31) and there are projects under development in Colombia and Sri Lanka (2:22; 2:30). A proposal has been submitted together with several Japanese parties to construct a larger deep seawater intake pipe on the same site of the current deep seawater intake at Kumejima, Japan (2:21).

The **formation of the supply chain** of the cluster is still an issue. The supply chain is sufficient for the first smaller-scale projects still requires work for the larger-scale ones (2:10; 2:106) due to the limited capacity of the current suppliers (2:11). To decrease risk in the supply chain, Bluerise has a strategy to source products locally or keep local stock and tries to keep suppliers committed through "long-term fixed price contracts, supplier guarantees, and financial supplier (equity) participation" (9:50). The limitations regarding suppliers necessitates international cooperation (2:85). Because Bluerise is situated in the Dutch city of Delft, it has easy access to knowledge via the local technical university and has relatively easy access to the Dutch offshore and maritime industry when specific expertise Is required (2:15; 9:10). A dialog with these industries has already started (2:33; 2:51) and has shown interest in OTEC (2:103).

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

Technical knowledge and knowledge regarding technological and economic viability is developed in the Bluerise cluster by **learning by searching**. Bluerise and the TU Delft collaborate on research of OTEC technology, including the thermodynamic cycle and resource viability (9:20). The main goal of the technical research is to increase economic viability of OTEC (9:3; 9:19). Together with UTM OTEC, Bluerise is doing feasibility studies for OTEC in Malaysia and neighbouring regions (9:43). Aside from Bluerise, the EU has initiated a study regarding renewable energy in overseas territories which includes OTEC (2:83) and the development bank of Latin America (CAF) has commissioned multiple studies regarding the use of deep seawater, mostly focused on SWAC but can be expanded to OTEC in the future (2:98).

Bluerise is currently hard at work to realise their Curacao project, from which the lessons **learned by doing** can be used for future projects (9:30). This project and the other projects in Jamaica, Colombia and Sri Lanka do include OTEC but are focused mostly on deep seawater cooling. Where OTEC is still relatively expensive and not yet economically viable for the scale of OTEC plants that are being developed, seawater cooling systems are already economically viable and has an existing market. Due to the similarities between the technologies used in OTEC and seawater cooling, much technological knowledge is created by executing cooling projects, while at the same time generating much needed revenue (9:16).

The laboratory-scale OTEC of TU Delft and Bluerise makes it possible to **learn by using** to some extent, by giving insight on how the technology can best be used (9:20). The larger-scale projects will eventually give even more insight into the process.

Due to the short-term dependency on SWAC in their projects, which are crucial for the continuity of the company and for OTEC development, Bluerise has **diffused their research** to include SWAC (2:40). The long-term goal is still successful marketing of large-scale offshore OTEC where it might not be possible to add SWAC to the project.

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

Bluerise **learns by interacting** with research institutes, governments and private companies. Together with TU Delft, OTEC technology is developed including, among other things, thermodynamic research (9:8; 9:20). With TU Delft, Saga University and Xenesys (both Japanese organisations) an MoU was signed to increase cooperative technology development (9:42) and with Curacao University a similar MoU is being drafted (9:41). Feasibility studies are being done together with UTM OTEC for areas in and around Malaysia (9:43).

To enhance international cooperation in the OTEC industry, a board member of Bluerise has founded the OTEC foundation. However due to this connection there might appear to be a conflict of interest. As a result, there are not many other companies joining the Foundation. To overcome this problem Bluerise is facilitating the founding of the OTEC Association, which will be totally independent to make it more attractive for other companies to join (2:44). Furthermore, there is regular contact with other OTEC developers worldwide (2:84; 9:25), both directly as well as through conferences such as the yearly OTEC symposium (2:17). For the realisation of projects, Bluerise uses local firms for things such as client acquisition, financing and regulatory work, New Leaf Power in Jamaica (9:31; 9:34) and Ecopower Lanka Engineering Services in Sri Lanka (9:35).

When required expertise is not available internally, help is sought from other knowledge providers and offshore and maritime industry to facilitate the development process (2:73). The knowledge and experience of external senior advisors is used for business development (9:1).

Industry associations such as the International Energy Association: Ocean Energy Systems, the International Renewable Energy Agency and Ocean Energy Association Europe give advice on government level regarding ocean energies, trying to get them on the agenda and realise things such as feed-in tariffs, subsidies and permits (2:12). Nationally, Topsector Water and Energie and the Nederlands Water Partnership have a similar expert ambition (2:13). These organisations educate policy makers on the possibilities of ocean energy and can educate the industry on the wishes of governments.

Scientific publications in SCOPUS were limited to one article from Bluerise co-authored by several Colombian organizations (search query: TITLE-ABS-KEY (otec) AND AFFIL ("Bluerise")). No published articles from the Delft University of Technology could be found. Therefore, no evidence for extensive knowledge exchange could be found from this indicator.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

The main **target set by industry** is the target of having the first commercial project with small-scale OTEC up and running before 2020 (2:87). This will not yet have a commercial-size OTEC plant but will enable track record building and knowledge development. The OTEC plants that will be built in the future will be onshore up to 10MW, after which floating offshore plants become a necessity (2:51). In comparison to the consultancy services that currently generate most of the revenue, the goal is to make project development the main source of future income (9:14). However, consultancy services generate a short-term revenue to enable further growth and development (9:13). Bluerise has made a commercial roadmap regarding commercial projects as well, with deep seawater cooling being the main focus for the short-term as these projects are bankable, while OTEC can be added to these projects immediately or later on (9:15). In the long term, OTEC will become the main technology. Early markets consist of tropical islands and coastal regions due to their above average dependence on expensive and polluting imported diesel fuel for their electricity (9:24) with target consumers being "utilities, large energy users, governments and project developers in the equatorial region" (9:57).

Targets set by regulatory bodies are seen as critical by the industry, especially in this phase of development (2:27). A clear vision and perseverance is somewhat lacking regarding new renewable energy technologies (2:79). This makes it hard to make projects financially viable (e.g. feed-in tariffs) and practically possible (e.g. availability of permits and plots of land and sea for projects). More support in these areas could have big effects on the speed of technology development (2:63). Support might grow when the first large scale plants are operational due to track record and reduced risk (2:53). Furthermore, feasibility studies regarding the resource are necessary before OTEC/SWAC projects can start, this is a task of the government (to contract a company to do this) as project developers cannot finance such a study on their own (2:70).

The EU is increasingly recognising the importance of overseas territories and has initiated a study regarding their energy supply (2:83). Caribbean countries see the benefits of ocean energy and cooling technologies as well and want to help develop them as a result of that (9:28).

Bluerise **expects** that OTEC will eventually fulfil 10% to 20% of the worldwide energy production with other renewables producing the rest (2:52). The OTEC market will grow rapidly when the first commercial OTEC plant proves technological viability due to decreased risks and the resulting cheaper financing of projects (2:52; 2:53; 2:54). Their **opinion** is that by introducing several additional revenue streams to OTEC in the form of, among others, SWAC, agriculture and aquaculture risks are minimized (9:48) and helps especially in the early stages of market diffusion.

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

As stated before, **introduction of niche markets** is seen as essential for the early stages of market diffusion of OTEC. As OTEC is not yet economically viable current commercial projects are dependent on the other applications of the same resource to make them feasible (9:2). Currently, SWAC is the most important aspect of early onshore OTEC installations (2:42; 9:15; 9:18; 9:48). Research is being done on the use of industrial waste heat sources in combination with cooler seawater as a demonstration of OTEC technology to decrease perceived risk for limited cost (2:41).

Efforts to enable market formation is being done in several ways, by increasing technology awareness, by educating people and policy makers and by building track record. When the first smaller-scale OTEC facility is up and running, track record is built which makes other potential clients more willing to invest in the technology (9:17; 9:23). Technology awareness is being increased in the market and people are being educated regarding the technology's properties by regularly visiting conferences (9:27; 9:32) and by establishing the OTEC Association, which has technology promotion as its main goal (2:48; 2:58).

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

Bluerise has been **financed** by subsidies, investments and loans. It received €400.000 in subsidies from the Dutch government and the EU (9:55), €2,5M from investments in the company (9:45) and recently over €650.000 in crowd funding loans (Bluerise BV, 2017a). Nevertheless, long-term company investors are hard to find (2:65). Revenue is generated to grow and develop with mainly consultancy services as well as some project participation (9:4; 9:11; 9:13; 9:27), where project participation will become more important and consultancy less important in the future (9:14). Revenue for 2017 was €146.000 while projected revenue for 2018 is €1M and increasing exponentially from there due to potential projects (9:45).

There are still issues to make the business case of OTEC work economically (2:28). It can compete with expensive diesel generated electricity in remote locations in the long term (2:54) although the required initial investment, a multitude of a diesel generator, is still a barrier. Furthermore, potential customers do not accept the risk of an unproven technology, partly due to the large investment. This means risks must be reduced, either in the form of track record or in the form of financial risk mitigation such as state guarantees (5:53). CAF and similar funds for the Caribbean could be important sources of funding (2:97), while costs should be decreased by cooperating more (2:59).

Access to **human resources** is good due to Bluerise's location near TU Delft an its cooperation with the university (2:99; 9:9). In terms of **physical resources,** it is especially difficult to obtain land plots and permits for OTEC, this could be facilitated better by governments in the form of specific policy regarding this topic (2:63).

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

Resistance against OTEC projects is limited but comes mainly from negative perspectives that are still wandering around based on outdated information and because it is relatively unknown (2:23). Furthermore, no one wants to be the first to build an OTEC plant due to the risk and expense of a first-of-a-kind, which will be much less for the following plants (2:24).

There are organisations such as IEA-OES and IRENA who **lobby for renewable energy technologies** worldwide (2:12) as well as organisations that focus specifically on the Dutch government (2:13). Currently, there is no organisation specifically for OTEC, which could be beneficial to have. Once the OTEC Association is founded, it could manage this task.

To **promote the technology**, Bluerise regularly visits conferences such as the yearly OTEC Symposium (9:7; 9:32) and publishes white papers to educate interested parties on recent activities and specific OTEC related topics (2:50). By joining and winning several international awards, Bluerise has not only won prices, they have increased brand and technology awareness (9:54). The previously mentioned OTEC Association and Foundation could promote the technology at government level, educate stakeholders (2:48) and motivate other parties to enter the OTEC industry to enable faster technology development and diffusion (2:60).

In the case of project development, Bluerise actively communicates OTEC benefits to local communities and decision makers. This together with partnerships with local companies takes concerns away and makes project support as broad as possible (9:51). Fabien Cousteau has been attracted as an ambassador for their Ocean Ecopark Curacao to promote the project and OTEC in general (2:60; 9:33).

4.3 France – Naval Energies / Akuo Energy

For this case two interviews were conducted. One with a senior business development manager working at Naval Energies and another interview with the project manager of the NEMO (New Energies for Martinique and Overseas) project at Akuo Energy. A second cluster is present in France, with Bardot Ocean as main driver for OTEC development (see Appendix C for a short case analysis of Bardot Ocean). Country borders are regularly used to separate different innovation systems in previous technological innovation systems literature. In this case however, it has been found that both Naval Energies and

Akuo Energy do not cooperate in any way with Bardot Ocean and no other connections between the two clusters has been found. Furthermore, the two clusters are possibly more connected to clusters in other countries than to each other, which is the reason why these clusters have been treated separately, and the cluster of Bardot Ocean is not integrated into the analysis of Naval Energies / Akuo Energy (as was done with the clusters of OTE Corporation and Makai Ocean Engineering, see section 4.4).

OTEC development in this cluster was started by Naval Energies, a marine renewable energy company that is part of Naval Group, a European leader in naval defence, when it began researching the technology and tried to initiate projects. Due to their technical focus, they introduced Akuo Energy, a renewable energy project developer and operator, into what now is the NEMO project in 2012 to handle the non-technical aspects. NEMO will be a 10.7MW net output offshore OTEC plant in Martinique and is the largest project and is the furthest developed (3:91; 7:1). The project did have serious setbacks and delays. When presented, construction was planned for 2015 and commissioning in 2018 (Akuo Energy, 2015; DCNS, 2011). Currently construction has not yet started, although Akuo Energies claims that the plant will be operational in 2020 (Akuo Energy, n.d.). There are other projects in being researched, with Naval Energies looking at OTEC in Malaysia in cooperation with UTM OTEC (DCNS, 2016) and Akuo Energy is investigating OTEC in Indonesia (7:9). These developments have not yet surpassed the stage of feasibility studies.

4.3.1 Structural analysis

The structural analysis discusses the more or less static aspects of an innovation system, i.e. actors, interactions, institutions and technological factors in the cluster.

Actors

OTEC technology is being developed by Naval Energies and they try to become an EPCI contractor for turnkey OTEC power plants (3:3). Subcontractors are used for specific expertise when this is beneficial for development (3:38) and practical research is being done together with the university of Reunion. Many local partnerships exist with universities where projects are developed (3:48). Akuo energy is a renewable energy project developer and operator developing the NEMO project with Naval energies.

As Martinique (NEMO project) and Reunion (prototype) are both French overseas territories, French policies and regulations are impacting OTEC activities. Although it is unclear which departments were involved, Akuo energy has worked extensively with the French government on policy creation for OTEC. The NER300 funding of NEMO was a decision of the European Commission on the advice of the European Investment bank.

Table 4.4: Actor overview, main OTEC developers marked in bold

Type	Actor
Private	**Akuo Energy** (201-500 employees)
	Naval Energies (approx. 13.000 employees, previously DCNS Energies)
	Additional subcontractors
Public	French national government (specific departments unclear)
	European Union • European Commission • European Investment Bank
Public-private	N/A
Research institute	University of Reunion
	UTM OTEC (Malaysia)
	Other (not specified) research institutes near project sites

Interactions

The network of OTEC related organisations is very flexible. Naval Energies has developed the technology and uses subcontractors whenever they deem fit. Furthermore, they can cooperate with any project developer who wants to work with OTEC so they are not bound to Akuo Energy. Akuo Energy on the other hand is similarly free. They are a renewable energy project developer and operator, which means they can buy technology for their projects from any provider and are not bound to Naval Energies, which means that this cluster can radically change in the course of time.

The European Union NER300 funding is critical to make the NEMO project financially viable. After this project the EU will probably disappear or at least play another role in this cluster. The research in institutes in the cluster are mainly dependent on where projects are being developed and therefore can change quickly as well.

Institutions

Before NEMO there was no French OTEC-specific policy. Now however there is policy for OTEC building permits (7:4). The usefulness of this policy is limited to projects on French territory.

Technological factors

Naval Energies is the main technology developer. They are working on several projects (3:48) and should be on the verge of starting construction on the NEMO project as the expected commissioning year is 2020 (7:31), although the state of this project is somewhat unclear and some contradictory information exists on the targets of Naval Energies (3:25). Specific technologies for an OTEC plant can be bought from subcontractors, such as pumps, pipes and specialist materials (3:38).

4.3.2 Functional analysis

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

Due to their role as main OTEC technology developer in this cluster, Naval Energies does most of the R&D. For this R&D they have built three test benches for different purposes, including an onshore 15kW OTEC **demonstration plant** on Reunion island to verify numerical simulations (3:1; 3:2).

Naval Energies is working together with Akuo Energy on their **commercial project** called 'NEMO' (New Energy for Martinique and Overseas), a 10.7MW net output OTEC plant in Martinique (3:91; 7:1). Akuo is the project developer and is responsible for things such as administrative authorization, financing, environmental and societal studies and Naval Energies provides the technology (7:2). The project was an initiative of Naval Energies in 2010 and introduced Akuo in the project in 2012 to handle the non-technical aspects (7:14). Besides the NEMO project, Akuo is investigating OTEC potential and developing potential projects without Naval Energies in Indonesia, which is interesting due to the large number of islands with high electricity prices (7:9). Technology suppliers will be chosen when project contracts are signed. Naval energies in turn is developing opportunities themselves by doing technical and commercial feasibility studies in Malaysia in cooperation with UTM OTEC (DCNS, 2016).

There have been years of delays for NEMO. When the project was presented in 2011, the start of construction was planned for 2015 (DCNS, 2011) and the plant should be operational in 2018 (Akuo Energy, 2015). Currently, the website of Akuo claims it to become operational in 2020 (Akuo Energy, n.d.). Currently there are no signs of construction yet, although according to Akuo the project is moving forward very well (7:15). Another OTEC project in Martinique named Nautilus was planned for commissioning in 2017 and would be the first commercial scale land-based plant with 5.6MW gross power output (Akuo Energy, 2015). This project has been put on hold, *probably* due to difficulties with NEMO and prioritizing that project over the land-based one.

Akuo Energy and Naval Energies work on **forming** different kinds of **supply chains**. The supply chain of Naval Energies is mostly aimed at solving technical problems by subcontracting firms with expertise such as pumps, working fluids, heat exchangers, specific materials and turbines (3:38) when this is faster, better or cheaper than developing a solution in-house (3:65). Only contractors who are "bankable enough to be able to commit on performance and the availability of the power plants" (3:68) are chosen. Akuo requires different suppliers for their role as project developer. They search for technology developers, financers and work with policy makers.

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

Naval Energies is the leading force behind the **learning by searching** in the cluster. They extensively research the technology behind OTEC with a dedicated R&D team of about 40 people (7:23), especially focusing on the energy module, cold water pipe and biofouling. Numerical simulations are verified using the 15kW plant in Reunion and two other test benches (3:1). While Naval Energies does the main R&D in-house, subcontractors are used for certain specific technologies in the OTEC plant (3:38). Akuo Energy does not do any technological research (7:47), although they do carry out some environmental and societal studies (7:2).

By working on commercial projects, Naval Energies and Akuo Energy **learn by doing** about the financial community and their position regarding OTEC and emerging technologies in general (3:31). Akuo has gotten much experience on the policy making aspect of doing a first-of-a-kind project. There was no clear legislation on issuing building permits for (offshore) OTEC plants so Akuo has created this policy together with the French administration (7:4). The complexities of this project were underestimated. Now it is much clearer what is required to realize an OTEC plant (7:15). The 15kW OTEC research prototype on Reunion island enabled learning about the process of development and construction of OTEC plants (3:1).

This research prototype enables **learning by using** by giving insight in the technical and operational complexities of a plant that uses ocean water in contrast to a laboratory plant that runs on refrigerated fresh water. Furthermore, it enables them to verify numerical simulations (3:1). Nevertheless, there are still many uncertainties about the technology, the impact on the environment and the process efficiency. The only way that this can be clarified is by building and operating a commercial plant, so this goal is being pursued (7:22). The idea is that all plants that follow the first-of-a-kind will be easier to develop as it will be 'common' technology (7:37).

Customer demands require Naval Energies to **diffuse their research** to include other technologies in their OTEC projects, mainly SWAC and fresh water (3:43).

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

Naval Energies and Akuo Energy found each other when Naval Energies was looking for a partner to help develop the non-technical aspects of their OTEC project and now complement each other in the NEMO project (7:14). By cooperating closely, they are **learning by interacting**. For parts of OTEC where knowledge of Naval Energies is lacking, they use subcontractors (3:38). Experts from other industries have another approach to problems and can therefore come up with innovations for OTEC. Furthermore, they have many local partnerships with companies, universities and public institutes in territories where they work on projects to gather knowledge on topics such as the local environment (3:48).

There is some cooperation between OTEC companies but more would be better according to Naval Energies, for example in some sort of association. Cooperation does not solve the main problem: finance (3:16), and with it do come IP issues. There should be a good reason to share knowledge to not lose your strong technological position on OTEC (3:47; 3:85). For that same reason, Akuo is not actively searching for opportunities to exchange knowledge (7:27). Akuo did actively cooperate with the French administration to create new policy regarding building permits for OTEC facilities. They combined their knowledge to create legislation that is beneficial for both the government and the industry (7:38; 7:39).

