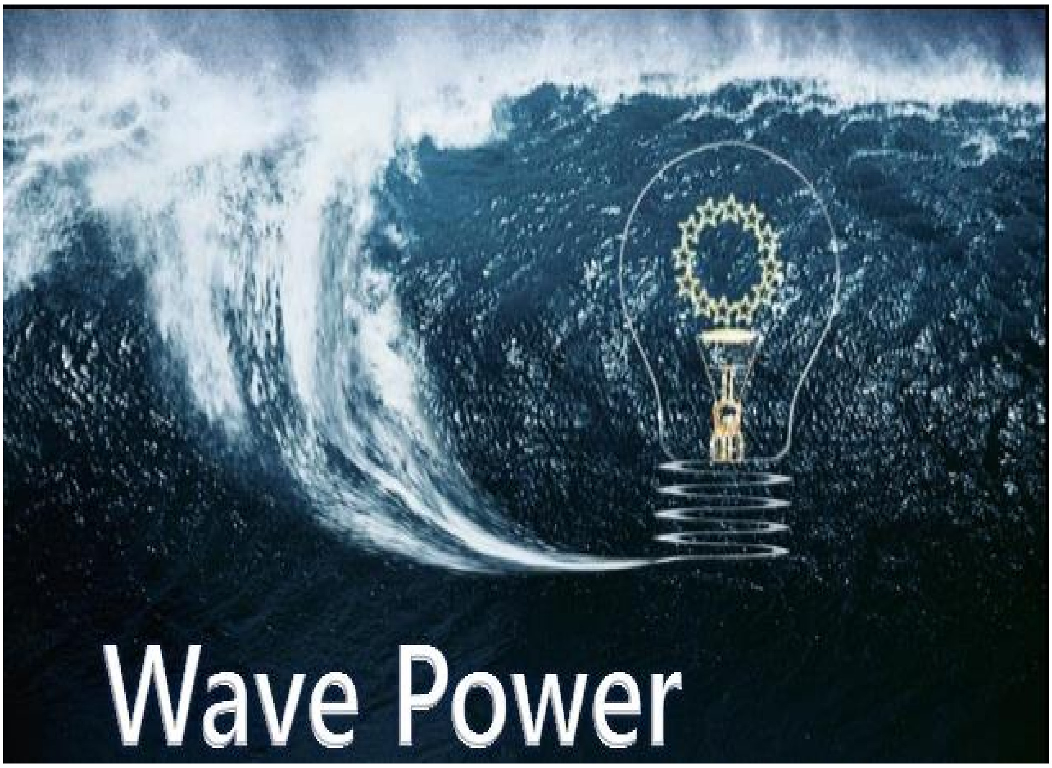
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

# Enabling factors to make Ocean Wave Power a competitive renewable energy source

- Case studies on modern Wave Energy companies in Scotland and Sweden

*Frencis Karagjozi & Gary Parker*

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**Enabling factors to make Ocean Wave Power a competitive renewable energy source**
- Case studies on modern Wave Energy companies in Scotland and Sweden

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# Abstract *(English)*

Wave power represents a major source of potential energy to address the global energy demand and modern climate issues. Although it has a huge potential, the current status shows that the source has not been harvested on a commercial scale yet. This is even the case in Scotland and Sweden, who have a modern industry development and a strong focus on their renewable energy portfolio.

The focus of this study is the wave power industry in these two countries. The aim of this research is to explore enabling factors to make ocean wave power a competitive renewable energy source in Scotland and Sweden. The theoretical perspectives used to explore this phenomenon consisted in three concepts: Competitive Strategy, Supply Chain Management and Economics of Innovation and Technology. A mixed-method, the sequential exploratory approach, has been used. As first sequence, qualitative data collection through several business case studies has been conducted. The case studies where enriched by semi-structured interviews. A mixed survey directed to an international wave developer population was the main source of quantitative data in the second sequence of the research approach.

As key results, 30 enabling strategic, supply chain and technological factors could be identified. These factors could be recognized in the three themes strategy, supply chain and technology and innovation to hinder the competitiveness of wave power in the past for both countries. Strategically implementing these factors enables wave power to become a solid element of the energy mix in Scotland and Sweden in the future.

# Sammanfattning *(Svenska)*


För att adressera den globala efterfrågan på energi är vågkraft en potentiell lösning till de moderna klimatfrågorna. Även om vågkraft har stor potential, är situationen sådan, att tekniken ännu inte har kunnat användas i kommersiell skala. Både Skottland och Sverige, trots sin moderna industriutveckling och stort fokus på förnybara energier, har haft svårt att komma igång med vågkraft.

Den här studien fokuserar på vågkraftsindustrin i Skottland och Sverige. Forskningens mål är att utforska de faktorer som skulle möjliggöra att vågkraft blir konkurrenskraftig, och skapar en förnybar energiresurs i Skottland och Sverige. Den teoretiska ramen som har använts för att utforska fenomenet bestod av tre perspektiv: konkurrenskraftig strategi, styrning av försörjningskedjan och ekonomi i innovation och teknologi. Den blandade metoden, sekventiella explorativa ansatsen, har använts. Först utfördes flera företags-fallstudier för att samla kvalitativ data, som sedan kompletterades med semistrukturerade intervjuer. Efter det gjordes en blandad undersökning som skickades till internationella vågkraftutvecklare, för kvantitativ data.

Studiens viktigaste resultat var de 30 strategiska, försörjningskeda relevanta och tekniska faktorer som identifierades och som möjliggör vågkraftens utveckling. De här är faktorer som tidigare har hindrat vågkraft från att bli konkurrenskraftig i Skottland och Sverige. Att strategiskt tillämpa de här faktorerna gör det möjligt för vågkraft att bli ett självklart element i den framtida energimixen i Skottland och Sverige.

# Abstrakt *(Shqip)*


Energjia e Valëve të oqeaneve dhe deteve paraqet një burim të madh të energjisë potenciale për të adresuar kërkesën globale të energjisë dhe çështjeve moderne klimatike. Edhe pse ajo ka një potencial të madh, statusi aktual tregon se burimi nuk është shfrytëzuar ende në një shkallë tregtare. Ky është edhe rasti në Skoci dhe Suedi, vende të cilat kanë një zhvillim modern të industrisë dhe një fokus të lartë në portofolin e tyre të energjisë së rinovueshme.

Fokusi i këtij studimi është industria e energjisë së valëve në këto dy vende. Qëllimi i këtij kërkimi shkencor akademik është shqyrtimi i faktorëve që fuqizojnë dhe mundësojnë që energjia e valëve të bëhet një burim konkurrues i energjisë së rinovueshme në Skoci dhe Suedi. Perspektiva teorike e përdorur për të eksploruar këtë fenomen konsiston në tre koncepte: Strategjia Konkurruese, Menaxhimi i Zinxhirit të Furnizimit, dhe Ekonomia e Inovacionit dhe e Teknologjisë. Është përdorur një metodë studimore e përzier dhe një qasje eksploruese me sekuenca. Si sekuencë e parë, është përdorur mbledhja e të dhënave cilësore (kualitative) nëpërmjet studimit të disa rasteve të biznesit, të cilat janë pasuruar më pas me intervista gjysmë të strukturuara. Si sekuencë e dytë për hulumtimin akademik, është kryer një sondazh i miksuar me në fokus një popullatë ndërkombëtare zhvilluesish të energjisë së valëve, i cili shërben si burimi kryesor i të dhënave sasiore (kuantitative).