Co-authorship of scientific publications was very limited. In SCOPUS only two articles were found from Naval Energies (previously named DCNS) (search query: TITLE-ABS-KEY (otec) AND AFFIL ("DCNS")) and none for Akuo Energy. Therefore, no evidence for knowledge exchange could be found from this indicator.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

The **targets set by industry** show what the expected timeline for OTEC is in the cluster. Naval Energies wants to start OTEC technology diffusion with a small commercial onshore OTEC plant of 500kW-1MW, the following steps become relatively increasingly cheaper due to the proof of concept. Risk decreases and makes finance much cheaper and decreases the required guarantees of the industry (3:25). Thereafter, 4-5MW and then 15-20MW (3:28). The timeline will be like this: able to take projects of 500kW in 2018 with construction in 2019. When construction starts, new larger scale projects can be taken on. Then larger scale (1MW, 4-5MW, 15-20MW) every 18 months to 2 years (3:29). Interestingly, this contradicts with the timeline of NEMO. No definitive answer was given on why this is the case.

Akuo Energy wants NEMO to be operational in 2020, with following project in 2021 or 2022 (7:31). To maximize the learning curve, plant designs should be used multiple times, e.g. the 10MW NEMO design could be built elsewhere and if you want more power you build two of these plants. When each new plant has a different design, the price will not decrease (7:20).

The first OTEC related target of Akuo is to finish the NEMO project (7:29), there is not a lot of work being done on subsequent projects due to the large scale and high impact NEMO might have on the market (7:33). After NEMO cost reduction must be achieved, similar to offshore wind 15 years ago (7:29). In future OTEC projects, Akuo wants to work with many different technology providers to create a competitive market (7:40; 7:41; 7:42), although it will not support another technical development. Only mature technology will be considered (7:48).

Naval Energies wants their OTEC technology to be competitive to the current energy prices in remote areas, which is about 200-300 euros per MWh (3:51). They are aiming to become an EPCI contractor and a turnkey supplier of on- and offshore OTEC plants worldwide (3:3).

Regulatory bodies have set targets in their encounters with OTEC. The French administration strongly supported the process of building a new regulation package when it became apparent that policy on OTEC permitting was not clear (7:3; 7:4; 7:16; 7:34) and is clearly engaged in eliminating policy hurdles for emerging RETs. Nevertheless, National and international policy on supporting emerging renewable energy technologies is often still lacking (3:24; 3:73). For example, although the European NER300 does support RETs and has been very beneficial for NEMO, it is not very suitable for emerging technologies because it is a production subsidy and not an upfront grant or guarantee (3:64; 3:73; 3:86), which is difficult for technologies such as OTEC that have large upfront costs. Dedicated guidelines should be set up for OTEC by the classification societies because the currently used nonspecific oil and gas guidelines make it more challenging to make a class approved design (3:56) and there are no regulations and permitting procedures and requirements for OTEC specifically, which hinders technology development (3:54; 7:4).

It is **expected** that OTEC must be (almost) competitive after the first-of-a-kind plant. This is possible in early diffusion by aiming for markets with high electricity prices (7:49) or at least there must be proven solutions with track record for the most challenging parts of OTEC technology. Furthermore, there must be a roadmap that shows how to go from the current situation to the situation where OTEC goes to acceptable levelized cost of energy for projects (3:83).

OTEC is currently in the same situation as other renewables 20 years ago. It has some USPs and it will develop similarly to RETs such as wind and solar PV (7:32). To do a project, one needs technology providers who can give full corporate performance guarantees, which means that large industrial corporations are required (3:88), which even then is hard to accomplish. Naval Energies expects that in the future upfront grants or guarantee mechanisms will be created by governments to get emerging technologies such as OTEC to full-scale (3:74).

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

The first-of-a-kind commercial OTEC plant will open the market because no one wants to be the first. Developing a relatively large scale OTEC plant is therefore an effective **effort to enable market formation** (7:21). It will take away many uncertainties and doubts regarding environmental impact and process details (7:22) and enable a decrease of the price of the following plants (7:30) to make it cost competitive (7:36). By offering additional products besides OTEC such as fresh water or cooling, the product becomes much more attractive, which increases the market size (3:44).

Naval Energies investigates SWAC and seawater desalination as potential **niche markets** due to customer requirements (3:27; 3:43; 3:44). These alternate uses of the resource will be crucial to create demand for early OTEC products (3:44) and according to Naval Energies are still interesting for offshore OTEC (3:46). Akuo energy sees similar opportunities for land-based plants with various cooling applications, seawater desalination and aquaculture but does not want this for their early offshore plants due to the added complexity of the design (7:25; 7:26).

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

The French cluster might be one of the more successful clusters regarding the mobilization of **financial resources**. NEMO has been granted €73M from the EU NER300 subsidy scheme, which was essential for the project viability (7:6). It is a production subsidy, so it does not offer upfront grants (3:13; 3:23). This does pose the issue of how to finance the construction of the first-of-a-kind plant (3:23). Partly due to this issue many projects that were awarded a NER300 subsidy failed (3:63) so the programme could use some improvements, especially due to financing and/or providing guarantees for the first-of-a-kind being the main hurdle for further technology diffusion. Financing of projects is usually sought in private loans due to lack of upfront grants or guarantee schemes from governments. These private investors require full performance guarantees from technology providers, who are not able to guarantee such large amounts of money (3:13; 3:23), while banks do not take any risk in these projects (3:78). To give these guarantees, large industrial corporations are required (3:36). Emerging technology developers have to follow the financing rules of mature markets, that is almost impossible (3:64).

When the first-of-a-kind commercial plant is financed and operating, the gap to grid parity must still be bridged (3:5; 3:11; 3:17; 7:34). There are two approaches. Firstly, the aim of both Akuo and Naval Energies is to make financing of projects easier by developing the technology in small steps. Each new plant then decreases the risk, which in turn decreases the required guarantees of the industry (3:26). After the first plant, financing next plants will be similar to financing other renewable energy projects (7:37). Secondly, by allowing competition in the market of technology developers Akuo Energy thinks that costs will be reduced (7:7).

Both interviewees did not see any issues regarding **human** or **physical resources**.

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

Due to the environmental benefits of OTEC power production compared to fossil fuel power and the limited effects that are expected as a result of pumping up large volumes of water, environmental organizations are positive about OTEC. Some are waiting for the first project to be built to better assess the impact, so there is currently **no resistance against projects** from them whatsoever (7:45). The technological aspects of OTEC are viewed positively (3:66).

There is much support from governments, local populations, and in France as well, with much support and high expectations (7:44). The French administration strongly **aided the** NEMO **project** in the process of building a new regulation package when it became apparent that policy on OTEC permitting was not clear (7:3; 7:4; 7:16; 7:34). Internationally however, OTEC specific regulations and permitting procedures and requirements are very limited or lacking completely. This is hindering technology development (3:55; 7:4).

There is a psychological barrier for many people regarding OTEC, which makes them **resist projects**. Firstly, they still think OTEC is not ready for commercialization. Secondly, a lot of false information has been released and overpromising has been done in the past regarding the cost and development phase of OTEC, which makes people not realize what OTEC actually has to offer and what it requires to further develop (3:72).

Lastly, the most important barrier is financial. OTEC projects require large upfront investments, relatively low running costs and no risk on the price of the fuel, in contrast to fossil fuel energy. The distribution of capital expenditures (CAPEX, upfront investments) and operational expenditures (OPEX, cost of operation, maintenance, etc.) of OTEC is radically different from what people are accustomed to with fossil fuel energy. For fossil fuel you have 20% CAPEX, 80% OPEX (10% operation and maintenance, 70% fuel) with >30% uncertainty of that 70% fuel costs. For OTEC projects, 70% is CAPEX and 30% OPEX with 0% uncertainty on the fuel price (3:22). Many people are not yet fully aware of the benefits of low risks on fuel cost and are resisting OTEC projects due to the large investment (3:22) so people must be educated (3:30). Another problem is that financers of OTEC and other emerging renewable energy technologies require full performance and availability guarantees on the first-of-a-kind plants. This severely constricts the possibilities to build these essential plants (3:82). Resistance against projects from financers will decrease after the first-of-a-kind has been built (7:37). Lastly, development is slowed by people that are just interested in OTEC when it reaches grid parity (3:31).

Both Akuo Energy and Naval energies have undertaken extensive **lobbying activities for OTEC** to governments for both changes or creation of policy and for funding. This was especially important for the NEMO project as political support was critical. Both companies have applied successfully for NER300 funding for the NEMO project (7:35). More lobbying activities of Naval Energies are currently aimed at making public stakeholders realize that support to emerging technologies should be different than support for more conventional technologies (3:62). A strong lobby by Akuo Energy helped to create new policy in France for OTEC permitting (7:38; 7:39) and Naval Energies is a member of the European Ocean Energy Association and is active in the French organisations of renewables and marine renewables to try to increase government support (3:60).

These memberships of Naval Energies are aimed at **promoting the technology** as well (3:60). Furthermore, they publish papers on their research and talk at conferences to promote their activities and OTEC in general (3:49). The best promotion of OTEC however, is the successful construction and operation of a commercial power plant. Therefore, completing the NEMO project would be fantastic for the publicity of and trust in OTEC (7:21).

4.4 United States of America – Ocean Thermal Energy Corporation / Makai Ocean Engineering / Lockheed Martin

For the analysis of the cluster surrounding Ocean Thermal Energy Corporation (OTE) in the United States of America, one interview was held with a member of senior management of OTE.

In the USA there are two important OTEC companies, OTE Corporation and Makai Ocean Engineering. Unfortunately, only OTE Corporation agreed to participate in this research. Nonetheless, information regarding Makai from other sources is incorporated.

In 1988, Ocean Engineering & Energy Systems (OCEES) was founded as an engineering consultancy firm and in 1998 it changed into a company that aimed to build land-based OTEC and SWAC plants. This firm evolved into the OTE Corporation. The company has built knowledge, a large network and did consultancy services for revenue, although an OTEC or SWAC plant are still on the drawing board only. The biggest achievement yet is the signing of a contract for a SWAC system for a newly built beach resort in the Bahama's. Currently that project is on standstill due to bankruptcy of the project developer after the land-based parts of the SWAC were already built. Contract negotiations are underway to finish it. While OTE has substantial technical knowledge regarding OTEC, for their projects they work as project developer and keeps in contact with potential technology developers and EPC contractors which they can hire for their projects. Their current focus is purely on commercialization. Research, development or pilot projects are not on the agenda. Their focus is so strong because they believe that a first-of-a-kind commercial OTEC plant will advance the whole OTEC industry to the next level by giving it better access to finance, more people willing to work on improving the technology and possibilities to learn from an actual working plant.

Makai Ocean Engineering is an engineering service provider. It started out as a developer of software for optimal submarine cable laying in 1973, worked on cable and pipelaying design and diverged their activities to include OTEC in 1978 with the development of 'mini-OTEC' in cooperation with, amongst others, Lockheed Martin. Since 2008, Makai is again working on OTEC with Lockheed Martin (Makai Ocean Engineering, n.d.-d). Makai Ocean Engineering and OTE Corporation have worked together on several projects, where OTE Corporation was project developer and Makai technology provider (OTE Corporation, n.d.), although it is not clear which projects.

4.4.1 Structural analysis

The structural analysis discusses the more or less static aspects of an innovation system, i.e. actors, interactions, institutions and technological factors in the cluster.

Actors

OTE works as main actor in their cluster in the role of project developer (5:70). Their idea is that all knowledge that they are currently missing to develop and construct an OTEC plant can be bought from technology developers and EPC contractors (5:69; 5:70; 5:72). There is no fixed group of companies that they cooperate with, all is dependent on price and added value (5:11). OTE is working with several US universities to do research for patents that they have filed, while cooperation is sought with universities in project areas for specific local knowledge (5:23). The National Energy Laboratory of Hawaii Authority (NELHA) has significant expertise on additional applications of the OTEC resource and the Makai demonstration plant is situated on their compound. OTE has very good access to NELHA researchers and their developed technologies and is therefore of value for future project development (5:43). The State of Hawaii supports currently ongoing testing on their heat exchanger testing facility (Makai Ocean Engineering, n.d.-d).

The US national government in the form of several departments is involved by giving grants and guarantees for research in certain cases (5:32). The US government has set rules and regulations regarding licensing of OTEC in 1980. The National Oceanographic and Atmospheric Administration (NOAA) is responsible for giving out these licenses (5:40).

Table 4.5: Actor overview, main OTEC developers marked in bold

Type	Actor
Private	**OTE Corporation** (11-50 employees)
	Makai Ocean Engineering (11-50 employees)
	Lockheed Martin (approx. 100.000 employees)
Public	US national government, including: • Department of Energy • Department of Defence • Department of Agriculture • Department of the Interior
	State of Hawaii
	Local governments at project locations
	National Oceanographic and Atmospheric Administration (NOAA)
Public-private	N/A
Research institute	National Energy Laboratory of Hawaii Authority (NELHA)
	Several US universities (unknown which ones)
	Local universities at project locations (unknown which ones)

Interactions

The network around OTE is very flexible. Due to the idea of contracting the relevant technology developers and EPC contractors and introducing these to each other when they need them (5:11; 5:29) means that changes can happen almost instantly. OTE cooperates with both US universities and universities in the countries where projects are planned or built. US PhD students do research that OTE cannot do themselves (5:23; 5:34), while local universities can supply local knowledge on topics such as environment (5:23). In return OTE can supply knowledge on their topics of expertise and guidance to students. NELHA has much knowledge on additional applications of deep seawater and could become an important partner for early projects (5:43). Several US government departments are used to obtain grants and guarantees to do research when required (5:67). To build an OTEC plant in the USA, a license must first be granted by NOAA (5:40).

Institutions

Policy on OTEC in the USA has been in place since 1980. However, no license for a plant has ever been granted so no one really knows what to do when one is actually requested. For early stage technologies there are policy waivers that minimize government interference (5:40). Internationally, renewable energy in general, including OTEC is seen as an important step in their energy supply (5:41; 5:60; 5:61).

Technological factors

The technological knowledge that OTE has is sufficient to commercialize OTEC. There is much experience due to previous research and other technological difficulties are easily solvable by specialist companies. Currently it is a case of finding a buyer and integrating different existing technologies to realize the first OTEC plant (5:9; 5:39). Makai has knowledge and still does research on the energy unit, heat exchangers, pipelines, environmental effects (Makai Ocean Engineering, n.d.-d), biofouling (Makai Ocean Engineering, n.d.-c) and has experience with mooring (Makai Ocean Engineering, n.d.-a).

4.4.2 Functional analysis

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

OTE's idea is that the added value of doing small-scale **demonstration projects,** as have been done in Japan by Saga University and in Hawaii by Makai Ocean Engineering (both approx. 100kW OTEC plants), does not have significant added value for technology and market development anymore. For this, larger scale projects of 5MW to 15MW are required that give large amounts of new data for technological research and show external parties such as financers the efficacy of the OTEC developers and their technology. Therefore, it is purely focused on commercial projects.

Location	Products	Stage	Est. $$*
US Virgin Islands	Electricity, Water, SWAC	Following a 2-year feasibility study, OTE has designed an OTEC system for the US Virgin Islands providing renewable energy and water for drinking, agriculture, and economic development for an entire community (EcoVillage). OTE's OTEC system has been approved by the USVI Public Services Commission	750 MM
US Territories/Pacific Rim	Electricity, Water, SWAC	Combined OTEC/Potable Water/Sustainable Food production opportunities - proposals submitted to the US Government and a major Defense Contractor for OTEC and/or SWAC Plants for Guam, Diego Garcia, and other Military Bases in the Asia Pacific region	867 MM
The Philippines	Electricity, Water, SWAC	Multiple OTEC/Potable Water plants - OTE has attended meetings with representatives of the Philippines government and is working with the US Department of Commerce and the US Embassy in Manila, Philippines to further discussions with several prospective business partners	850 MM
Africa - Zanzibar, Tanzania and Ghana	Electricity, Water, SWAC	OTEC/Potable Water plants - signed MoU	1.3 BB
American Samoa	Electricity, Water, SWAC	Signed MoU with American Samoa Power Authority and American Samoa Department of Commerce for OTE to prepare costs for several OTEC related projects including fossil-fuel free electricity, seawater, air-conditioning, and a comprehensive economic development plan utilizing the OTEC ancillary products such as potable/bottle water and high-profit aquaculture and agriculture opportunities	500 MM
Cayman Islands	SWAC	MoU and General Terms Agreement with Health City for a SWAC/Potable Water system	400 MM
The Bahamas	SWAC	SWAC plant in the Bahamas - OTE has designed a large SWAC system for the Baha Mar resort in The Bahamas. The system (when installed) will supply seawater cooling to five hotels and a 100,000 square foot casino.	425 MM

Electricity Water SWAC

*Estimated Revenues to OTE over the life of the contract

Figure 4.4: OTE Corporation projects overview. Reprinted from "StockWatchIndex Research Report OTCQB:CPWR" by StockWatchIndex, 2017*. Copyright 2017 StockWatchIndex, LLC.*

Makai on the other hand is operating a continuously running, grid-connected 100kW OTEC plant at the Natural Energy Laboratory of Hawaii Authority-site in Kona, Hawaii since 2015 as a result of a **pilot project** (Makai Ocean Engineering, 2015). In the past, Makai has designed multiple OTEC plants, did technological feasibility studies and heat exchanger tests among others, for OTEC development (Makai Ocean Engineering, n.d.-d). Furthermore, Makai has jointly developed the 'Mini OTEC' 50kW floating **pilot plant** that was commissioned in 1979 and is working together with the Japanese cluster on a 1MW OTEC plant in Hawaii (Makai Ocean Engineering, n.d.-b).

There are eight **commercial projects** which are currently under development by OTE (See Figure 4.4), of which three currently have a high likelihood of being constructed. A seawater air conditioning system for a tourist resort was being built until the whole resort project filed for chapter 11 bankruptcy after the onshore part of the air conditioning system was already built. Now the contract is being renegotiated to finish the offshore part (5:13; 5:14). The company was contracted for an OTEC plant in the US Virgin Islands in 2016 (Tidal Energy Today, 2016; 5:13), although there still is no power purchase agreement which is required for further development of the project and to reach the goal of finishing this project in 2021 (5:14). This project is potentially extending to include seawater desalination and agricultural aspects as well, to comprise a whole 'EcoVillage' (StockWatchIndex, 2017). Lastly, OTE is working together with a large US defence contractor to build a SWAC system for a military base (2:13). The other projects are still in the phase of preliminary meetings, proposals and MoUs with no clear idea on the timeline.

OTE has a large network of companies and people inside and outside the OTEC industry that they can draw on when trying to solve certain problems and reach certain goals due to a highly experienced executive team (5:49). To get in contact with these parties and get them interested in joining OTEC projects, OTE regularly attends regional and industrial conferences to further expand their potential supply chain (5:11). OTE is the project developer in these commercial plans. For each project they create a set of contractors for the other parts of the project, including EPC contractors and technology experts such as Lockheed Martin and Naval Energies in the past (5:11; 5:29; 5:69). All these parties are then introduced to each other by OTE to carry out the project (5:49). It is more temporarily contracting than **supply chain formation**. In turn, these larger companies have hired OTE for their specific knowledge as well (5:11).

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

Currently, there is not much **learning by searching** being done by OTE. There is a lot of research knowledge and experience in the company and it gets local information for projects from local universities, so OTE feels there is no direct interest to do more (5:31; 5:32). The same is true for the additional applications of the deep seawater resource such as seawater desalination, aquaculture and agriculture, knowledge is sufficient for commercialization. Aquaculture and agriculture have been researched for 25-30 years by NELHA (5:44). When a commercial OTEC plant is built, more R&D will be required in terms of system optimization and environmental impact, especially with the interest of the US Departments of Energy and Environment (5:32). Commercial plants will enable new research as well on topics that were not possible before, such as effects of storm, wave and biofouling effects on a commercial OTEC plant (5:45). Makai is **learning by searching** with research regarding heat exchangers, cold water pipelines, OTEC plant designs of 2 to 10MW net-power, environmental effects of deep seawater discharge and biofouling (Makai Ocean Engineering, n.d.-d).

The 100kW pilot plant enables **learning by doing** and **using** by Makai. OTE achieves **learning by doing** in the form of experience with the reactions of the financial world and how to present projects to financers in the future by actively developing commercial projects (5:26). One of the main lessons was that while fast upscaling of OTEC plants would be beneficial for technology development and kWh price, that was not an acceptable risk for financers, who demand upscaling in small steps to demonstrate the technology (5:77). Furthermore, these projects will give OTE experience on how to manage future OTEC and SWAC projects.