Si rezultat kryesor janë identifikuar 30 faktorë strategjikë, të zinxhirit të furnizimit dhe teknologjikë. Këta faktorë identifikohen si pengesa kyce në konkurrueshmërinë e energjisë së valëve në të kaluarën e të dy vendeve. Implementimi strategjik i tyre mundëson që energjia e valëve të bëhet një element solid në të ardhmen në portofolin energjetik të Skocisë dhe Suedisë.

# Abriss *(Deutsch)*

Wellenenergie ist eine wesentliche potentielle Energiequelle, um dem globalen Energiebedarf und modernen Klimafragen zu begegnen. Obwohl es ein hohes Potential aufweist, wird diese Energieresource noch nicht auf einem kommerziellen Level genutzt. Dies ist auch der Fall in Schottland und Schweden, die eine moderne Industrieentwicklung aufweisen und einen starken Fokus auf erneuerbare Energien legen.

Der Fokus dieser Studie liegt auf der Wellenenergieindustrie in diesen beiden Ländern. Das Forschungsziel ist es, Faktoren zu finden, die Wellenenergie in Schottland und Schweden dazu befähigen, eine wettbewerbsfähige erneuerbare Energiequelle zu werden. Der theoretische Rahmen zur Erforschung dieses Phänomens bestand aus drei theoretischen Perspektiven: Wettbewerbsstrategie, Versorgungskettenmanagement sowie Innovations- und Technologieökonomie. Eine gemischte Methode wurde hierbei angewandt: der sequentielle explorative Ansatz. In der ersten Sequenz wurden mehere Unternehmens-Fallstudien zur Sammlung qualitativer Daten durchgeführt, die mit semi-strukturierten Interviews vertieft worden sind. Eine gemischte Umfrage wurde anschließend in zweiter Sequenz an eine internationale Wellenenergieentwicklerpopulation versendet, um primär quantitative Daten zu erhalten.

Als Hauptergebnis konnten 30 strategische, lieferkettenbezogene und technologische Faktoren identifiziert werden. Diese Faktoren können in den drei Themenbereichen Strategie, Lieferketten sowie Technologie und Innovation als Wettbewerbsbarrieren für Wellenenergie in beiden Ländern in der Vergangenheit angesehen werden. Die strategische Implementierung dieser Faktoren unterstützt Wellenenergie auf dem Weg zu einem zukünftigen soliden Element im Energiemix von Schottland und Schweden.

# Abbreviations

| | |
|---|---|
| EIT | Economics of Innovation and Technology |
| EMEC | European Marine Energy Centre |
| EU | European Union |
| IP | Intellectual property |
| KPMG | Klynveld Main Goerdeler and Peat Marwick International |
| LCOE | Levelized Cost of Energy |
| LEC | Levelized Energy Cost |
| LIMPET | Land Installed Marine Power Energy Transmitter |
| SCM | Supply Chain Management |
| SLU | Swedish University of Agricultural Science |
| SP | SP Technical Research Institute of Sweden |
| SWOT | Strengths Weaknesses Opportunities Threats |
| TRL | Technology Readiness Levels |
| TPL | Technology Performance Levels |
| UK | United Kingdom |
| UN | United Nations |
| WES | Wave Energy Scotland |

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# 1. Introduction

This chapter has the purpose to introduce the problem, aim and research questions to the reader. In order to provide a broad picture of the problem businesses in the wave power sector are facing in Scotland and Sweden, the background will first be described (***section 1 and 1.1***) and funneled to the specific problem studied in this paper (***section 1.2***). The aim and research questions close the chapter in ***section 1.3***.

*"Planet Earth is facing an energy crisis owing to an escalation in global energy demand, continued dependence on fossil-based fuels for energy generation and transportation, and an increase in world population, exceeding seven billion people and rising steadily."* (Coyle & Simmons, 2014, 1)

The background of this thesis project is the global climate as well as the energy crisis and the search for possible renewable energy solutions to it (United Nations [online], 2016). It consists of several case companies in the countries of Scotland and Sweden.

Initially this study was oriented towards two major companies. First, the Land Installed Marine Power Energy Transmitter (**LIMPET**) developed by Voith Hydro Wavegen Limited which is considered the world's first wave power station to be used on a commercial scale. In 2014, the plant was closed for various reasons. (Alternativeenergysourcesinfo [online], 2016; Breaking Energy [online], 2016; Hebridian Marine Energy Futures [online], 2013; Highlands and Islands Enterprise [online], 2016).

Second, there are several companies working on the development of competitive wave power solutions in Sweden. One of them is Seabased Industry AB that is supported by Uppsala University, which is also used to see a new approach to the task to make wave a competitive renewable energy source (Eco-innovation observatory [online], 2016; EMEC [online], 2016, 1; Nordicgreen [online], 2016; Uppsala Universitet [online], 2016).

As the process progressed into literature review, more information poured in from the wave power industry and it became clear that other companies would be an optimal addition to the case study structure. Hence, the Scottish segment of the study was enriched with The European Marine Energy Centre (**EMEC**), Wave Energy Scotland (**WES**), and the former projects of Pelamis and Aquamarine. While the Swedish segment saw the additions of Waves4Power, Ocean Harvesting Technologies and lastly Offshore Väst. Chapter 4.1 in empirical background further illustrates these actors. This group of companies represents one major common purpose; which is that of striving to find solutions in providing energy through harvesting a clean and renewable source.

Energy is essential for the modern way of living. Individuals as well as societies depend on it (Coyle & Simmons, 2014, Everett *et al.*, 2012). As the quote at the beginning of this chapter indicates, this very important source is facing a crisis (Everett *et al.*, 2012; McKillop & Newman, 2005; Coyle & Simmons, 2014; Heinberg, 2009). The crisis has two main factors; a continuous rising demand and quite often, acute energy supply issues.

The demand is rising due to a continuous population growth worldwide and an increasing energy demand by developing countries that strive to have the same economic power as industrial countries (Coyle & Simmons, 2014; Everett *et al.,* 2012). As can be seen in *figure 1.1*, the world fuel consumption has more than doubled between 1971 and 2013 (IEA [online], 2015, 28).