As OTE has no plant operational yet so they do not have any **learning by using**. However, due to their complete focus on building such a commercial plant, they might be able to gain experience first-hand in the near future.

OTE has ambitions to combine their early OTEC plants with SWAC, seawater desalination, agriculture and/or aquaculture (5:25; 5:43; 5:75), however the amount of research that is done is small. Therefore, there was **research diffusion** in the past, although there currently is neither diffusion or convergence. It is more a case of doing that first project and then reacting on what happens next.

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

OTE works as a project developer and is aiming to integrate the technology of other companies that are experts in their field, including Makai, instead of relying on their own knowledge or that in the OTEC industry too much (5:70; 5:72). This results in strong **learning by interacting** between different industries. A network of contractors is available with expertise on each part of an OTEC plant, including pipe installation and pipe design (5:49). These partners are found through their network (5:49) and via conferences (5:11). Cooperation with other, mainly larger organisations (technology providers (5:68)), is done in an open and direct way. Nevertheless, legal documents are drafted to prevent any misconduct (5:48). The plan of OTE is to cooperate with local universities in project areas as well, as these can bring knowledge on (local) environmental aspects, while OTE can offer knowledge regarding topics such as aquaculture (5:23). What might somewhat hinder the interaction is that OTE has decided to present less on conferences than that they have before, by only presenting when projects are being built, which is currently not the case (5:51).

While OTE currently does not do much research themselves, they do patent new ideas. The actual research required for application of the idea is then often done by universities (5:34). Several students did research for OTE for their PhD work, where OTE offers guidance and the students deliver research results (5:23).

Makai is working closely together with Lockheed Martin and other organisations in their work to develop OTEC. As stated by Duke Hartman, VP Business Development at Makai, “Based on the lessons learned at this facility, we are working hand-in-hand with several of the world’s leading OTEC developers to design the next generation of commercial OTEC plants” (Makai Ocean Engineering, 2015). For their project goals, Makai cooperates with several OTEC project developers to obtain technical guidance for their engineering services (Makai Ocean Engineering, n.d.-d). This cooperation enables **learning by interacting** as they can learn from the expertise of other organisations.

Co-authorship of scientific publications was very limited. In SCOPUS one journal article was found that from OTE Corporation (search query: TITLE-ABS-KEY (otec) AND AFFIL ("Ocean Thermal Energy Corporation")), four conference proceedings and one regular article from Makai Ocean Engineering (search query: TITLE-ABS-KEY (otec) AND AFFIL ("Makai")) of which one was co-authored by Lockheed Martin and nine conference papers and regular articles from Lockheed Martin that were co-authored by 14 different other organizations (search query: TITLE-ABS-KEY (otec) AND AFFIL ("Lockheed")). Therefore, no evidence for extensive knowledge exchange could be found from this indicator.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

The main **target set by** OTE, is to commercialize their OTEC knowledge by acting as project developer. They aim to integrate the technologies of multiple technology providers (5:69; 5:70) not only in but outside the OTEC community as well, as these can come up with better or new ideas for a problem that has not yet been solved in the OTEC industry (5:72). The first OTEC project will demonstrate a land based 5-10MW plant commercially with integrated additional applications of the resource, such as aquaculture and seawater desalination (5:76). Due to the small scale, the first projects will be land-based due to less risk and cost compared to offshore plants. The long-term vision is completely offshore 100MW OTEC plants (5:18; 5:35) for either electricity generation or production of energy carriers or production of desalinated water (5:53). Seawater desalination is thought to be the biggest driver and the main early application of OTEC (5:22; 5:53) and is therefore used to sell early OTEC plants. OTE will not do fundamental research until they have built a commercial OTEC plant to do new research on due to the importance of commercialization (5:20; 5:33).

According to Makai, it has not yet been fully proven that OTEC is a commercially viable technology. It will require a successful first-of-a-kind plant to enable easier access to financial markets for subsequent projects (Gonzáles & Wabitsch, 2017). Therefore, their **target** is to validate the technology of a 5-10MW plant and simultaneously reduce cost to make OTEC more attractive to enable large-scale OTEC plants (Makai Ocean Engineering, n.d.-b).

OTE has to take into account both domestic (USA) government policy as well as the policy of the government in their target markets. There were **targets set by regulatory bodies** in the USA in 1980 in the form of policy on OTEC and licensing requirement and it has policy to protect early technologies from excessive government interference (5:40). However, no license has ever been granted so no one within the National Oceanographic and Atmospheric Administration (NOAA), who is responsible for these licenses, really has a clue how to issue such a license (5:40). Internationally, OTE feels very little resistance from governments (5:41). The OTEC resource is accessible mostly in the smaller and/or economically less stable countries in the tropics and are often islands. Many of their governments see problems that threaten their country and are caused by climate change, so they do their best to minimize it by making their energy supply more renewable (5:61), these are the first target markets.

So governments are not obstructing OTEC, although they are not helping very much either. The Paris climate change agreement is a step in the right direction, but clear actions have not yet followed from these countries (5:60). For example, the secondary costs of carbon-based fuels, such as pollution and resulting health issues, are still not included in the economic evaluation of new energy projects. A solution could be to trade carbon credits for the actual costs that are incurred by using these fossil fuels, which would make renewable energy technologies much more attractive (5:61).

The OTE interviewee has voiced several **expectations and opinions** regarding OTEC development. OTEC is really driven by the ability to use it for seawater desalination. Due to the location of many countries that have access to the OTEC resource, they are often largely dependent on expensive imported energy and energy intensive seawater desalination for their fresh water. When using OTEC, the costs of this water can be stabilized and reduced, while at the same time reducing the impact on the environment (5:37). The first commercial OTEC plant globally will probably be built before 2023 (by OTE or any other organisation), after which much more activity will arise in the OTEC industry due to the financial community embracing the technology (5:54). The emphasis will then be on cost reduction. The increased interest in the technology will result in a similar development path as that of solar PV (5:56).

Commercialization is currently not only hindered by lack of financial resources but by researchers as well. Many researchers who investigate anything will never say that it is ready for commercialization because they are dependent on it for their work. It is the same with OTEC, where several researchers keep on saying that OTEC requires more research and that more money should be made available for this. This slows down commercialization (5:45). Another barrier for the diffusion of OTEC is that everybody in the OTEC community knows each other but no one really shows their intentions and technological breakthroughs. That is one of the reasons why it might be better to work with other industries instead of with organisations within the OTEC industry (5:71).

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

When commercializing OTEC, OTE found biggest driver for OTEC to be seawater desalination due to the locations where OTEC resource is available. Many communities there have high energy prices and depend on desalinated seawater for their potable water supply (5:6). The first projects as mentioned in *entrepreneurial* activity are mainly SWAC projects (5:25). By adding other applications of the resource to an OTEC plant, multiple sources of revenue are created, limiting the risk of investors (5:8) and potential clients might be more tempted to give it a try due to the additional value. This is the reason why OTE targets to build early land-based OTEC plants that combine OTEC with other technologies (5:76). **Niche markets that might be introduced** are seawater desalination, seawater air conditioning, which have already been commercialized successfully in the past, and agriculture and aquaculture, which have been researched extensively by NELHA and are ready for commercialization (5:43). By adding these niche markets, OTE expands the potential market for the product and can be seen as **effort to enable market formation** as well (5:8).

SWAC is seen as currently the most economical product from deep seawater by Makai and is offering SWAC solutions to their clients. SWAC is not included in their larger scale OTEC plans due to their belief that OTEC is more economical offshore (Makai Ocean Engineering, n.d.-b).

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

The biggest barrier for OTEC concerns **financial resources** (5:3; 5:41). According to OTE there are four reasons for this barrier. Firstly, the dropped oil, wind and solar PV prices make it harder to be competitive (5:3). Secondly, to enable financing of early projects, these must be relatively small-scale plants to decrease the required initial investment, which poses an issue due to economies of scale. Compared to wind or solar PV, a demonstration of a commercial OTEC facility costs several times more, which makes it hard to prove the technological feasibility of the technology (5:19). Thirdly, financers require performance guarantees of the technology, which are too large for a small company to carry and no other companies are willing to give these guarantees because there is no track record (Makai Ocean Engineering, n.d.-d) (5:7). Lastly, it is getting harder to get capital investments in companies in the industry and for companies that make physical products in general. In the last decade increasing amounts of investment money is used for short-term gain in internet service in the likes of Google and Facebook. The money that is invested in those companies is not available for other companies anymore and is becoming a real problem (5:63; 5:64).

Revenue has been generated with consulting services (5:24) and shareholders have invested in OTE, which is a publicly traded company (5:27). Additionally, availability of government grants is investigated for research projects. The Departments of Defence, Agriculture, Interior or Energy have opportunities in which OTE research fits, so that their own research can be (partly) paid for by government funding (5:67). By developing projects, knowledge regarding the financial world has been gained which makes it easier in the future to get financing (5:26). The first commercial OTEC plant will demonstrate that the technology is viable to the financial community, it does not matter who builds it. It will open the financial market for OTEC (5:37; 5:55).

The value of additional technological OTEC research has diminished over time due to the limited data that laboratory-scale OTEC offers. This reduces the need for more **human resources**. Once the industry commercializes after the first commercial plants are built, more money and thus more people will get involved in solving issues in the OTEC technology (5:57).

Physical resources have not been mentioned and are likely not an issue right now, due to the scale of current plans.

Creation of legitimacy
Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

OTE has found that reactions to their activities are mostly positive. It has had 600-700 impact investors, so before going public. This shows that the public embraces the idea of OTEC. Governments like the idea as well and will be extremely impressed when OTEC is actually operational (5:74). OTEC is seen as extra interesting due to the volatility of fossil fuel prices and it is fairly cost competitive in remote areas (5:5), which **aids potential projects**. Understanding of OTEC is increasing, especially due to multiple revenue and product streams, from which remote communities can benefit not only economically but in the form of food and water supply as well (5:17). Alternative renewable energy sources such as wind and solar are unlikely to survive hurricane winds, which are seen on a regular basis in the tropics, while an OTEC system is much more robust (5:5). Furthermore, since the ratification of the Paris climate agreement countries are starting to think more about the pollution of their energy production. Makai their OTEC effort is getting **aid for projects** from different parts of the US government, who grant them research and development projects.

However, these countries that signed the agreement now must fulfil their promises (5:60), which is only happening slowly and somewhat **resists projects**. The actual cost of pollution should be attributed to fossil fuel energy. That would make renewable energy technologies much more competitive (5:58). Many potential buyers have false expectations of the cost of electricity, both from fossil fuels and renewable energy systems. By short term vision on capital expense, the benefit stability of electricity prices with OTEC is sometimes not acknowledged (5:42). And as no commercial plant has ever been built, performance guarantees are hard to come by, which in turn makes financing of this large initial expenditure difficult (5:7).

Some **lobbying activities for the technology** are undertaken. Government grants and guarantees are sought to enable things like feasibility studies and other research, as any government support makes the development process faster (5:65).

The current **promotion activities** involve regular attendance of conferences (5:10) and frequent work with the financial community (5:26). This results in an increased network for future projects and interest and trust in OTEC in general. In contrast to the past, their activities at conferences are limited to attendance only, talks will only be done when there is news about projects that are being built (5:51; 5:74). However, to really promote the technology, an early commercial OTEC plant must be built that shows the industry's technological efficacy (5:4; 5:74). Their project developments and research efforts get much media attention and therefore are good **technology promotion**.

4.5 Malaysia – UTM OTEC

For the Malaysian cluster, one interview was conducted with the director of the Universiti Teknologi Malaysia Ocean Thermal Energy Centre (UTM OTEC), a university department in Kuala Lumpur, Malaysia.

Interest in OTEC started in Malaysia after hydrographic surveys of the South China sea, conducted from 2006 to 2008, showed high OTEC potential with very deep cold-water troughs and warm surface water. Subsequently, several ministries and organisations have been briefed on the potential and what this could mean for Malaysia. In 2012, UTM got a mandate from the prime minister of Malaysia to further develop OTEC, which resulted in the founding of the UTM OTEC. This Centre has promoted OTEC rigorously from 2013 to 2015 in Malaysia as well as the regions surrounding it, increasing awareness on how it contributes to energy security and social economic development. In the meantime, financial and legal frameworks were prepared to be able to launch projects if funding became available. The first government funding for pre-feasibility studies arrived in 2016 (Mahdzir, Jaafar, Awang, & Thirugnana, 2016).

4.5.1 Structural analysis

The structural analysis discusses the more or less static aspects of an innovation system, i.e. actors, interactions, institutions and technological factors in the cluster.

Actors

UTM OTEC is the main driving force behind OTEC development and commercialization in Malaysia. This technology centre is financed by the Ministry of Education. There is no technology expert ambition from any actor as the general idea is that the time has come to apply existing OTEC technology on commercial scale in a real-world environment. There is no need for further development of the technology until the scale is increased further. Therefore, the main role of UTM OTEC is the promotion of OTEC to potential stakeholders, such as ministries, financers and potential buyers. The main industries that might be involved in the first developments of OTEC are the oil and gas industry, who can use the technology on their offshore platforms for electricity and seawater desalination, and the mineral water industry, as seawater desalination provides cheaper and better quality mineral water compared to groundwater. Therefore, UTM OTEC tries to involve these industries in the development process. The Academy of Sciences Malaysia, an agency under the Ministry of Science, Technology & Innovation, has written Science and Technology Foresight Malaysia 2050 (Academy of Sciences Malaysia, 2017) regarding important emerging technologies for the future including OTEC.

Table 4.6: Actor overview, main OTEC developer marked in bold

Type	Actor
Private	Oil and gas industry (i.e. Petronas)
	Mineral water industry
Public	Ministry of Science, Technology and Innovation
	Ministry of Education
Public-private	N/A
Research institute	**Universiti Teknologi Malaysia Ocean Thermal Energy Centre** (university: approx. 17000 students, 2500 research staff)

Interactions

The main interactions in the Malaysian cluster are between UTM OTEC and industry as potential client or investor to enable the realisation of a first-of-a-kind OTEC plant in Malaysia. OTEC is being promoted at national government level via the Ministry of Science, Technology and Innovation. Their research and promotional activities are currently funded by the university, which in turn is funded by the Ministry of Education.

Institutions

Although there is no specific policy for OTEC, it has recently been defined as one of 21 impactful emerging technologies in the Science & Technology Foresight Malaysia 2050 by a government think tank (Academy of Sciences Malaysia, 2017). This has not yet resulted in the creation of new policy although it might have an influence in the future.

Technological factors

OTEC technology is not being developed in Malaysia. Future projects would be completely dependent on technology that is bought from international technology providers. To enable this, UTM OTEC has regular contact with organisations such as TU Delft, Bluerise (Netherlands) (2:84; 9:43) and Saga University (Japan) (8:16).

4.5.2 Functional analysis

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

There are neither **commercial** nor **demonstration or pilot OTEC projects** developing in Malaysia yet. UTM OTEC is the main technology champion and tries to get a **commercial project** going in Malaysia by assembling all necessary stakeholders from which the university can eventually benefit financially (8:58). Continuous conversation between the university and potential technology providers, construction contractors, financers and clients should **form a supply chain** that enables the construction of (one of) the first commercial OTEC plants in the world (8:20; 8:60; 8:61). This has resulted in a set of technology providers ready to get into a project once funding and clients are found (8:54).

The main issue in commercializing OTEC in Malaysia has to do with the financing of the project. The search for funding from potential clients or engineering firms has not yet yielded result (8:59; 8:60) although pressure is increased on potential clients such as mineral water producers and the oil and gas industry to enter the OTEC industry as OTEC can consume part of their current market (8:29).

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

Focus in research is not on repeating things that have already been done by others, such as pilot projects and certain technology development. Activities revolve around promoting the existing emerging technologies to potential investors and stakeholders. It is more promotion instead of applied research because of lack of capacity/financial resources and due to good existing technology (8:18). As a result, the only **learning by searching** that is done specifically on OTEC is focused on where the current technology can best be applied in Malaysia and how additional revenue streams can improve the financial feasibility in different locations (8:21). There is much interest in the additional revenue streams that are possible with the deep seawater, such as seawater desalination, aquaculture and agriculture, which shows **research diffusion** in Malaysia. Research is being done on the growth of temperate crops in warm climates by cooling the earth. However, due to the lack of a facility pumping up deep seawater in Malaysia and no projects in the development phase yet, the technological research that is being done is on laboratory scale, using electrically cooled water as a source (8:39; 8:40; 8:41).

The Academy of Sciences Malaysia (part of the Ministry of Science, Technology and Innovation) has recently written a technology foresight report (Academy of Sciences Malaysia, 2017; 8:3). OTEC was one of 21 emerging technologies that was deemed impactful and which should get more consideration in the future.

A serious disadvantage of not having any OTEC research, pilot/demonstration projects and/or commercial projects is that the cluster does not **learn by using or doing** and it is totally dependent on others for the technology. One subject of research that UTM OTEC does aspire is the development of new working fluids that make the organic Rankine cycle work for smaller temperature differentials to be able to do OTEC in shallower parts of the ocean. This would however require private or international funding for the university (8:38; 8:50).

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

Although the cooperation between industry, government and other stakeholders is currently limited in Malaysia (8:14), there is growing **learning by interacting** among and within universities (8:16). UTM has entered an agreement with Saga University (Japan) and collaborates with TU Delft (Netherlands). Furthermore, universities in Southeast Asia, especially Indonesia and Malaysia, invite each other for cooperation and an annual seminar (8:16). UTM always encourages student exchanges, giving talks on events such as ocean seminars and keeping the website up to date. Within UTM OTEC, weekly student and fellow presentations are held for everyone to keep up with developments (8:43). An MoU is signed with local industry to work together on OTEC in Malaysia, potentially together with Bluerise (8:17).

Internationally, UTM has contact with Bluerise for the development of OTEC in Malaysia (8:17) and with other technology developers to learn from their projects and developments (8:23). The annual OTEC symposium is found to be very important for this purpose too (8:24), as well as the OTEC foundation, although UTM OTEC has never been approached by the Foundation for a contribution to e.g. the website (8:44). Furthermore, without actively trying to get involved in the formation of an independent OTEC Association, UTM OTEC is very positive about this possibility (8:13).

Co-authorship of scientific publications does not seem to have a large impact due to the focus on technology promotion rather than research. The only co-authorship that was found were four journal papers and one conference proceeding, co-authored by other universities (search query: TITLE-ABS-KEY (otec) AND AFFIL ("Universiti Teknologi Malaysia"))

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

An issue arises in Malaysia when one tries to define the targets set into the categories ‘set by industry’ and ‘set by regulatory bodies’ as most targets are set by a university. Due to their strict focus on commercialization and their goal to be as independent of the Malaysian government as possible, UTM will be defined as part of the industry for the sake of the analysis.

As stated, the **targets set by industry** emanate from UTM OTEC as there is not much activity besides the university in Malaysia. Their principle target is to make sure that a commercial OTEC plant is constructed in Malaysia within the foreseeable future, ideally being a first-of-a-kind to make Malaysia a breeding ground for the technology (8:19). They want to do this by using existing technology from technology providers, which will eventually generate revenue, which in turn will enable further research and development of the technology (8:37) and funding of the university for scholarships and education (8:55).

There are two markets that UTM OTEC aims for in their search for an initial customer. Firstly, the oil and gas industry is very large in Malaysia, has sizeable investment capacity and large power and fresh water demand on their offshore platforms. OTEC could be an interesting solution to their demand on deep sea offshore production platforms. Secondly, the mineral water industry is relatively large in Malaysia and is currently dependent on ground water of mediocre quality. Desalinated water produced with OTEC technology would be of higher quality, which is appreciated by their clients (8:30). A third application of cold deep seawater does not involve OTEC as such. The deep seawater could be used to cool the soil to enable growth of temperate crops in warm climates (8:31). Finding investments in this industry would be somewhat harder so it might be better to apply that as an additional revenue stream for the applications in the first two industries.

Water production is currently seen as the main goal and driver of the technology, as well as food production (8:31). Power production for household use will follow later, mainly due to lacking grid connectivity, which requires hydrogen production to store the generated energy (8:32; 8:49).

Targets set by regulatory bodies in the form of a focused policy regarding OTEC from the Malaysian government are currently missing (8:52). There recently has been research by the Academy of Sciences Malaysia on emerging technologies that might be influential in the future. OTEC was found to be one of 21 impactful emerging technologies (8:3) with a potential power output of 100,000MW in Malaysia alone (Academy of Sciences Malaysia, 2017). This might have an impact on the policy making process in the future.

One of the **expectations of experts** of UTM is that deep seawater will probably first be used for other applications than OTEC, after which OTEC can be added in the future (8:33). The OTEC electricity production should be used to produce hydrogen, which then can be used to offset the intermittency of other renewable energy sources. More technical research on this topic would be required (8:49). This would mean there is no umbilical required to connect the offshore facility with the onshore power grid. It is their **opinion** that Petronas or mineral water manufacturers should start adopting OTEC in Malaysia or make purchase agreements with companies that want to construct an OTEC facility (8:56) instead of the current attitude of wait-and-see. Furthermore, universities worldwide should work more toward the commercialization of OTEC instead of technology research. When the technology diffuses, resources will become available to develop the technology further (8:37).

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

Due to the low electricity prices and limited grid connectivity there is no real market for OTEC power in Malaysia in the near future (8:21). To **enable market formation** there is continuous conversation with companies in the oil and gas and mineral water industries, promoting OTEC and especially the additional applications of the resource, e.g. seawater desalination (8:25; 8:26) to get an initial customer for the technology. The only thing that currently limits diffusion of the technology in Malaysia is lacking funding for the initial investment. When a plant would be constructed, there would be buyers for the product. Funding has been discussed with parties from the Middle East due to their wealth but have not yet resulted in their actual involvement (8:57).

The focus on additional revenue streams of OTEC shows the importance of **introduction of niche markets** in the early marketing of OTEC technology in Malaysia (8:6). There are multiple locations in Malaysia where the OTEC resource is available and different niche applications are suitable for each location. Niche applications that have been identified as suitable for locations in Malaysia include seawater desalination, hydrogen production, aquaculture, agriculture (research is being done on growth of temperate crops in warm climates by cooling the soil (8:29; 8:41)) and electricity production (8:21).

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

Currently, the main barrier for OTEC in Malaysia is the lack of **financial resources** (8:57). Initial costs are an issue due to the habit of high level energy advisors to compare energy projects on capital costs only, while for a fair comparison fuel costs should be included (8:8). Furthermore, low electricity prices in Malaysia make OTEC electricity financially unfeasible without subsidy for all but the largest scale plants (8:22). Financial institutions, even development banks, have a wait-and-see attitude. Governments and banks should do a radical investment in a first-of-a-kind project which will spark the interest of other investors similar to how commercial interest has increased in natural gas (8:51; 8:53). Partners and investors are actively being sought by UTM OTEC for deep seawater and OTEC projects, such as Petronas (oil & gas industry) (8:20; 8:53), the mineral water industry (8:62) and independent investors such as investors from the Arab Emirates (8:57).

The parties working on OTEC in Malaysia are not actively involved in the acquisition of **physical resources** and it is therefore not a problem. The deep seawater resource is available only in some parts of Malaysia (8:2).

Human resources are not yet particularly relevant in the Malaysian cluster due to the lack of projects. When projects start to develop, more financial resources will become available, which in turn will enable recruitment of more human resources.

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

There is both **aid for and resistance against OTEC projects** in Malaysia. Support is increasing due to the depletion and resulting increasing prices of fossil fuels (8:5). The possibility of producing fresh water from seawater is another driver of OTEC, especially for more remote areas in Malaysia and the world (8:5). The large oil and gas industry in Malaysia creates both aid and resistance. Due to their large financial strength and power and water demand in remote offshore locations, the companies in this industry are ideal first customers for OTEC, which in turn attracts attention from the global OTEC industry (8:36). On the other hand, the large national oil and gas production makes energy prices low and competition tough.

Resistance against OTEC is especially due to the mentality of high level energy advisors and policy makers. People don't understand OTEC and so it doesn't easily get onto the agenda (8:15). Furthermore, many of them see OTEC only as a technology to generate electricity similar to other energy plants, while OTEC and its deep seawater resource can be used for many other value adding applications as well (8:7). Energy projects are often compared on capital expenditure and not over the entire lifetime of the project, which makes fossil fuel-based projects more attractive (8:8). The capacity of one OTEC plant is many times less than current large-scale power plants based on fossil or nuclear fuel, which means OTEC should be used in conjunction with other renewable energy technologies (8:9).

This requires a change in mindset. Lastly, the pollution and secondary costs of current power sources is not taken into account when choosing between renewable and non-renewable energy projects (8:10). Aside from mental barriers, there is still some uncertainty of the environmental effects of OTEC. Especially the growth of phytoplankton and fish poisoning are topics which should be researched further to take away concerns (8:11).

The main activity of UTM OTEC is **technology promotion**. OTEC is discussed with as many potential stakeholders as often as possible to promote the technology and get them involved (8:15). Especially oil and gas (8:36) and mineral water companies (8:62) are being contacted regularly to try to combine their network of (potential) technology providers, investors and clients (8:18). Via journal publications (8:47) and presentations on ocean seminars (8:43) UTM OTEC promotes the technology and their activities both nationally and globally.

5 Cluster performance: cross-case analysis & discussion

The aim of this chapter is to analyse the differences between the different clusters and what local and global effect they have on the development of OTEC. First comparisons will be made for the structure and each of the seven functions of innovation systems for the five main clusters that were investigated for this thesis, after which a short narrative will make a comparison for the four other clusters that were only analyses using publicly available data. Lastly, the quality of the results, implications for policy and research and used theory will be discussed.

The structural and functional analyses will include an overview of strengths and weaknesses on the different indicators that were used to determine the performance of each structural and functional element for each cluster. For each structural and functional element, the average performance is determined based on how the cluster performs on each indicator and is scored on a five-point scale (++, +, +/-, -, --). In general, each indicator performance score is treated equally to come to the average element performance score, although in some cases the importance of specific strengths or weaknesses can have such large effects that the average score is influenced more strongly.

5.1 Structural cross-case analysis

The structure of an innovation system shows if the boundary conditions for successful commercialization of the technology are fulfilled. Comparing the structure of the clusters gives insight in their performance. Just as in the cluster analyses, the cross-case analysis focuses on the actors, interactions, institutions and technological factors.

5.1.1 Actors

An innovation system can only perform well if essential actors are available. In case of OTEC, three types of actors are required which are not governmental (discussed in 5.1.3) or financial (not cluster-specific). *Technology providers* are required to develop technological knowledge to *project developers*. Both of these actors may use contractors to decrease the workload or enable actions for which there is no knowledge available in the OTEC-focused organizations. Another relevant group of actors are local companies and knowledge institutes when developing projects. These can aid the development of projects with local knowledge and increase goodwill in the local community. Although it could be of large value, the involvement of locals is not essential for the diffusion of OTEC. The size of OTEC developing organizations has an effect on what a cluster can accomplish in, among others, their technology development, promotional activities and guidance towards governments. Therefore, this is taken into account as well when defining the performance of OTEC clusters regarding actors. See Table 5.1 for an overview.

All clusters except Malaysia have multiple technology providers and a set of contractors. How strong these ties are to the set of contractors can differ from cluster to cluster, this cannot be quantified. There is no real project developer in Japan. The technology developers make plant designs and then appoint local industry companies to construct and maintain the OTEC facility.

The actor groups of the Netherlands, France and USA all include the most essential actors. Japan is missing project developers, what might cause issues with commercialisation of their technological knowledge. Malaysia only wants other clusters to come and build projects in Malaysia. This does not require any of the actors that are essential for the other clusters, only a technology promotor in the form of UTM OTEC.

Table 5.1: Overview of essential actors per cluster

	Technology providers	Project developers	(Potential) cluster-specific contractors	Involvement of local companies and knowledge institutes in projects	Size of orgs.	Avg.
Japan	Saga University, Deep Seawater Research Institute, Xenesys	N/A	Japanese (offshore) industry	Only domestic development	Small	+/-
Netherlands	Bluerise, TU Delft	Bluerise	Dutch offshore and construction industry	Yes	Small	+
France	Naval Energies, Bardot Ocean	Akuo Energy	Unspecified set of contractors	Yes	Large	++
USA	Makai Ocean Engineering, Lockheed Martin	OTE Corporation	Unspecified set of contractors	Yes	Large and small	++
Malaysia	N/A	UTM OTEC (until another project developer is attracted)	N/A	N/A	Small	-

5.1.2 Interactions

Interactions are essential in an innovation system. When actors from the previous section do not interact well with each other, the system will still not work properly. Interactions with governments and organisations that facilitate interactions are included in the analysis as well.

There is interaction between technology providers and project developers in all clusters that have these actors. In Japan there is much interaction with the government as OTEC is a government project there, fully funded and supported. The situation in Malaysia is similar, although due to the much lower budget there is less OTEC activity there. The French cluster has intensive interaction with the French government for policy creation. The Netherlands government supports innovation and entrepreneurship with knowledge and help with international contact. The interaction between organizations and the government in the American cluster is limited to requests for subsidies/research grants from the technology developers, there is no policy dialog. In Japan and the Netherlands are the only clusters with national organisations that facilitate interaction in the (ocean) energy and marine sector.

Malaysia is another topic entirely with regard to interaction. Due to the lack of both technology provider and project developer, these cannot interact. Nevertheless, there is much interaction between UTM OTEC, potential clients, financers and international project developers and technology providers.

Table 5.2: Overview of interactions per cluster

	Interaction between technology provider and project developer	Interaction between OTEC organizations and government	Organisations that facilitate interaction	Avg.
Japan	N/A	Yes, full funding, policy	Yes, GOSEA	++
Netherlands	Yes	Yes, support in international contacts, subsidies	Yes, OTEC foundation, national energy and marine industry associations	++
France	Yes	Yes, policy	No	+
USA	Yes	Limited, subsidies	No	+
Malaysia	N/A	Yes, full funding, policy	No	+

In Japan and the Netherlands, interaction is well organized. France is interacting well even though there are no facilitating organisations, due to the extensive national and international cooperation with project and technology developers and contractors. Interactions in the USA are good when focusing on business to business interactions, however government interactions are limited. Malaysia is again a little different than the rest, although interaction in this cluster is good.

5.1.3 Institutions

Institutions have effect on the possibility if permits can be acquired, subsidies are granted, how much policy work it will take to enable an OTEC project and in turn how much time and money must be spent on this. In case of OTEC, governments are usually not averse to OTEC but due to lack of experience with the product, bureaucracy can be an issue. To get an idea of the differences between the clusters, the focus will be on OTEC-specific policy, support mechanisms and the effect these policies have on OTEC development. OTEC specific policy includes rules and requirements regarding permitting for OTEC, including plant design, environmental effects and location. Support mechanisms include measures such as innovation subsidies, research grants and project specific subsidies.

Due to the dependence on the cold and warm water resource, OTEC can often not be constructed in the countries where it is being developed due to limited or no access to the resource. Therefore, the institutions of the country where the technology providers and project developers are located, international institutions and the institutions of the country where the project is being developed are relevant. The project locations are changing constantly and there are many countries in the world with access to the OTEC resource. Therefore, only the institutions of the country where the main cluster organizations are based are taken into account in this comparison.

Japan, France and the USA have OTEC-specific policy which helps the permitting process for new projects. This makes developing projects in these countries more interesting due to the limited time and money that must be spent on obtaining permits and makes it easier to supply the correct information to the government. The Netherlands does not have this, which makes it harder especially for small companies to develop projects. Malaysia does not have any projects in the pipeline, so policy has not yet been developed. It would be beneficial for future work.

Japan has a full funding programme for development of several renewable energy technologies including OTEC. The other countries have limited subsidies for renewable energy, innovation and/or research, which are very important for development of an emerging technology but not enough to bridge the gap in financing for the first-of-a-kind, also known as the ‘valley of death’. Malaysia has funding for promotion and limited research.

Table 5.3: Overview of institutions per cluster

	OTEC-specific policy available?	**Support mechanisms**	**Effects policy on OTEC development**	**Avg.**
Japan	Yes	Yes, full funding	Renewable Energy roadmap includes OTEC, aid for development and permitting	++
Netherlands	No	Yes, limited subsidies	Difficult to get permits	-
France	Yes	Yes, limited subsidies	Recent experience with permitting, new requests should be relatively easy	+
USA	Yes	Yes, limited research-specific grants	No experience with permitting, requesting permits should be easier then without policy	+
Malaysia	No	Yes, limited funding of OTEC promotion	OTEC department at UTM	+/-

Regarding institutions, Japan is very well prepared for OTEC development. Although France and the USA do lack some support mechanisms, their OTEC-specific policy is a driver for OTEC in their territory. In the Netherlands, there some more issues due to bureaucracy when requesting permits for projects.

5.1.4 Technological factors

There is a difference in technological knowledge between the different clusters. This is knowledge that is required to build onshore or offshore OTEC plants and a gap in essential knowledge means that the cluster might not be able to build an OTEC plant alone. Only the main organizations of OTEC clusters are taken into account. Contractors might fill (some of) the gaps.

Saga University in Japan has been researching OTEC for a long time and has done much research, especially on heat exchangers and the OTEC energy unit, which includes components used for the heat cycle and the heat cycle itself. Therefore, it has extensive knowledge on these topics. Other topics not so much. Bluerise and TU Delft in the Netherlands have mainly done research on the energy unit and less on other topics. Naval Energies, a technology provider in France has focused its research efforts on the energy unit, cold water pipe and biofouling of the system and is depending on contractors for what are the less OTEC-specific parts according to them. With Makai Ocean Engineering, Lockheed Martin and OTE Corporation, there is much technical knowledge in the USA cluster, only lacking offshore platform knowledge. Malaysia has no technical knowledge and is completely dependent on other clusters for the technology.

Table 5.4: Overview of technological knowledge per cluster

	Heat exchangers	Energy unit	Cold water pipe	Biofouling	Mooring	Offshore platform	Avg.
Japan	Yes, extensive	Yes, extensive	No	No	No	No	+
Netherlands	No	Yes	No	No	No	No	+/-
France	No	Yes	Yes	Yes	No	No	++
USA	Yes	Yes	Yes	Yes	Yes	No	++
Malaysia	No	No	No	No	No	No	--

5.2 Functional cross-case analysis

The functions of an innovation system allow the mapping of activities and events that aid in the development of a well-functioning innovation system and for proper development, all functions should be fulfilled. Activities and events can have both a positive and negative effect. This section discusses the differences of fulfilment of the system functions between each cluster.

5.2.1 Entrepreneurial activity

There is much activity in the OTEC landscape with many projects in the pipeline. The Japanese cluster currently has access to an operational OTEC facility, which is not only producing power but connected to a relatively large deep seawater industry as well, for research and to offset the cost of the cold-water pipe. Naval Energies (France) has a prototype real-world setup for research purposes that uses seawater and several other test facilities for technology development. Bluerise and TU Delft (Netherlands) have a laboratory setup and Makai Ocean Engineering has a 100kW pilot plant in Hawaii. In Malaysia, practically no technology development is undertaken due to the ambition to import technology. The entrepreneurial activity is summarized in Table 5.5.

Table 5.5: Overview of cluster projects

	Demonstration/pilot projects	Commercial projects under development	Formation of supply chain	Avg.
Japan	Yes, Kumejima 100kW in continuous operation. Developing larger scale facility.	No	Sufficient contacts with contractors to build medium-scale OTEC plants.	+/-
Netherlands	Yes, laboratory OTEC at TU Delft.	Yes, Curacao 500kW OTEC + additional revenue streams contracted. Three projects (mainly SWAC) under development.	Sufficient contacts with contractors to design and build medium-scale OTEC plants.	+
France	Yes, 15kW prototype in Reunion	Yes, 10MW offshore OTEC contracted. Feasibility studies in Malaysia, Indonesia.	Sufficient suppliers of 'basic' parts of an OTEC plant to decrease workload (complex R&D done in-house)	++
USA	Yes, Hawaii 100kW in continuous operation.	Yes, Bahamas SWAC project under construction, 7 other projects under development of which three high potential.	Sufficient contacts with contractors to design and build medium-scale OTEC plants.	++
Malaysia	No	No	In contact with technology providers and project developers to obtain a supply chain in case of project.	-

Commercial projects are a short-term ambition of all clusters except Japan, who want to do more research and are fully dependent on government funding. Although there is some uncertainty on the timelines that were given by interviewees, it seems that the first OTEC plant to be operational in a commercial project will be incorporated in the Ocean Ecopark project of Bluerise in Curacao, combining a small-scale 500kW OTEC plant with SWAC and other applications of the deep seawater and should be commissioned in 2019. The first commercial OTEC plant that is built independent of other developments is likely to be NEMO, a 10MW net power-output plant in Martinique, developed by French companies Naval Energies and Akuo Energy, which should be operational in 2020. Other projects are currently less developed and, in most cases, not contracted yet and with OTEC less important than the other applications of the deep seawater resource. OTE Corporation (USA) is constructing a SWAC facility without OTEC in the Bahamas. UTM OTEC is only championing the technology in Malaysia and is still searching for buyers and financers for projects and has currently no concrete projects under development.

All clusters have some sort of supply chain that they can use on projects. Especially France and the Netherlands are in an advanced stadium of commercializing their technology, although only USA and Japan, and to some extent France, are exceptionally strong on their demonstration activities. Japan is somewhat held back by not focusing on commercialization. Malaysia is not strong in entrepreneurial activity due to their aim of attracting other clusters to build there.

5.2.2 Knowledge development

Doing research and developing new knowledge is an essential part of enabling market diffusion by for example decreasing cost and increasing efficiency. When the knowledge developing activities of the five clusters are reviewed, large differences in approach can be observed especially between the Malaysian cluster and the other clusters. UTM OTEC is only promoting the technology and not developing it.

Table 5.6: Overview of knowledge development per cluster

	Learning by searching	Learning by using	Learning by doing	Research diffusion/convergence	Avg.
Japan	Yes, Saga University, Xenesys: heat exchangers energy unit, deep seawater applications	Yes, operating Kumejima 100kW OTEC plant (Saga University/Xenesys), deep seawater industry	Yes, construction of Kumejima 100kW OTEC plant, deep seawater industry	Yes, additional revenue streams from deep seawater	++
Netherlands	Yes, TU Delft, Bluerise: energy unit	Only laboratory-scale OTEC (Bluerise/TU Delft)	Yes, developing Ecopark Curacao 500kW+additional tech	Yes, additional revenue streams from deep seawater	+
France	Yes, Naval Energies: energy unit, cold water pipe, biofouling	Yes, Reunion 15kW OTEC prototype (Naval Energies)	Yes, developing NEMO Martinique, 10MW	Yes, additional revenue streams from deep seawater	++
USA	Yes, Makai Ocean Engineering: heat exchangers, energy unit, cold water pipe, biofouling, mooring	Yes, Hawaii 100kW OTEC plant (Makai)	Yes, construction of Hawaii 100kW plant. Construction of SWAC project Bahamas. No OTEC	Yes, additional revenue streams from deep seawater	++
Malaysia	No	No	No	N/A	-

Japan, USA and France have made substantial research efforts. The construction and operation of the Japanese demonstration plant has enabled stakeholders to learn from these processes for future projects and test their theories regarding among others the energy process and plant part design. In the USA much research can be done due to the research facilities of the National Energy Laboratory Hawaii Authority (NELHA) including a demonstration OTEC plant of 100kW. In the French case, most research is being done to enable the NEMO project that they are currently developing, and knowledge is created in the project processes. Akuo Energy has learnt much about policy creation and financing of such projects.

The Dutch cluster is similar to that of France, albeit on smaller scale. Research is still being done, mainly to fulfil their project obligations. By doing commercial projects, knowledge about the business processes is gained and new ways of learning are enabled when new commercial plants become operational. The American cluster is separated between OTE, who is more of a project developer and focused on commercialization as well and feel they already know enough from previous research and are minimizing their research efforts when possible, and Makai, who is clearly a technology developer, doing all kinds of research.