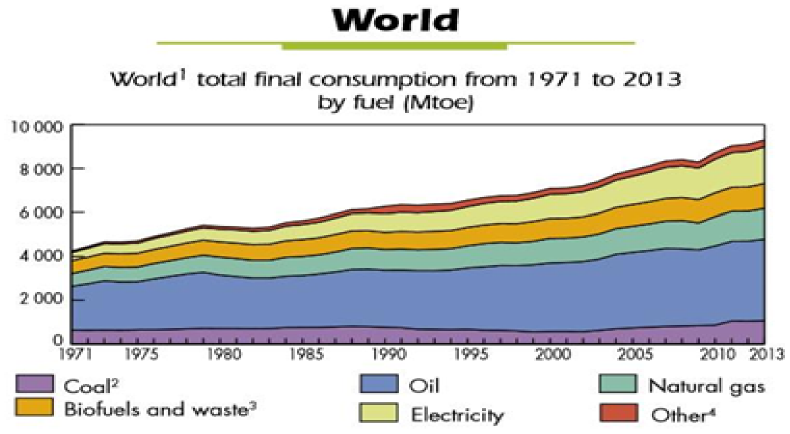
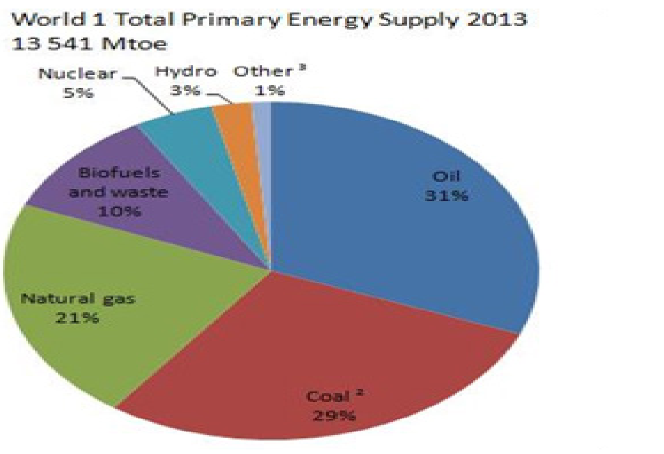



**Figure 1.1** World total final fuel consumption

1. World includes international aviation and international marine bunkers.
2. In these graphs, peat and oil shale are aggregated with coal.
3. Data for biofuels and waste final consumption have been estimated for a number of countries.
4. Includes geothermal, solar, wind, heat, etc

(Source: IEA [online], 2015, 28)

The trend that is shown in ***figure 1.1*** is very likely to continue and drives energy companies worldwide to explore for more energy sources to meet the needs of demand (Everett *et al.*, 2012*)*. ***Figure 1.2*** shows what these sources were in 2013 (IEA [online], 2015, 6):




(Own illustration based on: IEA [online], 2015, 6)

**Figure 1.2** World Total Primary Energy Supply

1 World includes international aviation and international marine bunkers.
2 In these graphs, peat and oil shale are aggregated with coal
3 Includes geothermal, solar, wind heat, etc.

As can be seen in ***figure 1.2***, 81% of primary energy supply came from oil, coal and natural gas which are often referred to as fossil fuels (IEA [online], 2015, 6). These sources have three main disadvantages, though.

First, they emit greenhouse gases that lead to global warming and climate change (Everett *et al.*, 2012). The United Nations (**UN**) held a conference in Paris from November 30$^{th}$ to December 11$^{th}$ 2015 to discuss possible solutions for the problem of climate change (United Nations [online], 2016, 1). The biggest influencing sector is electricity and heat production; 25% of the direct greenhouse gas emissions are an output of this sector (IPCC [online], 2014b, 64). If the climate changing influence from fossil fuels is to be stopped, their energy supply has to be limited (IPCC [online], 2014a).

Second, fossil fuel reserves are likely to be depleted in the future, because they do not regenerate. There are different predictions that vary with technological development and exploration of new potential fossil fuel resources, but it is likely that the fossil fuel supply will reduce drastically during the 21st century (Everett *et al.,* 2012).

Third, there are growing geopolitical tensions due to the explained demand and supply problems. Coal, oil and natural gas are concentrated in certain areas that become the center of conflict for these resources; like in the Middle East that has the majority of oil resources worldwide (Everett *et al.*, 2012).

All these factors put economic pressure on energy companies and countries to find alternatives for fossil fuels. The UN members in Paris agreed on a change towards renewable energy sources that emit only a small amount of greenhouse gases and that can solve problems in areas that suffer from energy poverty, most of all several parts of Africa (Everett *et al.*, 2012, United Nations [online], 2016). The question is: How can the shift to renewable energy sources be implemented?

## 1.1 Problem background

Renewable energy sources are defined as energy forms that are not depleted when they are used (Oxford Dictionaries [online], 2016, 1). There are many of these renewable energy sources on the planet and they have the potential to provide much (much) more than the human energy consumption is today. Most popular is energy from wind, solar, hydro, geo thermal and biomass (Clean Technica [online], 2016).

In spite of their huge potential, only hydro, biofuels and waste are used on a large global scale; and it can be argued that some forms of waste are not completely renewable, because parts of it are lost during the process (Everett *et al.*, 2012; IEA, 2015). Even if these are also considered to be renewable, only 13.4 % of global primary energy supply in 2013 came from renewable energy sources (IEA, 2015, 6). 4.8 % came from nuclear, which can even be seen as almost renewable, but that comes with huge risks for catastrophes (Everett *et al.*, 2012; IEA, 2015, 6). The share of the fossil fuels oil, coal and natural gas, however, was 81%, which illustrates a certain dependence on these sources even today (IEA, 2015, 6). Several countries of the world have reacted to this and try to use more renewable energy sources, despite the fact that the price for oil is constantly falling (Cruz, 2007; Frankfurt School [online], 2016). The need for renewable energy solutions is therefore, big.

For instance, the European Union set the goal of 27% share of renewable sources in its energy consumption until 2030 (EU Commission Energy [online], 2016). In 2013, this has only been around 12% (EU Commission Statistics [online], 2016). This sounds quite close, but changes in energy supplies are long-term projects and need much time for implementation. Some sources are highly supported by both the European Commission and some member states. Following the Renewable Energy Progress Report from 2015 by the EU Commission, the main sources of renewable electricity generation in 2013, for instance, have been hydro (43%), wind (28%), solar (10%) and solid biomass (10%) (EU Commission, 2015, 7). The development of wind and solar has been rapid in recent years, but it was not as efficient and flexible as hydro, especially when it comes to energy storage (EU Commission, 2015). Hydro power plants are usually located in water resources onshore. What is not that common is hydro power from offshore resources: the oceans. Here, the resource is called Ocean Wave Energy (Cruz, 2007). Why is this energy not used that much yet? (Everett *et al.*, 2012)

A European country that focused vastly on the development of wave energy from the beginning is Scotland. Here, the first commercially grid connected wave power plant was operating from 2010 to 2014 (Alternativeenergysourcesinfo [online], 2016). Several other countries, most of all Scandinavian countries like Sweden, are also working on the development of wave power (Nordicgreen [online], 2016).

## 1.2 Problem

*"There is one major resource that has remained untapped until now: wave energy. Its potential has been recognised for long, and mostly associated with a destructive nature. No solution has yet been found to harness it. Or has it?"* (Cruz, 2007, 1)

Primary renewable energy sources are needed to ensure the future of the supply and an ever growing demand for energy. This process must be considerably supported by governments and organizations around the globe. Wind and solar energy are already being used on a progressive scale and numerous projects are on the way. Ocean Wave Power, be it on the water surface or in depths as tidal, represents a huge potential into the renewables portfolio (Carbon Trust, 2006). However, seldom it is commercially grid connected as it is seen in the present.

This is even the case in Scotland which is considered to be one of the leading wave power countries and Sweden which is one of the top oriented renewable energy countries (EU Commission, 2015; ICOE [online], 2016; Swedish Institute [online], 2016). According to EMEC's latest data from December 2015, the countries of Scotland and Sweden do not have commercially developed projects that connect to the power grids (EMEC [online], 2016, 3). However, there are several Scottish and Swedish companies that focus on the development of wave power technology. These companies are focused on a vast array of technological projects that are still in development. As mentioned at the beginning, one of these projects was the LIMPET in Scotland which operated connected to the grid for a few years. Most other wave developing projects are only prototypes in different testing phases so far (EMEC [Online], 2016, 3).