The Malaysian cluster is a whole different story entirely. By focusing project development without having in-house technical knowledge, they are completely dependent on external organisations to supply the required technology. There is no funding or interest to develop the technology themselves and are therefore only working on creating a decent supply chain and network.

Concluding, all clusters perform well on knowledge development except Malaysia. The Dutch cluster does currently perform slightly weaker on knowledge development than Japan, USA and France, but the work on their commercial plant might change this.

5.2.3 Knowledge exchange

The consensus of cluster organisations on cooperation is that it is only worth doing when it provides something that would be unobtainable alone, due to the risk it poses for their competitive position.

Nevertheless, all actors in all clusters think that conferences on OTEC and marine renewable energy are useful to obtain information about the latest developments from the industry. Furthermore, they all cooperate with local universities and/or companies at their (potential) project sites. The universities offer local knowledge that is required for the project and in return the company can offer other knowledge in return, while the companies are hired for tasks that require knowledge of subjects such as the local policy, permits and environment.

In general, most knowledge is currently gained by doing projects. By hiring different contractors for different parts of the project, companies learn much from the different views from different industries on OTEC problems. Naval Energies (France) does much research on very specific parts and outsources the rest, OTE Corporation (USA) tries to outsource as much as possible and only steers the research and development efforts of their contractors in contrast to the extensive research being done by Makai (USA) who works together with other technology developers and research institutes to do much R&D. Bluerise (Netherlands) hires external technology providers when necessary for projects. Akuo Energy (France) has learnt much about the regulatory and permitting process in their work for NEMO, having to create new OTEC-specific policy together with the French administration.

The Japanese cluster is more open to cooperation and welcomes other OTEC companies to work on future projects in their cluster in the hope that it will open up the market for OTEC. Furthermore, the town where the OTEC demonstration plant is situated, Kumejima, has a sister-city agreement with Hawaii County including knowledge exchange regarding marine renewable energy technology. Research collaborations between Japanese private organisations and research institutes should help the development process as well.

Malaysia does not have much knowledge on the technology as their goal is to only promote the technology. They do gather knowledge via extensive interaction with national and international universities and has contact with Bluerise and Naval Energies to discuss feasibility of OTEC projects in Malaysia and enable studies for these potential projects and share their knowledge and contacts of the Malaysian market.

Table 5.7: Methods of knowledge exchange per cluster

	Learning by interacting	**Co-authorship of publications**	**Avg.**
Japan	Yes, conferences, national and international business and research institute cooperation for project development.	Insignificant	++
Netherlands	Yes, conferences, national and international cooperation with research institutes, use of contractors for development and construction of projects.	Insignificant	++
France	Yes, conferences, national and international cooperation with research institutes, use of contractors for development and construction of projects.	Insignificant	++
USA	Yes, conferences, national and international cooperation with research institutes, use of contractors for development and construction of projects.	Insignificant	++
Malaysia	Yes, conferences, national and international cooperation with research institutes and corporations to enable projects.	Insignificant	++

All clusters are strongly engaged in learning by interacting, either by actively doing cooperative research or by hiring contractors for specific aspects of their developments. There is not much to be improved.

Co-authorship of scientific publications turned out to be minimal. As it does not seem to significantly indicate knowledge exchange or affect interactions, this indicator has been omitted in the final assessment of the performance of *knowledge exchange*.

5.2.4 Guidance of the search

Guidance in clusters is essential to show all stakeholders where developments are going and help to define what is required to get there. Unified guidance from the industry gives regulatory bodies an idea about how they can better facilitate the development, while guidance from regulatory bodies takes away uncertainty from the industry and the financial community. Interviewees have voiced their short and long-term OTEC project targets as well as their perceived guidance of regulatory bodies.

The long-term vision of all clusters was similar, with an end-goal of 100MW offshore OTEC plants. The short-term goals and path to get to large-scale were different however. Bluerise (Netherlands) and OTE Corporation (USA) focus on doing as many commercial projects as possible, even if they are (mainly) SWAC or seawater desalination, with OTEC being of less importance in those projects. Both start with small-scale onshore plants combined with additional sources of revenue that use the same cold seawater resource, similar to the goal set by Naval Energies (France). Akuo Energy (France) on the other hand is fully committed to make the 10MW NEMO project in Martinique the first financially viable operational OTEC plant in 2020 (with subsidy).

Upscaling of the technology is done in small steps, or as fast as the financial community lets them go, to keep risks limited and new projects financeable in all clusters. Akuo wants to build multiple power plants of the same design to recoup the design costs over multiple projects, while Naval Energies wants to scale up as fast as possible. The Japanese cluster is set to build a new 1MW demonstration plant once they get financing and aim to build a 10MW pilot plant after that, which might be used in a commercial sense, although all upscaling should be funded by governments, either national or in international cooperation. These upscaling targets are set by the Japanese government. The focus up to the 10MW plant is completely on the domestic market the others have international ambitions.

The Japanese government has a clear renewable energy roadmap and the governments of France and the USA have OTEC-specific policy and permitting regulations. Nevertheless, in all clusters government focus is limited or lacking. In Japan, the government seems to be losing interest in the energy transition. Governments are positive about OTEC in principle but are not proactive in helping to realize projects. Nevertheless, France and the USA are now the only clusters where the regulations are ready to be applied when necessary.

The main cluster stakeholders have targets set about their future role in OTEC development as well. UTM OTEC, OTE Corporation, Bluerise and Akuo Energy aim to be OTEC project developers, while Naval Energies and Makai Ocean Engineering see themselves in the role of EPCI and EPC contractor respectively. These goals in the Japanese and Malaysian clusters are unknown.

The targets set by industry show that OTEC should be on the verge of commercial breakthrough in the Dutch, French and American clusters. The upscaling targets show that all clusters focus on small steps in upscaling, with different step size and time. It is a good sign that all clusters except Malaysia have set challenging targets. The targets themselves cannot be judged. When considering the targets set by regulatory bodies, the results show that improvements can be made. Only in Japan are these targets positive for OTEC development, while in the other countries there are no clearly defined targets or visions from the government. There is consensus that due to financial difficulties, the first commercial plant should be relatively small scale, and when operational it will quickly trigger diffusion and upscaling of the whole OTEC industry.

Table 5.8: Guidance in clusters, scale of organizations is shown in a scale of 1-5 from small to large

	Targets set by industry		Targets set by regulatory bodies	Expectations and opinions of experts (not judged)	Scale of orgs.	Avg.
	Year of first commercial project	Upscaling targets				
Japan	N/A	1MW in 2020, 10MW in 2030	Renewable energy roadmap with specific technology targets. Decreasing interest.	Small onshore OTEC should prove technological efficacy, then offshore large scale.	2	+/-
Netherlands	2019, Curacao 500kW	Large offshore plant in 2030	No clear vision regarding emerging renewable energy technology development.	Small onshore OTEC should prove technological efficacy, then diffusion and upscaling will be quick.	1	-
France	Naval: 2019 ~1MW (unspecified) Akuo: 2020 Martinique 10MW	Each 1,5-2 years larger scale (2-5, 10, 50MW) 2021-22: same design, then small steps up	No clear vision regarding emerging renewable energy technology development.	First-of-a-kind OTEC plant will trigger diffusion and upscaling.	5	+
USA	2021 5-10MW (unspecified)	Upscale in small steps	No clear vision regarding emerging renewable energy technology development.	First-of-a-kind OTEC plant will trigger diffusion and upscaling. OTEC is driven by possibility of seawater desalination.	4	+/-
Malaysia	N/A	N/A	OTEC is identified as influential emerging technology, no real targets have been set.	Other uses of deep seawater will diffuse first, after which OTEC can be added.	2	--

A factor that does not fit into the specified indicators that does have an impact on the effectiveness of the guidance of the industry towards policy makers is the size of the OTEC developing actors. One might imagine that (very) large organizations can be much more persuasive in their lobbying and promotion towards governments than smaller organizations. In Japan, the only private organization that specifically focuses on OTEC is Xenesys, which is a very small company, and it works together with Saga University. Therefore, guidance mostly comes from the university. In the Netherlands, Bluerise is mostly responsible for guidance, which is difficult to give for a young company that is only just leaving the start-up phase. In France and the USA there are large corporations involved in OTEC development, which has a large impact on their ability to steer the policy making process and getting OTEC under the attention of the relevant authorities. In Malaysia, UTM OTEC gives guidance. That research centre was set up by a decree of the national government and therefore they have the attention of policy makers, although due to their relatively small size their influence is very limited.

5.2.5 Market formation

Demand is required to commercialize a product. Emerging technologies such as OTEC often have only a small market due to potential buyers who do not see the immediate benefits or long-term gains and they might be dealing with technology lock-in from what they are currently using. In the case of OTEC, there are both psychological and financial barriers that hinder diffusion, which can be overcome by introducing other technologies based on similar technology as OTEC as well as other efforts for market formation.

Firstly, all clusters think that the introduction of niche markets will be essential to further OTEC diffusion. Additions that use the same deep seawater resource (seawater desalination, seawater air conditioning, aquaculture, etc.) are especially relevant for early onshore plants and decrease risk and increase value of a project. Therefore, they are all working on these technologies and adding them to their pilot and commercial OTEC projects. The best promotion for OTEC is building track record, which makes much more potential buyers interested and would therefore increase market size, especially when combined with the previously mentioned additional revenue sources. That is why the clusters that are working on commercial OTEC plants are perform better regarding 'efforts for market formation' than clusters that are not.

Table 5.9: Overview of market formation activities per cluster

	Introduction of niche markets	Efforts for market formation	Avg.
Japan	Yes, aquaculture, agriculture and seawater desalination (only onshore).	N/A	+/-
Netherlands	Yes, SWAC, aquaculture, agriculture and seawater desalination (only onshore).	Building track record, offering additional revenue streams with OTEC.	++
France	Yes, SWAC, seawater desalination, aquaculture.	Building track record, offering additional revenue streams with OTEC.	++
USA	Yes, SWAC, aquaculture, agriculture and seawater desalination (only onshore).	Building track record, offering additional revenue streams with OTEC.	++
Malaysia	Yes, aquaculture, agriculture and seawater desalination, hydrogen production.	OTEC promotion to potential early adopters in influential industries.	+

All clusters are scored equally on 'introduction of niche markets' while Malaysia and especially Japan perform less on 'efforts for market formation' due to lack of commercial projects.

5.2.6 Resource mobilization

Financial, human and physical resources were investigated for this function. These resources are essential to further develop and diffuse technologies such as OTEC. Human and physical resources were found to be no issue as the limitations on these parts were only caused by financial barriers. For financial resources, there are two main issues; firstly, it is very hard to find long-term investors for an industrial company and secondly, when searching for project investments banks are unwilling to loan any money without a full performance guarantee from the technology developer. Both issues are applicable to all early industrial companies and has a big impact on the ability of the OTEC industry to grow and develop. The first-of-a-kind commercial (1MW or more) OTEC plant will create more interest and trust in OTEC and will probably open up the financial market for more projects.

Due to the international issues with the financial market with high CAPEX (required initial investment) emerging technologies, the average performance of all clusters is weak, although there are some differences. The French cluster has obtained relatively large amounts of resources compared to the other clusters. This is due to the NER300 subsidy from the European Union and makes them perform best in total. The Netherlands and USA perform similar, just behind France. Malaysia is dependent on limited government funding for their current activities but appeal to the financial market for project development. The complete government dependency of the Japanese cluster is a risky strategy as government policy might change and therefore performs very weak.

Table 5.10: Overview of resource mobilization per cluster

	Financial resources		Human resources	Physical resources	F6
	Financial resource(s)	Financial barriers			
Japan	Government	Focused purely on (multi-)government funding.	Sufficiently available	Sufficiently available	--
Netherlands	(Investment) loans, subsidies and crowd funding	Financers require track record or full performance guarantees from technology providers.	Sufficiently available	Sufficiently available	-
France	Loans, subsidies (NER300)	Financers require track record or full performance guarantees from technology providers.	Sufficiently available	Sufficiently available	+/-
USA	Shareholders, loans, subsidies/grants	Financers require track record or full performance guarantees from technology providers.	Sufficiently available	Sufficiently available	-
Malaysia	Government (very limited)	Private and public financers are not willing to invest in unproven technology such as OTEC.	Sufficiently available	Sufficiently available	--

5.2.7 Creation of legitimacy

A relatively new technology such as OTEC can have problems with legitimacy when comparing it to other, more mature technologies. It is less well known, it does not have the same track record and it is often backed by relatively small companies. Consequently, the technology and the organizations behind it have a trust issue. There must be a strong reason for potential clients to buy the technology. Legitimacy creating activities can be undertaken by technology-backing organizations to overcome this problem. There can be aid for or resistance against projects that show that there is a legitimacy problem or a movement to overcome this from external actors. Lobbying activities for or against the technology can have a positive or negative effect on this function and technology promotion activities help to increase the technology awareness with potential new stakeholders, which might result in more support for development.

There is both aid for, and resistance against OTEC. The resistance is the same for all clusters. There is a psychological barrier with potential clients and investors, who do not realize the benefits of an energy source such as OTEC. Aid is given most to Japan with full financing In France, Akuo Energy got extensive policy support for permitting and subsidy for the 100kW NEMO project in Martinique. In the USA, companies can apply for waivers that eliminate most regulations for first-of-a-kind projects of emerging technologies and their shareholders show much support, which helps increase legitimacy as well. With only some financial aid in the Netherlands and potential buyers showing enthusiasm about the possibility of seawater desalination in Malaysia, these are the places where aid is the least. To get more aid from regulatory bodies cluster organisations lobby to governments. Japan uses their demonstration plant when lobbying for OTEC, they invite policy makers to educate them and try to enable more funding for their technology development. In the Netherlands there are many industry associations and non-profit organisations who lobby for marine (energy) companies to the Dutch government and internationally. Akuo Energy has lobbied extensively to the French government to create new policy for OTEC in France, which went well, and Naval Energies is currently lobbying to change emerging technology support structures to better fit high CAPEX technologies such as OTEC. In the USA, OTE Corporation sometimes lobbies for research budget when government research overlaps with theirs and Makai Ocean Engineering does much research which is supported by the US Department of Defence. No signs of positive or negative lobbying have been found in Malaysia.

Table 5.11: Overview of creation of legitimacy per cluster

	Aid for/resistance against projects	Lobbying activities for/against the technology	Technology promotion	Avg.
Japan	Aid in the form of financial and policy aid from Japanese government. Demonstration plant is unconvincing due to small scale.	Policy makers are invited to visit the demonstration plant. Lobbying for funding of expansion of OTEC facility.	Allowing visitors in demonstration plant and educating them. Conferences and other presentations. Publishing of scientific papers.	++
Netherlands	Some financial aid from Dutch government.	Dutch non-profit and industry associations lobbying for marine and energy technology.	Investigating technology demonstration with other heat sources. Conferences and other presentations. Publishing of white papers. Communicating benefits to local community near project site. Appointed an ambassador for Curacao project.	+
France	Policy aid from government. Financial aid from EU.	Extensive lobbying activities for policy creation to French government and for funding to EU. Lobby to change emerging technology support policy to better fit high CAPEX technology such as OTEC. Membership of several European and French renewable energy associations.	Publishing papers and present at conferences. Developing commercial OTEC plant.	+
USA	Investors aid company and projects. Government aid for research.	Lobbying is done for government grants for research and feasibility studies.	Attendance of conferences, no presentations. Frequent interaction with financial community. Operation of demonstration plant.	+/-
Malaysia	Seawater desalination capabilities of OTEC create legitimacy in potential markets.	N/A	The main task of UTM OTEC. OTEC is promoted globally to as many potential stakeholders as often as possible to get them involved. Scientific publications, conference presentations.	+
Global	Psychological barrier: Negative perspectives based on outdated information. Projects are compared on CAPEX.	Lobbying activities for (marine) renewable energies by international non-profit organizations.	Successful construction and operation of a commercial OTEC plant would be the best promotion.	

Promotion of the technology is used to increase technology awareness and create trust in the technology. All OTEC companies from the investigated clusters promote the technology and their brand at conferences and in papers. Japan extensively uses their 100kW demonstration plant in Kumejima for promotion of OTEC by offering visitors free tours in and around the plant. Their time in the plant is used to communicate the benefits of OTEC and give visitors an understanding of what OTEC is and what it could be in the future. Furthermore, the Japanese cluster works closely together with a coral expert which legitimizes OTEC when people are questioning the environmental effects. Bluerise is investigating the possibility to prove their technology efficacy in other places with industrial waste heat. By communicating benefits to local communities and creating partnerships with local companies for projects, they create goodwill for their projects. OTE Corporation is currently doing much work on their commercial projects and interact frequently with the financial community to increase their technology awareness. The other main OTEC developer in the USA, Makai, continuously operates the Hawaiian 100kW OTEC plant, showing technology efficacy. UTM OTEC might be the organisation that promote OTEC the most, as this is their primary objective. They extensively promote OTEC to all potential stakeholders in- and outside Malaysia, including potential contractors, buyers and financers. The French cluster is currently not very actively promoting aside from conference attendance and the publishing of papers, they only try to finish the 10MW NEMO project in Martinique. A successful construction and operation of that plant would be the best kind of promotion.

Japan is the most proficient in creating more legitimacy for OTEC with their demonstration plant that is open to visitors for free. The French cluster is doing a good job as well, with strong lobbying activities and a relatively large project under development they show that OTEC is getting more mature. The Dutch cluster gets only limited aid and the American cluster is not promoting very much. The main activity of the Malaysian cluster is OTEC promotion and they are very good at it, other activities not so much.

5.3 Cross-case analysis of other clusters

Of the nine OTEC developing clusters that were identified at the start of the research, four clusters were not available to participate in this research. In the course of the research, Makai Ocean Engineering was found to be so interrelated in the cluster of OTE Corporation that this was in fact one cluster. However, the three other clusters of Bell Pirie Power Corporation (UK/Philippines), KRISO (South Korea) and Bardot Ocean (France) were clearly separate from the other clusters. Through literature review some information on these clusters was found (see Appendix C). The cluster analyses cannot be compared with the five main clusters of this research due to too limited and unvalidated data. However, a brief overview of the found information can be used as context. This cross-case analysis is a brief narrative of what has been found.

All three clusters consist of one main OTEC developing organization. KRISO and Bardot Ocean are both technology providers, while Bell Pirie Power Corporation is a project developer. KRISO is a large state research institute working on a 1MW OTEC plant in Kiribati. No signs of interaction between the KRISO OTEC effort and other OTEC or non-OTEC organizations could be found and that is therefore a weakness of the cluster. Furthermore, their short-term goal is offshore OTEC and they seem not to research niche markets such as SWAC and seawater desalination, missing potential additional revenue streams which could be critical in the early phase of OTEC diffusion. Their focus seems to be on research instead of commercialization and might therefore be missing opportunities to diffuse the technology on larger scale.

Bardot Ocean is privately owned and part of Bardot Group (51-100 employees) and is working on a 2MW OTEC facility in the Maldives. An 'OTEC simulator' prototype was built for knowledge development. Additional use of the upwelled cold seawater is seen as a large opportunity. Bardot Ocean does have issues with financing due to the high CAPEX of OTEC projects.

Bell Pirie is a small enterprise which works extensively with other technology providers and project developers such as Naval Energies and Akuo Energy, to develop an offshore project of unknown size in Zambales. Currently policy issues are holding it back with missing power purchase agreement and government service contract due to too large uncertainties on the performance of OTEC. Bell Pirie promotes OTEC and lobbies at governments as much as their company size allows.

5.4 Conclusions of cross-case analysis

In the cross-case analysis of each structural and functional element, strengths and weaknesses were identified for each cluster. This section summarizes the weaknesses as a basis on which recommendations are built in the next section. Malaysia will be discussed separately due to their different aims as a cluster.

Table 5.12: Overview of cluster performance. Scored on a five-point scale (++, +, +/-, -, --). Structure: Actors, Interactions, Institutions, Technological factors. Functions: F1: Entrepreneurial activity, F2: Knowledge development, F3: Knowledge exchange, F4: Guidance of the search, F5: Market formation, F6: Resource mobilization, F7: Creation of legitimacy

	Structure				Functions						
	A	Int	Ins	T	F1	F2	F3	F4	F5	F6	F7
Japan	+/-	++	++	+	+/-	++	++	+/-	+/-	--	++
Netherlands	+	++	-	+/-	+	+	++	-	++	-	+
France	++	+	+	++	++	++	++	+	++	+/-	+
USA	++	+	+	++	++	++	++	+/-	++	-	+/-
Malaysia	-	+	+/-	--	-	-	++	--	+	--	+

5.4.1 Structure

The Japanese cluster is focused on research and not on commercialization. One of the side effects is that there is no project developer who pushes large scale (commercial) development. In both Japan and the Netherlands, the OTEC developing organizations are relatively small and consequently have less influence and resources than larger organizations. Interactions are good in every cluster, although national and international organizations that facilitate interaction are missing in France and USA. In the Netherlands there are no regulations for permitting of OTEC and only limited subsidies, so government support could be improved. In France and the USA, policy for OTEC is available, although support mechanisms are limited. Technological factors are more difficult to compare due to different specialisations. Nevertheless, the Dutch cluster only has real knowledge on the energy unit and much less on the other subjects. Japan has very extensive knowledge on heat exchangers and the energy unit but not on other topics that are essential for OTEC as well.

5.4.2 Functions

Even though the Japanese cluster currently has one of the best facilities to do hands-on research, it might be in danger of being overtaken by commercial developments of other clusters if it keeps depending on governmental funding and initiative. The Dutch cluster does not have real-world demonstration or commercial OTEC facilities, which makes them less able to develop the technology than other clusters that do.

Japan, France and the USA are ahead compared to the Dutch cluster regarding research with their pilot plants that use deep seawater. The Dutch cluster is doing a good job as well on the energy unit, although whether they can keep up with the other clusters depends on their ability to construct their first commercial project.

Organisations in all clusters are extensively exchanging knowledge. Especially Japan is very open to knowledge exchange with other OTEC corporations and seems to care more about the technology development and diffusion than about their competitive position in the market. The organisations in the other three developing clusters are more protective of their intellectual property within the OTEC industry, although these clusters are much more willing to hire contractors for certain parts of their OTEC plants. By doing that they introduce new knowledge and approaches from experts in their field to OTEC problems, which might lead to interesting solutions.

All organisations have similar short-term targets with trying to build an economically viable OTEC plant as large as possible and long-term targets are large offshore plants. The early onshore plants will definitely incorporate other applications for the deep seawater, which are of more importance than OTEC in most of the cases and will help to develop the OTEC. It is good that all clusters have targets, although it is difficult to say which of the set targets are reliable and it is impossible to assess their value. Only Japanese regulatory bodies have set clear targets regarding OTEC, while in other clusters there is much uncertainty about the position of the government. On average, guidance quality is similar in all clusters, although the small size of the organizations in the clusters of Japan and the Netherlands means that the effect of their efforts is only limited. Guidance by industry could be better in Japan and guidance by regulatory bodies could be improved in the other clusters.

Introduction of niche markets is investigated by all clusters to offset risk and increase demand for OTEC products. Building track record in developing commercial plants is done by the Dutch, French and American cluster to form a market. The Japanese cluster is not really forming the market due to their focus on research.

Lack of financial resources is the main barrier for all clusters. The French Akuo Energy did do a very good job at securing the NER300 subsidy. The clusters of Bluerise, Naval Energies/Akuo Energy and OTE Corporation are all mainly dependent on loans and investments for the financial resources of their project development, while Saga University/Xenesys is completely dependent on the Japanese government. Due to decreasing interest of the Japanese government, this is a risk for the further development of OTEC in this cluster. Furthermore, they miss out on learning from commercial project development. Therefore, resource mobilization is negative for all clusters except Akuo Energy and especially negative for Japan.

Mainly the Japanese cluster is extensively promoting the technology, while the commercial activities of the all clusters have a positive influence on the legitimacy of the technology as well. Government policy, or the lack of, can delay projects and can be costly. Nevertheless, governments are generally willing to aid in policy creation and problem solving. The US and French cluster and seem less occupied with promotion of OTEC, while the limited aid for the Dutch cluster is a barrier for development as well.

5.4.3 Malaysia

The Malaysian cluster with UTM OTEC is different than the other clusters. They do not develop anything, they only promote OTEC and facilitate activities of other organisations in their country. Therefore, their only strengths are technology promotion, creation of legitimacy and to some extent market formation. The necessity of fulfilling all structural and functional aspects is questionable however, due to their aim to attract other clusters to build in Malaysia. This does beg the question if there will be a role for them in the future or if organisations from other clusters will take over.

5.5 Discussion of results and recommendations

This section discusses the results of the cross-case analysis by defining underlying reasons and potential solutions to weaknesses of cluster, starting with the structural elements are discussed, followed by functions, with Malaysia in a separate sub-section due to their different goals. Lastly, the general performance of each cluster is assessed.

5.5.1 Structure

When the structure of an innovation system is not complete, it will be difficult or even totally unable to commercialize their product. The appropriate actors, interactions between them, facilitating institutions and the required technological factors are boundary conditions for a technology to diffuse properly.

Actors

The cross-case analysis helped to define an issue with actors in Japan. The lack of project developers in the cluster complicates commercialization of the technology because there is no one benefitting directly from developing as quickly and efficiently as possible. All OTEC-specific stakeholders in Japan are mainly focused on technology development, which creates a dependence on public funding, which in turn could lead to slowdown of development when this funding decreases. This could be solved by finding one or more suitable project developers such as a renewable power producer who can cooperate closely with the existing cluster. The small scale of organizations in both Japan and the Netherlands cause a lack of influence of these clusters towards policy makers and other stakeholders.

Recommendation:

- Japan: Including one or more (large) project developers in the cluster could be beneficial for commercialization and increase influence and strength.
- Netherlands: By integrating a larger organization in the cluster, influence and strength could be increased.

Interactions

Due to the lack of commercial actors in Japan, that cluster has an issue with interactions as well. Nevertheless, they do cooperate with project developers from other clusters and therefore, interaction in Japan is as good as it could be, and no improvement is currently required. Another issue is that there were no (active) organizations who facilitate interaction in France and the USA. Activities of such organizations could help other actors to build a network and promote the technology more easily. An independent international organization that is purely focused on OTEC could be a good solution. An example is the OTEC Association, which is an initiative of Bluerise specifically aimed to fill this gap. When this organization is backed by many actors in the international OTEC community when it starts operating, it will be a credible independent industry association. In the clusters with interaction issues, more activity from existing local (renewable) energy and marine industry associations might be beneficial as well.

Recommendation:

- Global: Industry support for the establishment of an independent international OTEC industry association (e.g. the OTEC association proposed by Bluerise) could facilitate interactions and technology promotion.

Institutions

The institutions regarding OTEC are an issue in the Netherlands. There are no regulations for permitting specifically focused on OTEC, which means regulations are used that were drafted for the oil and gas industry or other industries, which in turn makes it unnecessarily complicated to prove that OTEC designs are safe or requires the design to be more robust and expensive than necessary. A solution would be to make OTEC-specific guidelines and regulations to speed up the process and decrease cost and industry uncertainty.

For all clusters except Japan, support mechanisms are limited and/or not suitable for OTEC. The high CAPEX required for OTEC plants make regular support on electricity production or research not sufficient for commercialization. The development of new support systems by policy makers that better facilitate high CAPEX emerging technologies would be beneficial.

In France, the current OTEC regulations had to be created from the ground up for the NEMO project in Martinique. There was much support by the French government and now enables new projects to obtain permits easier. In the USA, OTEC regulations have existed for a long time, although permits have never been issued yet. One interviewee saw that as a risk, as confusion from employees at the responsible agency might again lead to delays and added bureaucracy although the only way to find out is apply the permitting procedure to a project.

A limitation of the analysis of institutions is that only the local institutions of the developers' country were taken into account. OTEC has a global market, which means that local institutions are only of limited significance for the development of the technology. More important are the institutions of countries where OTEC projects are being built. Due to the many different countries with access to the deep seawater resource, it is not feasible to map all institutions, and not very relevant for cluster comparison as well because the institutions per cluster depend on their choice of market.

Recommendations:

- Netherlands: New OTEC-specific regulations from the Dutch government would facilitate project viability and decrease uncertainty regarding permitting.
- Netherlands, France, USA: Policy makers could investigate new support mechanisms suitable for high CAPEX emerging technologies.

Technological factors

There are large differences in focus per cluster regarding OTEC related technological research subjects, which limits the relevance of the analysis of these technological factors. It is impossible to define if specific topics should be valued higher than others. Another limitation of the is that only knowledge of OTEC-specific actors is included, not that of (potential) contractors. Therefore, knowledge that shows as missing in this analysis might be available elsewhere within the cluster. It was not possible to get a complete overview of contractors and their specialties.

The Dutch cluster has focused on less research subjects than other clusters and therefore depends largely on contractors for knowledge that is required to develop and construct complete OTEC facilities. On the other hand, the main technology providers and project developers of the American cluster have developed extensive knowledge on the widest array of subjects, with the French cluster in a similar position. The Japanese cluster is in between the French and Dutch cluster, with very extensive knowledge on several subjects. Therefore, it seems that the American and French cluster have a significant technological edge compared to the other clusters. No recommendation can be made on actions that should be taken due to the limitations of this analysis.

5.5.2 Functions

Entrepreneurial activity

The Japanese cluster lacks commercial development of OTEC, which negatively influences the chances of successful short-term technology diffusion. The organizations within the cluster could focus more on commercializing the technology they develop, which can be done by either expanding their own activities or by attracting an external project developer to whom they can sell their technology for commercial use.

Although the Dutch cluster has a laboratory OTEC facility, it lacks an operational OTEC facility to learn about the effects of seawater and larger scale on the system. When their project in Curacao, including 500kW OTEC, is successful, this barrier would be resolved. It would be very beneficial to have an operational OTEC plant in the cluster to prove technological efficacy.

Most projects that are under development are currently more SWAC or seawater desalination oriented, with OTEC playing a minor role. This is due to OTEC not being very cost competitive in small scale and because it is an emerging technology with high perceived risk. By adding additional applications of the same cold-water resource, additional revenue streams are created and risk is reduced. Furthermore, the cold-water resource is frequently available near remote tropical islands where both heat and potable water supply are an issue, which makes such an OTEC plant more appealing than a plant that only produces electricity. This approach leads to projects being more financially viable and it creates opportunities to establish track record when (financing for) OTEC is not yet possible, in turn resulting in faster adoption.

Recommendations:

- Japan: Investigate if the focus on research efforts is affecting technology development or diffusion. Increasing efforts for technology commercialization might be beneficial.
- Netherlands: An operational OTEC plant would vastly increase the possibilities to do other projects.

Knowledge development

Knowledge development varies from cluster to cluster. The Dutch cluster their learning by using and doing suffers from lack of research facilities, with only a laboratory-scale OTEC plant. By successfully constructing and operating the Curacao Ecopark with 500kW OTEC, this gap to the others could be closed. Nevertheless, more knowledge developing activities would be beneficial.

In the Japanese case on the other hand, research is currently purely for research sake. Eventually they too want large scale OTEC but now they do not believe the technology is ready for commercialization and are trying to get funding from the government for more research. Development is focused on domestic technology application on small scale.

Recommendation:

- Netherlands: If possible, do more R&D. An operational OTEC plant would vastly increase the possibilities for knowledge development.

Knowledge exchange

Knowledge exchange in the OTEC industry is generally very good. There was however an issue with one of the indicators that was chosen. There is not much literature from the main OTEC developers and the existing literature was often relatively outdated. Even less that was co-authored by another OTEC developer so findings on this indicator did not add much to the results in this thesis.

Guidance of the search

In all clusters except Japan, there is no clear vision from the government regarding emerging renewable energy technology development. This creates unnecessary uncertainty in the industry. It is not clear if permits will be (easily) granted, if there will be any support for projects and how much support it will be. When governments would express their vision clearly, similar to the renewable energy roadmap of the Japanese government with clear technology targets and associated support, technology providers, project developers and project investors would perceive less risk and would be willing to invest and develop more. Furthermore, the broad scope of renewable energy plans of governments, which include wind, solar PV, solar thermal, geothermal and hydro power among others (IRENA, 2018), decreases the focus on separate, and especially less mature technologies, which then might get less attention in policy creation and support mechanisms.

In the Japanese cluster an issue is observed that leads back to their focus on research. There is no clear target from industry regarding commercial projects. Again, the solution would be for the main developing organizations to broaden their scope, or to introduce commercial project developers to focus more on commercialization. Another issue in this cluster is the declining interest of the government in their renewable energy roadmap due to failure of many other renewable technologies. When this trend continues, the whole cluster could be in danger of running out of funds.

The targets set by industry do show that OTEC could be on the verge of commercial breakthrough in the Dutch, French and American clusters and more projects are in the pipeline in the other clusters that were not thoroughly analysed. Of course, there is large uncertainty on how fast diffusion will be and how big the eventual market will become. The small scale of organizations in Japan and the Netherlands causes their guidance to be of limited effect compared to that of larger organizations.

Recommendations:

- Netherlands, France, USA: Governments should create a clear vision on development of emerging (marine) renewable energy, including OTEC. Incorporate a large organization in the cluster to improve the effect of guidance efforts.
- Japan: Industry could benefit from increasing their commercial efforts. Incorporate a large organization in the cluster to improve the effect of guidance efforts.

Market formation

All clusters are at least investigating the possibility of introducing niche markets that use the same deep seawater resource. Early OTEC plants alone are not economically viable. By reusing the cold water that comes out of the OTEC plant for seawater desalination, cooling of buildings or agricultural fields or aquaculture, the risks of OTEC and the cost of the cold-water pipe can be spread, making the technology much more attractive. Offshore this is much harder due to the relatively large distance from shore. The increased complexity of offshore plants compared to onshore plants make that adding even more complexity for additional revenue streams might not be feasible for early offshore plants. In the long term these applications of cold water might become essential for further technology diffusion. New concepts could increase economic viability of large scale offshore projects.

The additional products, and especially the seawater desalination, are sometimes essential for buyers and can be much more interesting than OTEC electricity. This in combination with the economic benefits make early OTEC especially interesting in remote (island) areas due to high electricity prices and dependence on seawater desalination for potable water.

The Japanese cluster is not actively trying to form a market for their products due to their focus on research. This could be solved by involving other commercial actors.

Recommendations:

- Global: Additional revenue streams to onshore OTEC should be extensively investigated by all clusters.
- Global: Creating new concepts on how additional revenue streams can be added on offshore OTEC could help increase economic viability.
- Japan: If the Japanese cluster aspires to commercialize their technology, a project developer should be attracted.

Resource mobilization

When talking about resource mobilization, financial resources were instantly mentioned as the main barrier for OTEC in all interviews, while the other resources were not a problem, or were related to the lack of financial resources. Due to the limited and unsuitable support structures from governments, project developers depend on private investors for funding of the company and their projects. This poses a problem due to the high perceived risk of an emerging technology without a first-of-a-kind project that shows the technology efficacy. Loans for these kinds of projects are very expensive and banks demand full performance guarantees, which means that the technology developer must guarantee for the full amount that the product will work as they say it will. Due to the large upfront investment most companies are unable to afford this guarantee, which in turn makes it impossible to get funding for projects.

Risk for financers must be reduced to overcome the financing problem. The Japanese and USA clusters are doing this by building track record with their demonstration plants. The other clusters must first build a pilot or commercial plant to do this, so they (Bluerise, Naval Energies, OTE Corporation) mostly aim to start with financeable small-scale OTEC, combined with additional revenue streams with less perceived risk, even though this undermines the economies of scale. The NEMO project in Martinique is a peculiar exception, being a complex 10MW offshore plant. The French cluster was lucky with the NER300 subsidy but will not get one next time. It is essential that somewhere a first-of-a-kind commercial OTEC plant will be built, which will reduce perceived risk and enables the building of track record and reduction of project cost.

Currently, the French cluster has mobilized the most resources due to the NER300 subsidy combined with private loans, where other clusters are even more dependent on loans or government funding. The Japanese cluster does have a risky source of income with the Japanese government, which has decreasing interest in their renewable energy roadmap. By investing some effort in commercialization and/or finding alternate financial resources, their funding might become more secure.

Recommendations:

- Japan: Find new sources of funding to decrease risk of diminishing government funding.
- Global: Risk of early OTEC could be decreased by starting with small-scale onshore plant.

Creation of legitimacy

In four clusters, promotion is an important part of their activities. All feel that successful operation of a commercial OTEC plant would be the best possible promotion of the technology, regardless of who builds the plant. Although the USA cluster has promoted OTEC extensively in the past, it is now doing less than other clusters on this activity. With the existing legitimacy issues for OTEC, it might be beneficial to increase these activities again. Not only to promote their own products but OTEC in general as well.

There are three general reasons for the globally prevalent legitimacy issues, as well as some cluster-specific ones. The first reason why OTEC is not as attractive as it could be, is the existence of a psychological barrier among policy makers and potential clients which affects all clusters similarly. In the past many different views were published regarding the technology, potential and state of development of OTEC and not all were equally reliable. These views are still stuck in the minds of potential buyers and financers, who must be re-educated to see the benefits of OTEC and how the technology can be further developed and diffused. Furthermore, many high-level energy officials in governments and companies are used to compare projects mainly on capital expenditure instead of lifetime cost and do not take into account the absence of risk on the resource. This mindset is not favourable for technologies such as OTEC. Potential stakeholders should be educated more on the benefits of OTEC and be shown a fair comparison between OTEC and (fossil fuel) alternatives, for example by inviting stakeholders for public tours in OTEC demonstration plants, or by working together with the financial community which indirectly promotes the technology there, making them more accustomed to the idea.

The second reason is a chicken and egg dilemma. No one wants to be the first to build an OTEC plant due to high risk and cost compared to the subsequent plants. Due to the lack of a first-of-a-kind plant, there is no proof of technological efficacy, which in turn makes financing of projects more complicated. Even in the Japanese and USA clusters, which have operational OTEC plants, it is hard to get financing. According to financers, their technological efficacy is not sufficiently proven due to the limited size of these plants.

Lastly, there is no (international) independent OTEC industry association which could promote OTEC and lobby to governments for policy enhancements, although Bluerise is currently working on such an organisation in the form of the OTEC Association. This kind of association would require support of most of the OTEC developing organizations for funding and legitimacy.

Recommendations:

- France, USA: Increased promotional efforts for OTEC would educate potential stakeholders. Show them a demonstration plant and present the financial, environmental and societal benefits to change their mindset.
- Global: Industry support for the establishment of an independent international OTEC industry association (e.g. the OTEC association proposed by Bluerise) could facilitate lobbying activities and technology promotion.

5.5.3 Malaysia

The activities of Malaysia do not really fit in the structure and functions of a technology innovation system due to their focus on technology promotion and the attraction of other clusters to build in Malaysia. They are missing actors and are weak regarding technology factors in structure and most functions are not very strong either. The first question is: is that is a problem when you are not trying to develop OTEC? But then the next question is: Is Malaysia really an OTEC cluster if they do not develop any technology and do not show entrepreneurial spirit?

Probably, Malaysia with UTM OTEC have a place in the OTEC industry, but they will not be the ones who go down in history as the most influential organization in the market diffusion of OTEC. Furthermore, UTM OTEC is working on its own, together with developers from several other clusters. This shows that UTM OTEC is not (part of) a cluster, as it was defined in the beginning of this thesis, but a separate organization that has some characteristics of a contractor and client.

5.6 OTEC feasibility

Aside from the performance of the individual OTEC developers, the technological potential and cost of OTEC energy impact OTEC diffusion as well. The cost of OTEC is currently the largest barrier for further development and diffusion while technically, small and medium-sized plants are already possible. Therefore, to assess the feasibility of OTEC in general, first the technology and economy are assessed. This section is concluded by looking at the possibility of combining the strengths of all studied clusters to obtain an alliance of organizations that should theoretically perform as optimal as currently possible to see if that would enable OTEC to diffuse without too much problems.