Beginning in late 20$^{th}$ century, wave power has seen several significant strategic achievements with some full-scale models being tested, but with still several contending commercial approaches (Cruz, 2007). Hence, the problem herein identified, is to understand why and assess how these wave developer businesses cannot move from testing to actually operate connected to the grid. There is academic literature in the fields of engineering and economics about the problem. Cruz (2007) shows that there are clear technical solutions to harness wave energy from an engineering point of view. Different potential approaches do exist, as can be seen in ***appendix 1***. In economics, Wee *et al.* (2012) point out that wave power could theoretically be used like other renewable energy sources in the energy supply chain. However, in Everett *et al.* (2012) it does almost not exist as a sustainable energy source. While technological and economic solutions already exist, a vacuum has been identified in literature about business strategy and organization for wave power (Blanchard, 2010; Personal messages[1]; Porter 2004a, b). There are many potential theoretical business concepts that could

[1] (Arne Vögler, personal message, 2016-03-02; 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre

help to address this vacuum, but none that applies directly in wave energy. Therefore, there is a need to do research on the business perspective connected to the problem that the wave energy sector is facing in both Scotland and Sweden. Porter (2004a, b), Blanchard (2010) and Hall & Rosenberg (2010) are used in this paper in combination with different methods to collect empirical data; primarily case studies on wave developing businesses in Scotland and Sweden.

## 1.3 Aim and delimitations

The aim of this master thesis is to explore enabling factors to make Ocean Wave Power a commercially competitive renewable energy source in Scotland and Sweden. This exploration shall be guided by the following three research questions:

- *RQ1. How* is the wave power supply chain organized in Scotland and Sweden?
- *RQ2. Why* is wave power not competitive in Scotland and Sweden so far?
- *RQ3. How* can wave power become a competitive renewable energy source in Scotland and Sweden?

The focus of this paper lays with the countries of Scotland and Sweden due to several reasons. First, these two countries have been chosen due to the advanced and rich programs that have been or are currently under development. Several companies, identified through this study, have developed frontier breaking and technological design portfolios. Second, the geographical constraint and the prompt responses received from companies in these two countries were determinant factors, hence the deliberate choice to pursue. Third, both Sweden and Scotland are world recognized for their comprehensive renewable energy market mindset, but also the stress put into projects that keep the environment in high consideration. It is important to state here that, as this is a study based on cases from the field, it cannot and will not make attempts to generalize any findings and/or scenarios nor create traits of transferability.

It is important to state here that although mentioned in the paper, environmental and social aspects will not be the main focus. Therefore, our scope is around the economic aspect of the wave power implementation. This scope will focus on the strategic and technological framework while exploring constraints around them.

After the presentation of the problem, aim and research questions, the following chapter 2 contains the theories that have been chosen to address them and why the concepts contribute to the purpose of this paper.

---

Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01).

# 2 Theoretical perspective and literature review

This chapter introduces the chosen theories to address the problem, aim and research questions of this study. First, the reasons for chosing the concepts of Competitive Strategy, Supply Chain Management and Economics of Innovation and Technology are explained. Second, each concept and the important elements for the topic of this thesis are presented. A synthesis will close the chapter and lead the reader to the next chapter, where the appropriate methods will be described.

The starting point for the theoretical perspective used in this paper was the problem that Ocean Wave Power is not yet commercially competitive in both focus-countries and that there are no studies – as far as we know – that have explained why. The aim of this study is to find enabling factors to change this situation. Therefore, theories were needed that were useful to guide the exploration for possible solutions to this problem. Even though wave power was quite present in engineering and economic literature, there was a vacuum in business literature identified. The research questions, however, pointed to certain existing theoretical business concepts that could help to fill this gap. First of all, the goal of this research project asked for business administration theories that could shine a light on the commercialzation and competitiveness of an innovation. For this endeavour, Porter's theory on Competitive Strategy is a very relevant approach that helps to analyze situations businesses face in order to become competitive. A central element to explore the competitive situation in a market is to use the SWOT analysis connected to Porter's work. This way, strengths, weaknesses, opportunities and threats can be identified that help to answer the two research questions *Why is wave power not competitive in Scotland and Sweden so far?* and *How can wave power become a competitive renewable energy source in Scotland and Sweden?*. For a complete picture of the competitive situation, however, Competitive Strategy Theory is not sufficient. As Porter puts it ''…the essence of formulating competitive strategy is relating a company to its environment'' (Porter, 2004b, 3). Further, a central characteristic of competition is that firms are mutually dependent, thus creating the need to react to other actors' actions in the market (Porter, 2004b, 88). This made clear that another theory was needed to add a bird's eye perspective to answer the two research question about competitiveness and to see where the SWOT elements were located in the market. A way to gain the bird's eye perspective in an industry and especially in the renewable energies is Supply Chain Management (Blanchard, 2010; Cecere, 2014; Dam-Jespersen & Skjott-Larssen, 2005; Ivanov & Sokolov, 2010; Haas *et al.,* 2011; Fouquet, 2013). This is also highly needed to answer the first research question *How is the wave power supply chain organized in Scotland and Sweden?* To understand the organization of a supply chain, it is essential to know what a supply chain is and how it can be managed. Wee *et al.* (2012) additionally refer to Porter's value chain approach that links all the stakeholders in the fulfillment of the customer's needs. They stress that the promotion of renewable energy is very much depending upon stakeholder's understanding that this energy source can be profitable and has its value. This is where Supply Chain Management can offer a better understanding. Therefore, Competitive Strategy and Supply Chain Management have not only a strong connection to the aim and research questions, but also to one another. Since the business field of renewable energy is to a huge extent connected to technology, however, another theory was needed to pay tribute to this specific field in order to answer the research questions. Economics of Technology and Innovation add this theoretical perspective by focussing on economic necessities for businesses with the intention of developing new technologies. Especially collaboration and infrastructure on an institutional, policy and legislative level; be it formal, normative or implicit, play a central role for the aim of this paper (Arora *et al.*, 2001; Fagerberg *et al.*, 2005; Hall & Rosenberg, 2010).

Before starting to study the unknown elements of this research project with help of the identified theories, it was important to have a look at what is already known in connection with the research topic in the three concepts. For this purpose, relevant sources have been systematically identified, located and analyzed. Although many books, scientific papers, reports and web pages have been considered that provided an overview about the wave energy market in general and specific to the two countries that are in focus in this paper, there was no material with clear statements to the aim and research questions that are studied in this thesis. The sources in the literature review were chosen with respect to their contribution to the design, conduct or interpretation of this project as presented in Chapter 1 and Chapter 2. A business approach to competitiveness of wave power as a potential source in the energy market in the three chosen theories has been identified as a main theoretical gap (Everett *et al.,* 2012; Robson, 2011).

The following sections further describe the theories of Competitive Strategy (***section 2.1***), Supply Chain Management (***section 2.2)*** and Economics of Innovation and Technology (***section 2.3).*** A theory synthesis (***section 2.4***) will close Chapter 2.

## 2.1 Competitive Strategy

‘*’Every firm competing in an industry has a competitive strategy, whether explicit or implicit*” (Porter, 2004b, xxi).

The importance of a strategy is based on the idea that it is a framework for the purpose of providing precise directions to the firm. Hence, a strategy is a set, pathway or conduit of decisions necessary to support organizational, operational and financial objectives for the specific firm (Dagnino, 2012). This strategy is a product of theoretical and prior planning but also can be achieved through the experience gained in operational activities that a firm/business has gone through (Porter, 2004b).

Furthermore, a firm needs to formulate a strategy that can implement to eventually determine whether it will survive and be successful in the marketplace or become extinct. The process of formulating this strategy is based on the premise that strategic management is structured through rational discipline but most importantly, on a rigorous market analysis in search for competitiveness (Chevalier-Roignant &Trigeorgis, 2011). Therefore, ‘’competitiveness is here taken to mean the possession of the capabilities needed for sustained economic growth in an internationally competitive selection environment, in which environment there are other (countries, clusters, or individual firms, depending upon the level of analysis) that have an equivalent but differentiated set of capabilities of their own’’ (Fagerberg *et al*., 2005, 544).

### 2.1.1 Competitive Strategy in Wave Power

The past three decades have seen intensive research and development as well as strategic improvements in the wave energy sector (Cruz, 2007, preface). However, wave power is yet to meet a maturity level to be considered competitive as an energy source. First of all, a consistent and comprehensive strategy is necessary to develop through the approach of technological and economic viability (Clément *et al.*, 2002). This comprehensive strategy has to do majorly with a structural change that is focused on technological innovations of various origins and forms. With its beginnings in the 1970’s, wave power is still considered an industry of emerging nature. Emerging industries are brand new or reformed activities that have been going through a process of structural changes and adaptations. Such transformations are characterized by strategic decision-making and technological innovations, shifts in costs structures and changes in consumer awareness, needs and behavior, but also new economic opportunities (Porter, 2004b, 215). These transformations are often a strong factor working against strategy formulation due to the fact that there are no rules of the game. Furthermore, common structural characteristics are technological uncertainty, strategic ambiguity, high initial cost, supply and grid networks, subsidies, etc. (*ibid.*).

On the other hand, the commercial status quo and outlook of wave power has to be considered, whose prospects have been a hotly discussed field (Thorpe, 1999). The reasons have been many, but they mainly focus on the underlying cause of strategic decision making and technological maturity (*ibid*.) However, the concept of commerciality refers to the ability a business entity has to buy and sell goods and services within a sound economic feasibility framework as well as to provide a clear income strategy that leads to profitability (Collin, 2006).

### 2.1.2 SWOT theoretical approach

SWOT analysis, as it is known today, can be considered one of the most respected and prevalent tools of strategic planning throughout numerous disciplines (Glaister and Falshaw, 1999). It is an acronym for Strengths, Weaknesses, Opportunities and Threats and is used in identifying an organization's core competencies, potential strengths and surrounding market environment, while using those to respond sector's threats and own weaknesses, exploit opportunities and strategically envision itself (Ayub *et al.*, 2013). Hence, it helps an organization, firm, or a market/industry in the process of strategic planning and decision-making. Another valuable aspect of this analysis is in problem identification and awareness within an organization. Through the process of implementing SWOT analysis, most organizations often are able to identify issues within themselves, especially when it comes to implementing intelligence gathering results and strategic implementing techniques, leading to better forecasting strategies (*ibid*.). Organizations are on a day-to-day competitive environment, thus creating the need for formulating effective strategic analysis and intelligence processes. SWOT analysis seems to give the added value of connecting an organization's market standing to its supply networks dynamics and eventual economics of the sector in which it operates (Ayub *et al.*, 2013).

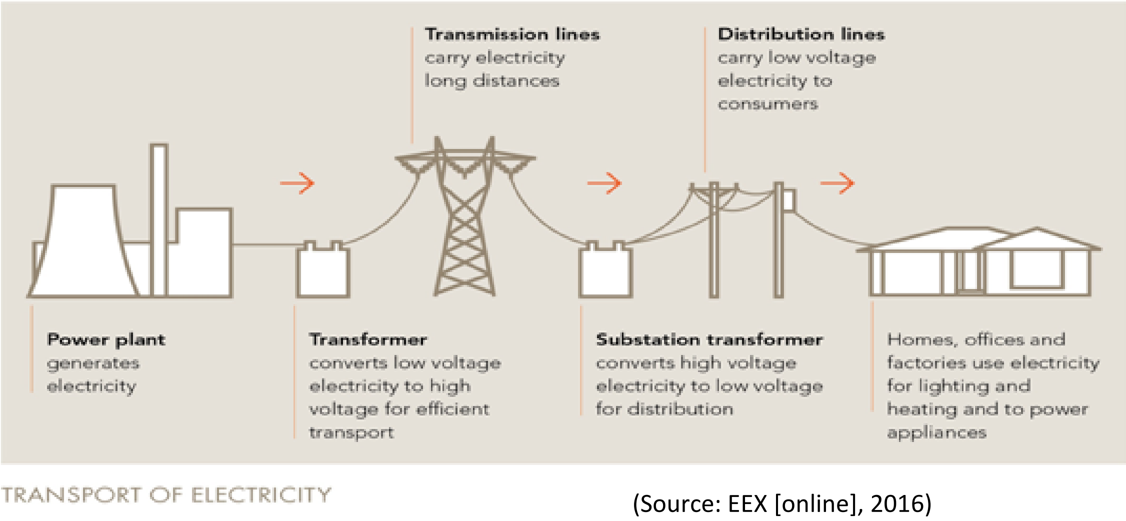
## 2.2 Supply Chain Management

*"A supply chain is only as strong as its weakest link."* (Lysons & Farrington, 2006, 92)

Supply Chain Management (**SCM**) is "the work of co-ordinating all the activities connected with supplying of finished goods" (Collin 2006, 404). This contains the development and implementation of efficient and economical supply chains (Ivanov & Sokolov, 2010). Additional to the understanding of competitive strategy related to Ocean Wave Power, it is therefore essential to have a look at two central influencing elements of competitive advantage in general: the supply and value chain (Porter, 2004a). While a supply chain is defined as "a sequence of events that cover a product's entire life cycle, from conception to consumption" (Blanchard, 2010, 3), a value chain is "the sequence of activities a company carries out as it designs, produces, markets, delivers, and supports its product or service, each of which is thought of as adding value" (Collin 2006, 438). To explore enabling factors to make Ocean Wave Power a competitive renewable energy source, it is thus an important aspect to look at both chains. However, different industries and companies have different supply as well as value chains. As a result, there is no supply or value chain strategy that can be used for all existing chains. This creates a need for companies and organizations to manage their individual chains (Blanchard, 2010). For the case of the wave developing industry, it is important to know general implications for the renewable energy supply (2.2.1) and its value chain (2.2.2).