5.6.1 Technology

All interviewees agreed that small to medium-sized OTEC plants up to 10MW are currently technologically feasible. These plants can be made from a selection of currently existing technologies and only require detailed plant design. Technological advancements are required for larger plants, especially concerning the cold-water pipe and large capacity heat exchangers. However, no one has stated this as a significant barrier for technology diffusion and all think this is a solvable issue.

5.6.2 Economy

The economics of projects are the main barrier for OTEC development and diffusion. For early 10MW and 100MW plants, levelized cost of electricity (LCOE) of $350/MWh and $150 to $280/MWh are estimated respectively, compared to $40 to $100/MWh for coal fired power plants and $40 to $140/MWh (Ocean Energy Systems, 2015) for solar PV and (offshore) wind (Kost, Shammugam, Jülch, Nguyen, & Schlegl, 2018). Especially small-scale plants are and will never become economically viable anywhere. For medium-size plants of <10MW net power output, grid parity might be reached on remote locations that are dependent on expensive imported diesel for their power due to economies of scale. If grid parity will ever be reached in less remote areas for large-scale plants of 10MW to 100MW depends on the degree to which technological learning effects and economies of scale will have effect on the energy price of OTEC. However, there are many uncertainties in the estimates of cost reduction and the reduction that is required to compete with large-scale fossil fuel power plants cannot be underestimated. This makes it highly unlikely that OTEC will become cost competitive compared to other (renewable) energy sources soon.

A large benefit of OTEC is that it can be used as an alternative energy source for renewable baseload power due to the stability of the power output compared to intermittent renewable energy technologies such as solar PV and wind. Intermittent power sources would require large overcapacity and expensive power storage facilities to maintain grid stability. This means that OTEC is much more feasible for scenarios where the majority of the power in an energy system is generated renewably and where it can be seen as an alternative to intermittent renewable energy technologies combined with power storage. Furthermore, the possibility to use the deep seawater for other uses, such as seawater desalination, aquaculture, agriculture and seawater air conditioning, can have a positive effect on especially onshore OTEC feasibility. The additional revenue streams can help to improve the economics of projects.

Although the technological feasibility of OTEC is not very problematic, the economics are another matter entirely. Due to the high LCOE even for medium-sized OTEC plants, development is very hard as it does not make sense for private investors to invest in such projects. Only in some very specific circumstances can these plants be economically feasible, and even then, the risk for the investor might be unacceptable so extensive (government) support will be required to scale up OTEC. The predicted price of electricity from large-scale OTEC plants is relatively high compared to other (renewable) energy technologies and it will therefore probably be a niche product for the coming two decades OTEC. Only when the majority of produced power is renewable, OTEC might become competitive compared to large-scale fossil fuel power plants and some of the intermittent renewable energy technologies.

5.6.3 The optimal alliance of clusters

Due to the large differences in strengths and weaknesses in the different OTEC clusters, they might be able to complement each other to create an optimally performing alliance. The overview of the results from section 5.4 is shown again in Table 5.13. The results show that when combining the clusters of Japan and France and all structural elements should be in place for further development of OTEC although for the functional elements it is slightly more complicated. *Function 4: guidance of the search* and *function 6: resource mobilization* both do not perform optimally. The problems with resource mobilization are at least partly caused by the above-mentioned issues with the economic feasibility of OTEC and cannot easily be solved by clusters, only by governments. The less-then-optimal performance of guidance of the search has to do with little focus of governments on OTEC and the limited scale of OTEC development efforts.

Table 5.13: Optimal alliance of clusters. Scored on a five-point scale (++, +, +/-, -, --). Structure: Actors, Interactions, Institutions, Technological factors. Functions: F1: Entrepreneurial activity, F2: Knowledge development, F3: Knowledge exchange, F4: Guidance of the search, F5: Market formation, F6: Resource mobilization, F7: Creation of legitimacy

	Structure				Functions						
	A	Int	Ins	T	F1	F2	F3	F4	F5	F6	F7
Japan	+/-	++	++	+	+/-	++	++	+/-	+/-	--	++
Netherlands	+	++	-	+/-	+	+	++	-	++	-	+
France	++	+	+	++	++	++	++	+	++	+/-	+
USA	++	+	+	++	++	++	++	+/-	++	-	+/-
Malaysia	-	+	+/-	--	-	-	++	--	+	--	+

On closer inspection of the performance of the structural element *institutions*, where Japan performs very well, an issue arises. For Japan, the institutions are very beneficial, with the government supporting their research efforts and possibly the financing of larger scale OTEC plants to improve on their current 100kW demonstration plant. However, cold water resources for OTEC are limited in Japan, as well as in the other studied clusters so for large scale diffusion much broader support would be required, not only from the government of the developing cluster but from governments of potential OTEC construction sites as well. The places where early OTEC might be a suitable energy technology are often remote island states and have limited resources to carry the risks of such high cost projects and governments of countries where the OTEC developers reside are often not willing to fund projects abroad.

The performance of *technological factors* of France is very high, but this is compared to the other clusters. They do have much knowledge on the different parts of an OTEC plant, although it is not enough for large-scale OTEC plants. This is an issue due to the previously mentioned economic feasibility of small to medium-scale OTEC.

Concluding, it is not enough to combine all well-performing elements of the different OTEC clusters to obtain a well-functioning innovation system that enables large-scale OTEC diffusion. Extensive support from governments and development banks is required to develop OTEC to a point where it might become economically viable. This might be hard to accomplish due to the large risks and uncertainties involved in technology development and the limited financial strength of most countries with access to the OTEC resource. However, the importance of the unique aspects of the OTEC technology (stable electricity production year-round and the possibility to use the resource for food and potable water production) might increase with increasing amounts of electricity obtained from intermittent renewable sources and increasing water and food shortages worldwide. These trends could become the cause of extensive government support that is required to realize commercial OTEC diffusion.

5.7 Assessment of the research quality

The objective of this thesis was to obtain a broad overview of the OTEC industry and the performance and potential of the clusters in this industry through qualitative research with an exploratory nature. In this section, the choices that were made for this purpose are discussed, as well as the limitations to the research that occurred due to these choices. Furthermore, the chosen research concepts are discussed, and recommendations are made for similar future work.

5.7.1 Scope and validity of the research

Innovation research that uses technological innovation systems for analysis of renewable energy industries is not new. However, the OTEC industry has not been mapped or analysed and no innovation studies have been carried out earlier in any form. This had several effects on this thesis. Firstly, the lack of (scientific) information sources regarding the OTEC industry meant that the scope had to be made wide deliberately, to be able to create an overview of the properties of and activities in the OTEC industry and assess as much of the industry as possible. This wide scope did have a negative effect on depth and validity of the research.

Secondly, much information had to be obtained through interviews. Due to the relatively small size of the industry, the number of potential interviewees was limited. This makes it hard to validate the obtained information and made it impossible to obtain a complete set of information from each cluster. Future research could further increase validity and depth by doing more interviews and validating information from this thesis with different cluster representatives.

5.7.2 Assessment of assumptions

The assumptions that were made in the beginning of the research based on literature review, influence the validity of the results and therefore are assessed for their quality. The research framework was based on three main assumptions:

1. The clusters that were defined at the beginning of the research are the most relevant sets of organizations that develop OTEC and should be analysed individually due to differences in approach and no or very limited inter-cluster cooperation.
2. The main OTEC developing organizations are the centre of their respective cluster.
3. The clusters that are analysed in-depth for this thesis form a good representation of the whole OTEC industry.

Nine clusters were defined at the beginning of the research. From these nine clusters, organizations from five clusters were willing to participate in interviews. During the process, the first assumption has held up relatively well. The nine clusters were found to be highly relevant and no other potential clusters worthy of analysis were identified. There was some overlap in the clusters however. For example, the Japanese cluster cooperates with organizations from the Dutch and American clusters, while the Malaysian cluster cooperates with the Dutch, Japanese and French clusters, and the clusters of Makai Ocean Engineering and OTE Corporation (both from the USA) were found to have such intensive cooperation that they were merged into one cluster. This overlap does not affect the validity of the research, but it does give rise to the question where a cluster starts and where it ends. This is a question that researchers should answer for themselves depending on the specific conditions of the research subject. In this case, the choice was made to group organizations around industry-defining projects and this choice seems to be the right one when regarding the results.

It was found that each organization that was defined as the centre of a cluster was indeed the main OTEC developing organization and therefore the driving force behind OTEC development and/or commercialization. In the American cluster, Lockheed Martin was added to the main organizations even with their on-and-off involvement in OTEC development, especially due to the influence they can exercise due to their large size, although this does not influence the validity of the assumption.

Of the nine clusters that were defined in the beginning of this research, three were unwilling to participate or could not be contacted. The two USA clusters were merged into one. Only the clusters of Bardot Ocean (France), KRISO (South Korea) and Bell Pirie Power Corporation (UK / Philippines) were not represented in the research. Bardot Ocean has comparable aims to Naval Energies (France) and

Makai Ocean Engineering (USA) as they want to become an EPCI contractor. Their size is similar to that of Makai as well. KRISO is a government funded organization focused purely on research and is therefore comparable to Saga University in Japan. The small Bell Pirie Power Corporation is similar to Bluerise as they are trying to realize OTEC projects on islands in the role of project developer with some technological knowledge and in close cooperation with contractors. Therefore, these clusters all have similarities to the clusters that were investigated in-depth and as far as could be concluded from publicly available literature, researching them more thoroughly would not have resulted in radically different results of the study.

5.7.3 Quality of research concepts

To assess the performance of the clusters, the research framework of technological innovation systems was used. To map the structure, four elements were chosen as proposed by M. Hekkert et al. (2011) and R. A.A. Suurs (2009) (except networks, that was changed to interactions as in the paper of Wieczorek & Hekkert (2012)): *Actors, interactions, institutions* and *technological factors*. The functional elements were obtained from literature as well (M.P. Hekkert et al., 2007; S.O. Negro, 2007; R. A.A. Suurs, 2009) and were used to map the activities and events in the clusters that influence the development and diffusion process of the technology.

Although the research framework was created by thorough study of innovation literature and the framework generally fitted the research objective well, some issues were found with the chosen elements. Therefore, these will be discussed in this section.

Structure

The structure of an innovation represents the more or less static aspects of the system. This is a regularly used concept in the scientific field of innovation studies. Nevertheless, an issue arose due to the particularly small number of elements. Obviously, the definition of each element is open for discussion, but to describe a whole innovation system with just four elements means that this definition becomes extremely wide and important details might get lost in the analysis. It was very hard to specify the essential structural factors that define a well performing innovation system using this theory.

Functions

The choice of functions was made based on the idea that the list of factors proposed by M.P. Hekkert et al. (2007) was extensively validated in other literature. In this research it has proven its use to obtain an overview of the activities and events in OTEC innovation clusters. The element that was proposed by Bergek, Jacobsson, et al. (2008) and not by Hekkert et al. was the *development of positive externalities*. Positive externalities imply the cost or benefit that is incurred on an external party without their consent. Especially in the case of renewable technologies, these externalities can play a major role in the technology diffusion, in case of OTEC mainly the environmental benefit compared to fossil fuel power with no air, soil and water pollution and subsequent health issues. Due to the large influence that these externalities can have on the adoption of renewable energy technologies, it is puzzling why this function is not taken into account in the FIS framework of Hekkert and in hindsight it could have been of benefit for this OTEC innovation study to take this function into account as well.

The set of indicators that was used for the technological innovation system functions was based on indicators that were used in previous researches and adapted to fit the objective of this study. Therefore, individually, these indicators are valid but as a set they have not been used earlier so validity cannot be guaranteed. Some issues did arise with the indicators during the research.

Several indicators had some overlap. The indicator *introduction of niche markets* and *efforts to enable market formation* sometimes overlapped as several clusters were adding these niche applications to their OTEC facilities to form a market. Issues with the mobilization of *physical resources* and *human resources* were usually due to the inability to mobilize *financial resources*. *Aid for/against projects* could overlap with *financial resources* when aid for a project was in the form of a subsidy. The indicator *co-authorship of scientific publications* did not prove useful in the research due to limited published works, which were mostly relatively old and co-authorship did not occur often.

5.7.4 Research framework recommendations

In essence, the research framework that was used for this study was successful as it made it possible to reach the research objective. However, some improvements could be made to obtain even better results in future studies. The technological innovation system theory has been very useful although it would be better to choose a larger number of more focused structural elements instead of the small number of very broad elements that were currently used. Furthermore, the list of functional elements proposed by Bergek should be used when researching renewable energy technologies due to the addition of the highly relevant function *creation of positive externalities*.

5.8 Policy and research relevance

The conclusions from this research are relevant for improvement of both government policy and as guidance for private organizations. The found limitations of the current (government) support mechanisms show that these might need to be changed to better accommodate for high CAPEX innovations. Especially because OTEC plants only become economically viable above 100MW power output, the support for OTEC projects is essential for further development. OTEC regulations for permitting are currently insufficient in most countries, which costs time and money for companies. An internationally accepted set of regulations which could easily be adapted to national policy would be very beneficial.

Individual cluster organizations can use the results of this thesis to compare themselves against other clusters and identify their strengths and weaknesses. Subsequently, they can decide if and how they want to improve their weaknesses based on the solutions offered in the discussion of the cross-case analysis.

5.9 Theoretical contribution and comparison to former literature

This thesis research framework is based on the Technological Innovation Systems framework from (Wieczorek & Hekkert, 2012). The main theoretical contribution is that the method used in this thesis is different from 'regular' innovation system studies. Here, multiple exploratory TIS analyses are made from multiple clusters from the same industry, after which they are compared. Consequently, an indication of the performance of these clusters can be determined without an extensive quantitative research. Furthermore, some recommendations are made for using the TIS framework for renewable energy technologies which could improve the validity of future studies.

5.10 Recommendations for future research

Several knowledge gaps have been identified during this research. The following topics could be explored for further insight in the innovation process or OTEC.

5.10.1 Validate and further expand on the results of this research

This research has a very exploratory nature and is purely qualitative. The most valuable data was obtained through interviews with one to two interviewees per cluster. Consequently, the validity of the results and conclusions cannot be guaranteed. Future work could expand on these results and validate the conclusions of this research by doing in-depth TIS analyses of each cluster individually.

This would enable much more thorough qualitative research as well as validation of the results by quantitative research.

The method of this future work could be based on the manual that was written on TIS research by M. Hekkert et al. (2011). Based on the qualitative part of the study, diagnostic questions could be defined for each innovation system function that can be answered on a Likert scale by experts. Subsequently, the cause of the found drivers and barriers can be proven statistically.

5.10.2 Legal analysis of countries with deep seawater resource

Difficulties in obtaining permits for OTEC projects and unclear regulations for such projects are frequently mentioned by interviewees as a barrier for the development of OTEC plants. An analysis of the legal system regarding permitting and regulations that affect OTEC or renewable energy projects in general would enable governments to improve their regulations and give project developers an idea of where OTEC projects could be carried out with the least bureaucratic interference.

5.10.3 Study support mechanisms for emerging technology that require large initial investments

Government support was found to be critical for OTEC development towards mass diffusion. However, it became clear that support mechanisms are currently not suitable for technologies such as OTEC. Most support mechanisms are suitable for technologies that can either be scaled up in small steps, or for technologies that require low upfront investments in general. However, OTEC was found to be a technology which has neither of these characteristics. OTEC plants require extremely high initial investments followed by low operating costs. Furthermore, they are economically unfeasible in small to medium scale, which makes upscaling in small steps problematic.

If policy makers decide that the benefits of OTEC weigh up to the development costs, different support mechanisms are required. A study into existing support mechanisms and recommendations regarding improvements that can be made towards supporting technologies such as OTEC would then be of large value.

6 Conclusions

Ocean thermal energy conversion could offer large environmental and societal benefits. Globally, ocean thermal energy conversion (OTEC) technology providers and project developers are working hard to make the technology diffuse on large scale. This research attempts to shed light on the global OTEC innovation activities with the following research question:

What is the performance and potential of Ocean Thermal Energy Conversion innovation clusters worldwide?

An innovation cluster is defined as one or more key players in the industry, around which other facilitating actors have clustered to enable significant technology development and/or technology diffusion, or in this case the execution of OTEC projects. Nine clusters have been defined in the worldwide OTEC industry. Of these nine clusters, five (in Japan, the Netherlands, France, the United States of America and Malaysia) were willing to participate in this study and are therefore the main research subjects. Four clusters (in South Korea, Philippines and another in France and in the USA) were unable or unwilling to participate. To determine the performance and potential of the clusters, the technological innovation system framework has been applied. Four structural elements (actors, interactions, institutions and technological factors) were defined to describe the current state of a cluster and seven functions of innovation systems (entrepreneurial activity, knowledge development, knowledge exchange, guidance of the search, market formation, resource mobilization and creation of legitimacy) were obtained from literature to define the structure-building activities in clusters. Eight semi-structured interviews were conducted with relevant people from the five clusters in addition to the limited information that was publicly available and gave input to a cross-case analysis that compares the performance of the clusters per structural or functional element.

Table 6.1: Overview of cluster performance per structural and functional element. Scored on a five-point scale (++, +, +/-, -, --). Structure: Actors, Interactions, Institutions, Technological factors. Functions: F1: Entrepreneurial activity, F2: Knowledge development, F3: Knowledge exchange, F4: Guidance of the search, F5: Market formation, F6: Resource mobilization, F7: Creation of legitimacy

	Structure				Functions						
	A	Int	Ins	T	F1	F2	F3	F4	F5	F6	F7
Japan	+/-	++	++	+	+/-	++	++	+/-	+/-	--	++
Netherlands	+	++	-	+/-	+	+	++	-	++	-	+
France	++	+	+	++	++	++	++	+	++	+/-	+
USA	++	+	+	++	++	++	++	+/-	++	-	+/-
Malaysia	-	+	+/-	--	-	-	++	--	+	--	+

Table 6.1 shows an overview of the performance of the clusters on the structural and functional elements. Several trends can be observed. *F4: Guidance of the search* and *F6: Resource mobilization* score less than the other elements for all clusters, while all clusters perform very good on *F3: Knowledge exchange*. Clear guidance to the industry in the form of OTEC development targets from governments would aid the development process. However, OTEC is often not included in renewable energy development plans, in comparison to technologies such as wind, solar PV and geothermal energy. Similarly, guidance from industry to governments is hindered by the relatively small scale of many OTEC developing organisations. A bad fit was found between support mechanisms of regulatory bodies and high CAPEX technologies such as OTEC. Most mechanisms support only the electricity production and not development and construction, while OTEC companies cannot get financing for construction of their projects due to the high risk on large investments for private investors. This means that mobilization of financial resources is extremely difficult. All clusters perform very well on *knowledge exchange* due to the general willingness to hire contractors to solve OTEC problems. By

hiring contractors instead of developing everything in-house, knowledge from expert contractors is transferred into the OTEC industry.

The Malaysian cluster performs worse than other clusters on average. The main actor of the cluster is a university that is only promoting OTEC to potential local stakeholders and international financers to enable construction of OTEC plants in Malaysia by actors from other clusters. Therefore, it underperforms on most elements that are required for technology development. Results showed it did not meet the criteria of a cluster and should be seen as a client/contractor.

The Japanese cluster performed well on all research related elements due to their strong focus on technology development, while this same focus caused it to perform worse on entrepreneurial and commercial elements. Their dependence on the Japanese government as their single source of funding makes them perform very poor on resource mobilization. The Dutch cluster suffers from lack of OTEC-specific support from the Dutch government and has issues inherent to a young start-up; limited research and funding for research setups, which is visible in *knowledge development* (learning activities) and *entrepreneurial activity* (demonstrating and commercializing technology). Nevertheless, the Dutch cluster does perform well on many other elements due to their development of a commercial OTEC plant. The French cluster performs good to very good on almost all elements due to both a strong technology provider and a strong project developer, which creates good scores in entrepreneurial and knowledge elements, as well as the structural elements *actors* and *technology factors*. It performs somewhat better than other clusters on *resource mobilization* due to the NER300 subsidy of over €70 million for their 10MW commercial project. The American cluster performs very similarly due to a similar structure with strong actors. Nevertheless, they perform worse on *creation of legitimacy* (activities that align social rules, norms and perception towards the technology) due to very limited technology promotion activities.