### 2.2.1 The Energy Supply Chain

Fouquet (2013) stresses on that energy is not like every other commodity. It has certain unique features. One way to see this, is to have a look at the supply chain. There are basically two ways to look into it. First, there is the transportation chain of electricity as shown (***figure 2.1)***:

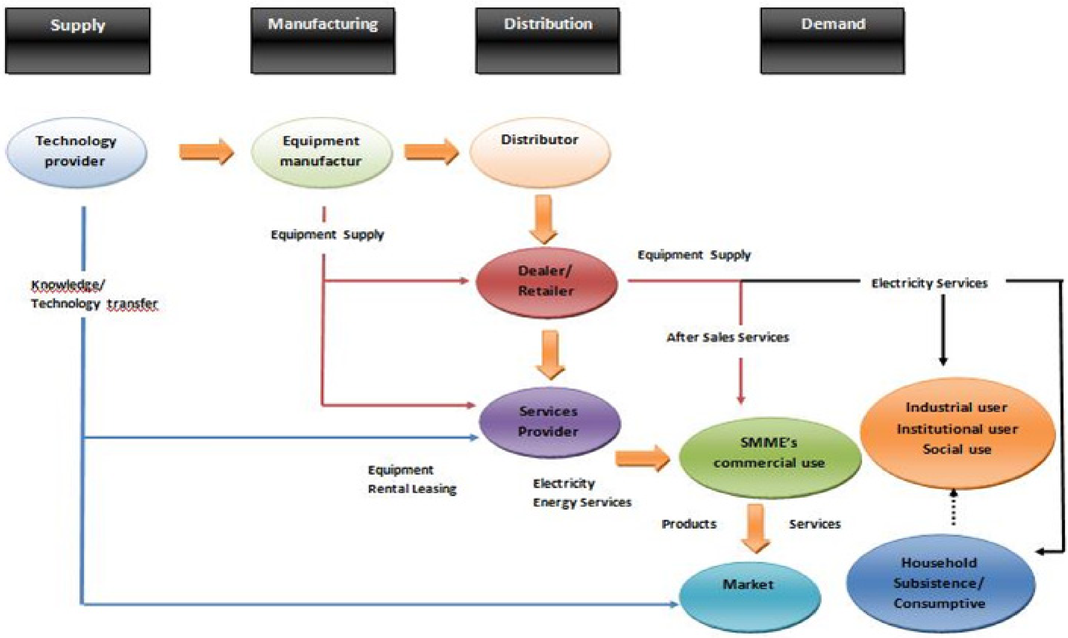



(Source: EEX [online], 2016)

**Figure 2.1** The Electricity Supply Chain

This chain in ***figure 2.1*** is the same for all energy sources, fossil fuels as well as renewable. A power plant generates electricity that needs to be converted to high voltage in a transformer. From here it needs to be send using transmission lines to a substation transformer that reconverts the electricity into low voltage. This way, the electricity can be provided to consumers through distribution lines.

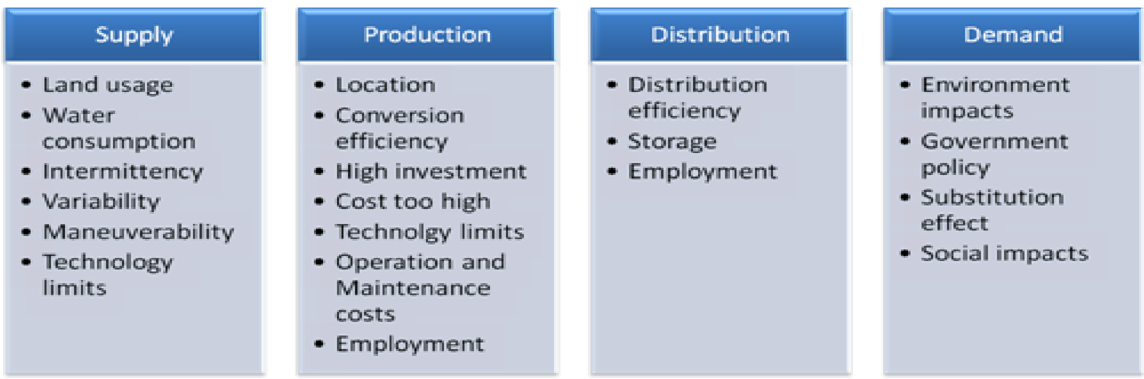
Second, the supply chain can be analyzed in more detail with a closer look at supply, manufacturing, distribution and demand (***figure 2.2)***:




(Source: Own illustration based on: Wee *et al.*, 2012, 5456)

**Figure 2.2** The Energy Supply Chain

Initially, as illustrated in ***figure 2.2***, there is the supplier. In most cases of renewable energies, these are the technology providers. Logically, in case of Ocean Wave Power, these are the wave developing companies. Wee *et al.* (2012) point out that key to success in these areas is technology which emphasizes the importance of this link in the chain. It provides the knowledge for all the other links. The technology providers and manufacturers then need to offer the equipment that is required by the distributors of electricity and energy services to supply the demand in the market (Wee *et al.,* 2012). All of these four areas have certain issues to consider as can be seen in ***figure 2.3***:



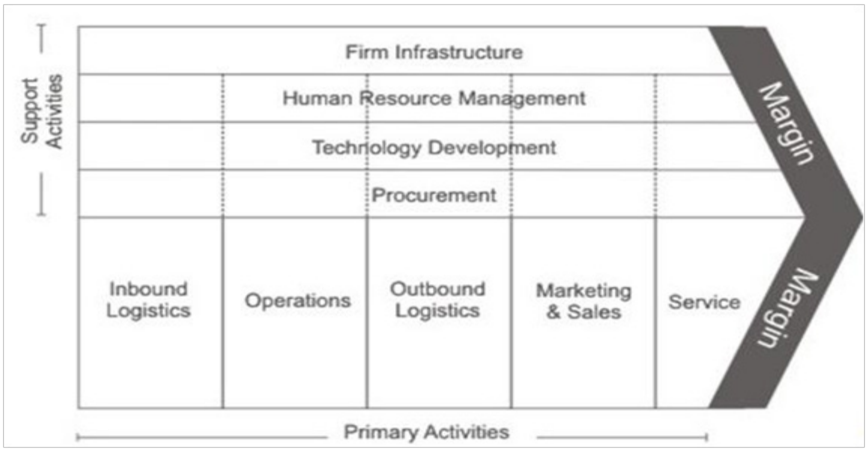

(Own illustration based on: Wee *et al.*, 2012, 5456)

**Figure 2.3** Concerns or renewable energy

***Figure 2.3*** shows that there are several potential weaknesses and strengths in all links of the chain that differ between the energy sources that are used. Therefore, these concerns are central elements for comparing the competitive advantages and disadvantages between different energy sources. Thus, it is important to analyze these factors to develop a successful competitive strategy for Ocean Wave Power.

2.2.2 The Energy Value Chain

Value chain analysis is further illustrated by Porter. He developed a generic diagram network which is illustrated in ***figure 2.4*** which makes the energy value chain much more comparable to other chains (Porter 2004a):




(Source: Porter 2004a, 46)

**Figure 2.4** Porter's Generic Value Chain

Porter distinguishes in ***figure 2.4*** between primary and support activities to analyze the value chain.

The primary activities are inbound logistics, operations, outbound logistics, marketing and sales and service. Inbound logistics consider suppliers and every activity that is connected to receiving, storing and disseminating inputs. These inputs are then transformed into outputs like products or services in the operations. In outbound logistics, every activity surrounding the output is aggregated. Marketing and sales lead to the contact with and information of the customer and service includes everything that needs to be considered after the purchase is conducted. Secondary activities are procurement, human resource management, technological development and infrastructure. In procurement, inputs are purchased; while human resource management manages personnel. Technological development is essential for the value that is created when inputs are transformed into outputs and infrastructure is important for the needs inside a company like finance or general management (Porter 2004a).

Wee *et al.* (2012) stress on that all stakeholders in the energy value chain are connected to serve the customer's needs. Therefore, it is of high importance for the renewable energy industry to show that renewable energy sources can be profitable and of high value. ***Figure 2.5*** shows crucial aspects that need to be considered:


(Own illustration based on: Wee *et al*, 2012, 5462)

**Figure 2.5** Stakeholders and Values of Renewable Supply Chains

In ***figure 2.5*** it can be seen that there are different stakeholders and value criteria that influence the competitiveness of a renewable energy source within the chain. All these different stakeholders and value factors need to be considered in the analysis of ocean wave power as well and can be possible factors to enable it to become competitive.

## 2.3 Economics of Innovation and Technology

*''Collective invention occurs when competing organizations share knowledge about the design and development of new technologies''* (Hall & Rosenberg, 2010, 575).

As can be seen in supply chain theory, the technology provider has a key role in the supply of energy (see ***figure 2.2***; Wee *et al.*, 2012). This is especially the case for wave power, because it is where the current development of the whole industry focuses at present; with wave harvesting devices that are still in development and not competitive in the market (Cruz, 2007).

Economics of Innovation and Technology (**EIT**) is the theoretical framework that explores the concept above. The ground base for EIT was initially brought forward in the early 1960's by the Austrian-American economist Joseph Schumpeter. He identified innovation and technological development as the critical dimension for economic change (Pol & Carroll, 2006). Over the years, Schumpeter's concept has been revisited and further enriched. Today, modern academic research points out that radical innovation remains unpredictable when it comes to commercial products and technical use. Technological and innovative decisions, on a major scale, vastly require comprehensive political processes, often involving professionals, interest groups and developers that aim at unique and independent self-interests. This is more important than balanced and careful estimation of costs, benefits and measurable risks. (Arora *et al.*, 2001; Fagerberg *et al.*, 2005; Hall & Rosenberg, 2010).

Furthermore, EIT reflects on the vital importance of networks of innovators. Networks can significantly contribute to the innovative capabilities of firms by (Arora *et al.*, 2001):

- Exposing them to novel sources of ideas
- Enabling fast access to resources
- Enhancing knowledge transfer

Hence, firms and developers are enabled to accomplish what they would not be able to, alone. This has led to increased patenting thus creating added intangible asset buildup. However, enhancing the flow of information among current participants and openness to new entrants is identified as a central challenge for networks. Consequently, network relations are identified on an individual basis, thus making corporate level relationship a need (Arora *et al.*, 2001). This has to be ensured in every step of the development process of a new technology. Two scales to monitor the development stages of technologies are: the technology readiness levels (**TRL**) and technology performance levels (**TPL**). According to an ICOE conference paper from 2012, there is a possible guideline for funding requirements coming out of the interdependence of TRL and TPL (Weber *et al.,* 2013). For more detailed information, see ***appendix 2***.

## 2.4 Synthesis of theoretical perspective

This chapter described the theoretical perspective of this paper. Due to the complexity of the problem, scope and aim studied herein, not a unified theoretical framework, but a variety of theoretical approaches is used to examine the research questions of this study. Competitive Strategy and SWOT analysis help to understand the two research questions about why wave power is not competitive yet and how it can become competitive in the future. Supply Chain Management adds a bird's eye perspective to this and was necessary to answer the research question about how the wave energy supply chain is organized. It became clear that not only the supply chain and the actors within the chain as well as concerns in renewable supply chain are essential, but also the value chain connected to it, as illustrated by Porter. To become competitive, the businesses in the wave energy sector need to create value for the different stakeholders involved in the whole process. To gain an understanding of the environment the businesses studied in this paper operate in, the knowledge about the value chain is essential. Eventually, Economics of Innovation and Technology add the perspective of the different actors in technology businesses and the effects that collaboration can have in this field. The three concepts have been identified as the key concepts in relation to the aim of this research paper.

The chosen conceptual framework needed certain methods to gather empirics that relate to the theories herein presented. These are the core of the following chapter 3.

# 3 Method

In this third chapter, the research design including the used methods to gather data about the problem, aim and research questions in connection with the theoretical perspectives of this study are further explained. It illustrates the different approaches to gather empirics from the three sources case studies (***section 3.1***), survey (***section 3.2***) and other qualitative information (***section 3.3***) to answer the research questions about *How is the wave power supply chain organized in Scotland and Sweden?, Why is wave power not competitive in Scotland and Sweden so far?* and *How can wave power become a competitive renewable energy source in Scotland and Sweden?* After the description of the different method approaches to collect data from the different sources, the collection of data is further described in ***section 3.4***. How the quality of the data is ensured and the data analysed is central element of ***section 3.5*** and ***section 3.6.*** Ethical considerations close this chapter.

To address the problem wave power businesses are facing and to follow the aim of exploring enabling factors to make Ocean Wave Power a commercially competitive renewable energy source, methods were needed that helped to gather empirical data to answer the research questions with regard to the three theoretical perspectives Competitive Strategy, Supply Chain Management and Economics of Innovation and Technology which were chosen in this paper. Thus, a first step was to choose a research design. Many reasons led to conduct this study in a multy strategy design. This was due to several potential benefits (Robson, 2011):

- *Triangulation* The combination of qualitative and quantitative data can enhance the validity of findings
- *Completeness* The combination of different approaches helps to gain a more complete pictue of the topic studies in this paper
- *Counterbalancing weaknesses and have stronger inferences* Limitations of each approach can be balanced and strengths of both approached used
- *Complex phenomena can be dealt with* The combination of approaches is especially useful in real world settings

These advantages of the multi-strategy design were the reasons for chosing such a design to study the problem of this paper. However, there are several multi-strategy designs to choose from. Since the aim of this study was to explore the phenomenon of wave power competitiveness, the sequential exploratory design has been used, because it exactly stresses on this. A first sequence of qualitative data collection and analysis is herein the priority. Yet, a second sequence with qualitative data collection and analysis follows, which makes this a muli-strategy approach (Robson, 2011). After the general research design was constructed, it had to be decided which forms of qualitative and quantitative data collection methods to use. The core of the qualitative data was decided to lie in case studies of the different businesses that are exactly trying to solve the problem in this paper. They are the actors that try to make wave power a competitive renewable energy source and are therefore important to be studied. However, to limit the subjectivity of these actors and to take account of the complexity of the topic, additional qualitative sources were needed that had the potential to enrich the empirical data with a broader perspective. For this purpose, governmental institutions and investors needed to be included in the thesis as well. They are the actors that need to be convinced to make an energy source commercial.

The second sequence, the collection of quantitative data, was conducted after having the first qualitative information to address the aim of this study. This was primarily conducted by an online survey that has been sent to a worldwide wave developer population, but also by asking the case companies about the quantitative data. To further enrich the picture of the complex problem, the survey also contained several questions about the qualitative information that had been collected from the case companies and additional sources to compare the Scottish and Swedish market to a worldwide population of competitors (Merriam & Tisdell, 2015; Neuman 2009; Robson, 2011).