Although all OTEC developing clusters perform well on most structural and functional elements, technology diffusion might still be difficult. Because OTEC is expected to only be competitive in the form of large-scale plants, extensive government support would be required to develop the technology further. However, the governments and organizations in the OTEC clusters can strengthen their case by improving on their weaknesses, for which several recommendations have been produced.

General

- Support mechanisms should be adapted to better fit high risk, high CAPEX technologies.
- Governments should include OTEC in renewable energy development plans.
- An independent (international) OTEC industry association could perform lobbying and promotion activities to governments, clients and financers independent of clusters, which could facilitate the legitimization of OTEC as a viable alternative for other (renewable) energy technologies.
- Onshore OTEC can be outfitted with additional production that uses the same cold-water resource, e.g. seawater air conditioning, seawater desalination, aquaculture. Development of concepts for these kinds of additional revenue streams for offshore plants is currently very limited, although these could increase offshore OTEC viability.

Cluster specific

- The organizations in the Japanese cluster might create more opportunities for realizing commercial OTEC in the future by increasing their effort for commercialization of OTEC compared to their research efforts by introducing external project developers.

- By searching for new sources of funding, the Japanese cluster could decrease the risk of diminishing government funding.
- OTEC-specific permitting and regulations from the Dutch government could be beneficial for technology diffusion in the Netherlands and its overseas territories.
- By including large organizations in their clusters, the Japanese and Dutch cluster could magnify the effect of their efforts for guidance towards governments.
- By doing more R&D and/or realizing commercial OTEC plants, the Dutch cluster could decrease their technical knowledge gap compared to other clusters.
- Both the French and American cluster could increase their technology promotion efforts to educate potential stakeholders. Together with the Japanese cluster they have the best demonstration facilities where they could present technological, financial, environmental and societal benefits to overcome the outdated information regarding OTEC that is embedded in peoples' minds.

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Appendix A: Interview protocol

The interview protocol includes everything that is necessary to do the interview: questions, introductory texts as well as the method that is used to contact the potential interviewees. Below, the interview questions and associated texts are shown. Due to the limited amount of time available for each interview (approximately one hour), the number of questions that can be asked is restricted. However, it is expected that not all interviewees have the required knowledge to answer all questions, which should make it possible to do the whole interview in the set time. It is however possible that the interview does take longer than expected, which is why the most relevant questions are marked in bold font. If time is starting to become an issue, only the bold questions will be treated. If some time is left at the end of the interview, one can revisit previous subjects and do some of the skipped questions.

There are two versions of the interview shown below. The first version has been used in the first interview with Bluerise to both validate the interview protocol and gather research data, while the second version has been used in the remainder of the interviews.

Validation interview

PURPOSE of RESEARCH

- Get a better understanding of the emergence of OTEC networks/clusters and innovation systems worldwide
- Provide recommendations how to facilitate these clusters better and what can be done on this at the global level

INTERVIEW

Bold questions are most relevant, non-bold questions can be skipped in case of time shortage.

There is a distinction between a GENERAL focussing on a first mapping, solely together with Bluerise, aiming at networks and structures around the world, and a more in-depth part focussing on specific clusters around core firms in different parts of the world, which is meant for a second step in this research which will also involve international organisations.

GENERAL

STRUCTURAL QUESTIONS ONLY!!! FOCUS ON ACTORS AND THEIR ACTIVITIES AND NETWORKS. TWO PARTS: BLUERISE AND ALL. WHAT DO I NEED TO KNOW TO PROCEED WITH THESIS?

BLUERISE ONLY STRUCTURAL INTERVIEW!

ACTORS

1. **What are the main developers of OTEC in the world and how do you consider their state of development of OTEC?** *(industrial, knowledge institutes, universities)*
    a. France
    b. Korea
    c. United States of America
    d. Japan
    e. Netherlands
2. **All of these clusters at least have plans to build an OTEC plant, with which organisations do they cooperate to realise these plans?** *(Value chain, public bodies, interest organisations, venture capitalists)*

NETWORK

3. **Are there initiatives to enable and facilitate cooperation within the industry itself, and between industry and external institutes such as universities?** *(are there many technical publications concerning OTEC development? Are these useful for other parties in OTEC?)*
4. **What is the role of governments in the development of OTEC in these clusters?**
5. **What is the attitude of the main companies in the aforementioned clusters towards inter-cluster cooperation?** *(are there any partnerships between the main developers?)*

INSTITUTIONS

6. **What are drivers and barriers for OTEC?** *(environmental NGO's, competing technologies, general public, governments, etc.)*
7. **What are main developments globally regarding OTEC?** *(pilot plans, technological, political, socio-cultural, economic)*

GENERAL STRUCTURAL INTERVIEW

ACTORS

1. **What are the main developers of OTEC in the world and how do you consider their state of development of OTEC?** ***(industrial, knowledge institutes, universities)***
   a. France
   b. Korea
   c. United States of America
   d. Japan
   e. Netherlands
2. **Are there initiatives to enable and facilitate cooperation within the industry and external institutes such as universities?** ***(are there many technical publications concerning OTEC development? Are these useful for other parties in OTEC?)***

NETWORK

3. Are these developers connected?
4. **How can OTEC development be stimulated globally and how could OTEC parties collaborate on this?**

INSTITUTIONS

5. **What are drivers and barriers for OTEC?** *(environmental NGO's, competing technologies, general public, governments, etc.)*
6. **What are main developments globally regarding OTEC?** ***(including pilot plants, and plans, technological, political, socio-cultural, economic)***

SPECIFIC FOR CLUSTER/COMPANY

Functions	**Interview questions**
1. Entrepreneurial Experimentation and production	**7. What are the main OTEC pilots and plans in your network or cluster?** (what is the role of you*r organisation in these pilots and plans? How did the pilot/plan develop? What have you learned from this pilot? What are main results?* ***What has been learned from those pilots so far? And how do you expect that it will develop further?***)

	8. **Who are the main actors/stakeholder in your OTEC network?** *(have cooperated in pilot plant, plans; global/cluster-level, Research/Companies/Govt/Civil Society)* 9. Have there been entries or withdrawals of companies from your OTEC network that could have a big impact your organisation or OTEC development in general? 10. **What is needed to realise a next scale OTEC plant in your cluster and what is missing for that?** *(expertise, physical resources, institutions)*
2. Knowledge Development	11. **Are you familiar with patents on OTEC developments?** 12. **Who is doing most (relevant) R&D in your cluster and how much R&D is done?** *(Is it sufficient for commercial success in the near future? If not answering main question: what type of organisations?)* 13. Is there a difference in the knowledge required for small and larger scale OTEC and if so, is this being addressed? 14. **What are other possible applications of OTEC plants and to what extent are they researched?**
3. Knowledge Exchange	15. **How does knowledge exchange work within your cluster?** *(Intermediary organisations? Collaboration with other firms, universities, research organisations?)* 16. **How does knowledge exchange work globally?** *(Intermediary organisations? Your organisation?)* 17. **How do you publish research findings?** *(reports, press releases, journal articles, conferences; What percentage of work is published? Why?)*
4. Guidance of the Search	18. **What targets have you set for OTEC in the future?** 19. **What are your expectations regarding further future developments of OTEC?** *(technological, political, socio-cultural, economic)* 20. **How do targets set by regulatory bodies, such as governments or international organisations, influence OTEC development?** *(example: NGO's, United Nations Environmental Programme)* 21. What is the role of (local) governments in pilots and pilot plans?
5. Market Formation	22. **What is needed to develop the market for OTEC (further)?** *(from technology developers, policy makers, general public)* 23. **How can the market development for OTEC be stimulated/accelerated?**
6. Resource Mobilization	24. **What resources are needed to develop and implement OTEC further in your cluster?** *(financial, knowledge, human)* 25. Are these resources sufficiently available?
7. Counteract resistance to change/Legitimacy creation	26. **How are the reactions to your pilots and plans?** *(from general public, governments, environmental organisations)* 27. How are drivers and barriers for OTEC being exploited or addressed? 28. **How can OTEC development be stimulated globally and how could OTEC parties collaborate on this?**

Final version

In this research, it is assumed that multiple groups of organisations work on OTEC in parallel, thus cooperation between these groups is limited. For these groups, the term 'cluster' is used and is defined as: *"The main technology-developing company and the cluster of organisations that cooperate or otherwise influence the research, development and market diffusion for their OTEC product".* This is a frequently used term in the following questions.

PURPOSE of RESEARCH

- Get a better understanding of the emergence of OTEC networks/clusters and innovation systems worldwide
- Provide recommendations how to facilitate these clusters better and what can be done on this at the global level

The interview starts with four general questions, after which the questions get more specifically cluster-related.

GENERAL INTERVIEW QUESTIONS

1. What are main developments globally regarding OTEC?
2. What do you see as important drivers and barriers for OTEC?
3. What initiatives are undertaken to facilitate cooperation within the industry itself, by parties in industry, government or other stakeholders?
4. And for cooperation between industry and external institutes such as universities?

CLUSTER-SPECIFIC INTERVIEW QUESTIONS

5. What are the main OTEC pilots and plans in your network or cluster?
6. What has been learned from those pilots so far?
7. Who are the main actors/stakeholder in your OTEC network?

8. Right now only pilot plants with relatively low power output exist. What would be your next step in larger scale OTEC?
9. What is needed to realise a next scale OTEC plant in your cluster and what is missing for that?
10. Who is doing most (relevant) R&D in your cluster and how much R&D is done?
11. What are other possible applications of OTEC plants and to what extent are they researched?

12. How does knowledge exchange work within your cluster?
13. How does knowledge exchange work globally?
14. How do you publish research findings?

15. What targets have you set for OTEC in the future?
16. What are your expectations regarding further future developments of OTEC?
17. How do targets set by regulatory bodies, such as governments or international organisations, influence OTEC development?

18. What is required to develop the market for OTEC (further)?
19. What resources are needed to develop and implement OTEC further in your cluster?
20. Are these resources sufficiently available?

21. What is the attitude of organizations in your cluster towards inter-cluster cooperation and do you know examples of inter-cluster collaboration?
22. How are the reactions to your pilots and plans?

Appendix B: OTEC projects by country, as of March 2017

Country	Operational	Under construction	Planned	Proposed
AFRICA				
La Réunion (French territory)	15 kW			
AMERICAS				
Bahamas (USA)				10 MW
Curacao (Kingdom of the Netherlands)			500 kW	
Hawaii (USA)	105 kW			1 MW
La Martinique (French territory)		10 MW		
US Virgin Islands				8 MW 15 MW
ASIA				
India				20 MW
Japan	30 kW 100 kW		1 MW	
Malaysia				Multi-MW
Maldives				2 MW
Philippines			10 MW	
South Korea	20 kW			
Sri Lanka				10 MW
OCEANIA				
Kiribati		1 MW		
Total	**270 kW**	**11 MW**	**11.5 MW**	**66 MW**

Appendix C: Analysis of other clusters

In chapter 2, nine relevant clusters were identified which might be interesting for research. Organizations from five of these clusters were willing to provide more information for this research and four clusters were not willing to contribute or did not respond to invitations. During the research, the cluster of Makai, USA, was found to be intertwined with the cluster of OTE Corporation and was therefore integrated in the regular cluster analysis in the main part of this thesis. The other three clusters have been analysed using the limited publicly available information and will be discussed in condensed form in this section.

France – Bardot Ocean

Structure

Bardot Ocean, an OTEC developer, and DORIS, an offshore engineering corporation are working together on a 2MW OTEC facility in the Maldives (Bardot Ocean, 2016a). For this project, they are bound to the Maldivian institutions and have to work on local policy creation. They do not benefit from the work of Akuo Energy on French OTEC policy. There is no connection to the Naval Energies/Akuo Energy cluster.

Functions

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

Bardot Ocean has **commercial** offerings with net power output ranging from 0.3MW to 20MW. It has been contracted in 2016 to build an OTEC plant for an eco-resort in the Maldives (Bardot Ocean, 2016b) which will produce 2MW electricity and meet the resort needs of potable water and air conditioning. This project was planned to be operational early 2018, no further information on progress has been released since it was first announced.

An OTEC Lab simulator (Tidal Energy Today, 2017) was introduced by Bardot in 2017. This **demonstration project** consists of a 10kW gross power output OTEC laboratory prototype which runs on refrigerated and heated water to test and optimize components and energy cycle of OTEC plants with different boundary conditions.

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

With their demonstration plant and commercial project, they are both **learning by doing** and **using**. The OTEC simulator and their aim to be an EPCI contractor in the OTEC industry suggests that they do much **learning by searching** themselves.

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

Bardot Ocean cooperates with DORIS suggests **learning by interacting** (Bardot Ocean, 2016a), although details are missing in publicly available information.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

The **Target** of Bardot is to offer EPCI services for development of OTEC plants and **expected** in 2016 to complete their first OTEC project for the eco-resort in the Maldives early 2018.

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

Bardot Ocean **introduced** SWAC as well as seawater reverse osmosis technology for seawater desalination as **niche markets** alongside OTEC. Additional deep seawater can be tapped for agriculture and aquaculture.

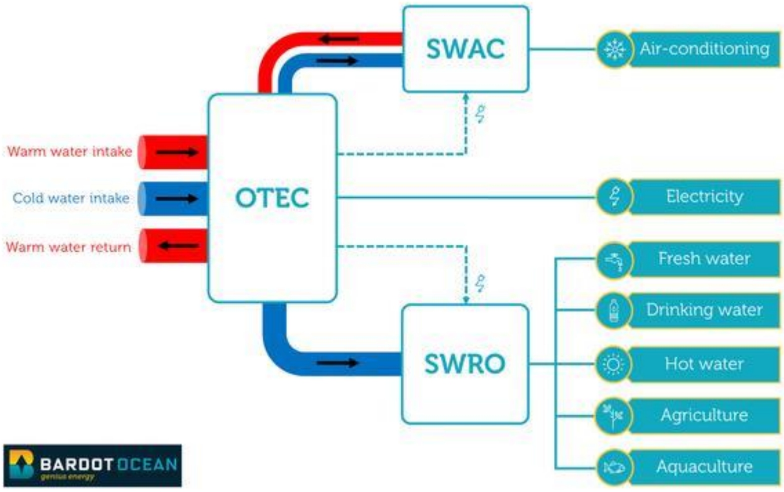

Figure 0.1: Niche markets introduced by Bardot Ocean. Reprinted from bardotocean.com, retrieved 25-03-2018. Copyright Bardot Ocean.

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

No information was found on resource mobilization.

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

There is much **aid for OTEC projects** due to the possibilities of reduced pollution, energy cost and fossil fuel dependency in remote areas. However, environmental and social impact must be minimized during construction and operation to prevent **resistance**. The high CAPEX of OTEC projects is an issue (Bardot Ocean & ACOA Conseil, 2017). Bardot Ocean presents at conferences for **technology promotion**.

Philippines/UK – Bell Pirie Power Corporation

Bell Pirie Power Corporation, based in London and focused on developing OTEC in the Philippines, is working on a project off the coast of Zambales. A memorandum of understanding has been signed between Bell Pirie, Naval Energies, Akuo Energy and PNOC Renewables Corporation (fully owned subsidiary of the state-owned Philippine National Oil Company) for the development of this project. Bell Pirie is currently discussing the feed-in tariff with the Philippines Energy Regulatory Commission (Icamina, 2016; OTEC Foundation, 2016a). What is missing for the project are local endorsement, power purchase agreement and a government service contract from the Department of Energy (OTEC Foundation, 2016a).

Functions

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

Bell Pirie is working on a **commercial project** entailing a 10MW offshore OTEC plant off the shore of Zambales, Philippines. It is aiming to be a power generation company and has partnered with French project developer Akuo Energy and technology provider Naval Energies to obtain their required **supply chain**. The design of the NEMO offshore plant that is under development in Martinique will be reused for this project (OTEC Foundation, 2016a).

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

There is no learning regarding the technology when purely looking at Bell Pirie power corp. The partners in the project are currently mainly focused on the NEMO project in Martinique so their involvement will be limited until Bell Pirie solves all the issues with the Philippine government. Although not technical, there is some **learning by doing** involved in this interaction regarding OTEC project development for both Bell Pirie and the Philippine government.

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

By cooperating with Naval Energies and Akuo Energy, Bell Pirie can **learn by interacting**. They can benefit from the experiences that their partners get from developing the NEMO project in Martinique.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

The **target** of Bell Pirie for the 10MW project was to have it operating in 2018. Due to major delays in granting the feed-in tariff it will not be commissioned before 2022. The **target set by** Philippine **regulatory bodies** was similar. Nevertheless, the Energy Regulatory Commission will not set a feed-in tariff before there is more certainty on the performance of OTEC technology (Icamina, 2016). The target for operationalization of the plant has subsequently been pushed back to 2022 (OTEC Foundation, 2016a).

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

There is no indication of **efforts to enable market formation** or any interest in the **introduction of niche markets**. This might be due to the focus on offshore OTEC, which makes adding additional production streams more difficult.

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

Financial resources are the main barrier for the 10MW plant in this cluster. Due to technical uncertainty no feed-in tariff is set, which in turn increases the risk for investors to an unacceptable level. Furthermore, technology providers must provide performance and availability guarantees, which can be difficult for a technology with high capital expenditure, such as OTEC (Icamina, 2016).

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

There is both **aid for** and **resistance against projects** from the Philippine government. On the one hand they want to increase the share of renewable energy and are willing to invest in projects. On the other hand, they do not accept the risk of an emerging technology such as OTEC, which delays projects significantly. Bell Pirie of course extensively **lobbies for OTEC** to the government to get an acceptable feed-in tariff. Furthermore, they promote OTEC and their own product at conferences such as the yearly OTEC symposium (Icamina, 2016; OTEC Foundation, 2016a).

Korea – KRISO

The Korean Research Institute of Ships and Ocean Engineering is, as far as public information shows, the only, or at least the main OTEC developer in Korea. This institute is state-owned and falls under the Ministry of Oceans and Fisheries. It seems to operate independently.

Functions

Entrepreneurial activity

Indicators: Commercial projects, Demonstration and pilot projects, Formation of supply chain.

Since 2013, KRISO has a 20kW **pilot plant** which is used for research purposes. An offshore 1MW **commercial plant** is under development to be installed in Tarawa, Kiribati, and should be operational in 2020. A timeline for larger scale offshore OTEC shows 10MW around 2025 and 100MW after that (OTEC Foundation, 2016a).

Knowledge development

Indicators: Learning by doing, Learning by searching, Learning by using, Research diffusion/convergence.

KRISO is a technology developer. It is **learning by searching** by doing much technical research for the whole design of OTEC plants, including the energy cycle, floating platform, cold water riser and mooring systems (OTEC Foundation, 2016a). With their pilot plant and by developing the Tarawa Plant they are **learning by doing** and **learning by using**.

Knowledge exchange

Indicators: Co-authorship of scientific publications, Learning by interacting.

From publicly available information, it seems that KRISO is missing the opportunity to **learn by interacting** due to their individual approach. It is not clear if they are cooperating with local or non-local companies.

Guidance of the search

Indicators: Expectations and opinions of experts, Targets set by industry, Targets set by regulatory bodies.

As stated in *entrepreneurial activity*, the **target set by** KRISO is to steadily increase the scale of their OTEC plants. They are a technology developer and are working towards 1MW operational in 2020, 10MW in 2025 at the latest and 100MW OTEC plants not much later (OTEC Foundation, 2016a).

Market formation

Indicators: Efforts to enable market formation, Introduction of niche markets.

Niche markets such as SWAC, seawater desalination or aquaculture do not seem to play a big role in the plans of KRISO. This might be due to the offshore focus, which makes adding these additional product streams more difficult compared to onshore plants.

Resource mobilization

Indicators: Financial resources, Human resources, Physical resources.

There is no information available regarding the resources of this cluster.

Creation of legitimacy

Indicators: Aid for/resistance against projects, Lobbying activities for/against the technology, Technology promotion.

KRISO actively presents their plans and activities at conferences (OTEC Foundation, 2016a).