The following sections will further describe the specific sources and aspects of this method approach.

## 3.1 Case studies

As result of the needs of this study, case studies have been chosen as primary source of qualitative data, but also as a source of quantitative data in the second sequence of the sequential exploratory approach. This is due to the fact that this research project touches on a new research area, as wave power is; where the existing theories presented, however useful, lack specificity applicable to the wave power industry in Scotland and Sweden. This gap has been the theoretical endeavor in this study (Eisenhardt, 1989). Furthermore, Yin (2014) suggests that case studies are especially useful when questions of *How/Why* are being addressed about a contemporary set of events over which the investigator/s has/have little control over. Furthermore, the qualitative approach helps in investigating a current phenomenon within a real life context. This is especially the case when the boundaries between the phenomenon and context are not clear (Yin, 2014). All these reasons lead to the focus on case studies as primary empirical source for qualitative data in the first sequence of this study that led to the identification of useful quantitative data for the second sequence.

In qualitative research, a case is the study where a situation is depicted, a person or organization that portray the interest of the study (Robson, 2011, 135). The case study can be an illustration of field experience on a specific topic and business entity. In the qualitative approach, the study of cases represents a pre chosen strategy to conduct research, develop knowledge on a recurring and modern phenomenon. As Robson (2011) suggests, this research involves an investigation on empirical grounds of this phenomenon within its present context by using multiple sources of evidence. This can be done through a predesigned strategy that involves either direct interviews or a participation/observation approach, or both. This strategy is interested on research and collection of evidence using multiple methods. A general guideline of the main sources of evidence, as presented further down, has been used to study the cases. Crucial points of study are (Yin, 2014):

- Qualitative semi structured interviews
- Electronic mass media communications
- Formal studies and administrative documents
- Formal studies from institutions
- Proposals and progress reports
- Publicly used files

The most important defining characterizing quality herein is the focus on several short particularly selected cases in both countries of the study. These cases represent majorly a qualitative approach with very minor quantitative components. Furthermore, the case study approach in this paper has matured as the logical research strategy due to the initial exploratory design of the wave power sector and surrounding complexities in the countries of Scotland and Sweden. Therefore, good faith, honest intentions, the academic infrastructure and professional exploration have been tools to demonstrate the worthiness of the findings (Yin, 2014).

### 3.1.1 Qualitative interviewing

The study of the cases in this paper has been enriched through the numerous face-to-face interviews conducted on video conference settings or individual basis. These interviews have been of qualitative nature in which special focus has been given to the nature and specific interviewee. Furthermore, a specific semi structured interview guideline was used to control and contain the quality and orientation of the conversation (***see appendix 3***). Starting with a general conversation, further questions were developed to collect information on the wave sector segment in which the specific interviewee is involved. Industrial, organizational and strategic choices, supply chain perception and suggestions in regards, as well as future planning into technological development were also part of the interview. Furthermore, governmental entities, especially the Energy and Climate Change Directorate in Scotland and Energimyndigheten in Sweden have been interviewed by email interview-questionnaires. These institutions have been included in the interviewing process due to the fact that they are considered important legislative and supportive actors in new technological markets such as the wave power sector. In these procedures, certain rules of thumb have been considered, please refer to section 3.4.

### 3.1.2 Thematic coding approach

To be able to process the qualitative data that was needed to be collected in this study, a clear analytical structure was needed to be able to use the empirical data in the analysis chapter to answer the research questions. The factors that needed to be explored to address the aim of this study fit into the approach of thematic coding, as illustrated in ***table 3.1***; which is a generic approach to the exploration of qualitative data (Robson, 2011).

**Table 3.1** Phases of Thematic Coding

| Phases of Thematic Coding Data Analysis | |
|---|---|
| *PHASES* | *PROCESS* |
| *1* | Familiarize and thorough knowledge of data. Transcription and reading. Note down preliminary themes. *(See section 5, the empirical study/results)* |
| *2* | Generation on initial codes through interaction with the data. Creation of similarity in extraction of codes. *(See section 5, the empirical study/results)* |
| *3* | Recognize & categorize themes. Gathering all data relevant to potential identified themes. Revise the initial codes and/or themes. *(See section 5, the empirical study/results)* |
| *4* | Develop and deploy a thematic map of the analysis. *(See section 6, analysis and discussion)* |
| *5* | Deployment, interpretation and comparison. Different aspect of data and how they play into the theoretical framework. Describe and summarize to demonstrate the quality of the analysis. *(See section 6, analysis and discussion)* |

(Source: Own illustration based on Robson. 2011. 476)

The analytical approach presented in ***table 3.1*** is a method of study in which the actual phenomenon under study is experienced. Following the five phases allowed this research project to to gather quantitative empirical data in chapter 5 that could be processed to be used to answer the research questions in the analysis in chapter 6.

According to Robson (2011), the present actuality of participants is recorded and it can be used to construct and examine the ways in which strategies and events have created a certain reality within the sector. Qualitative studies involve some form of coding at the early stages of data analysis, because it allows the researcher to define what the data being analyzed are about (Gibbs, 2007, 38). Once data is collected, coding allows for identifying as representing something of potential interest and labeled to the same theoretical ideas. As the process of data collection goes ahead, new chunks of data are linked to already established codes, thus creating a structural analysis of themes (Robson, 2011, 474). Codes and themes occurring in the data can be determined inductively from reviewing the data and/or from relevance to research questions, previous research or theoretical considerations.

### 3.1.3 Quantitative data analysis

In the second sequence of the sequential exploratory approach, there was little quantitative data involved. It is essential to understand how quantitative data can be summarized and presented. Robson (2011) stresses on that this is not only valid for fixed and multi-strategy designs, but also for studies like this in which rather flexible designs are used and qualitative data is the main source. Small amounts of quantative data do not demand statistical tests, though. Simple techniques are all that is needed; statistical software is not necessary. However, to limit the potential for error in very simple "by hand" calculations or by using an electronic calculator, the software Minitab 17 (Minitab [online], 2016) has been used to analyze the quantitative data (Robson, 2011). Descriptive statistics have been conducted by determining the minimum, maximum, mean and range for cost per kWh, device lifespan, initial investment, number of employees and years of studying wave power with the help of minitab. The results can be seen in ***table 5.4*** in chapter 5.

The approach guided the analysis of the qualitative data. The next section will describe the central element of the second empirical source, the survey.

## 3.2 Survey

Just like interviews, questionnaires are considered to be a widely resourceful method in social research in gathering data (Robson, 2011, 235). A questionnaire survey is the secondary instrumental method used for data gathering in this paper. In academics, surveys are tools to seek information, data and findings regarding a phenomenon in the world today (Robson, 2011, 236). Furthermore, the survey has been used as part of a non-experimental fixed design, with sequential exploratory and descriptive intentions. This is also due to the fact that the questions have been designed with the confidence that they will induct the same meaning to all respondents, thus minimizing subjective bias (Robson, 2011).

### 3.2.1 Choice of the Survey Method

A structured questionnaire has been sent out to wave developers worldwide. The tool that has been used to create the survey, collect and analyze the data is Netigate (Netigate [online], 2016). The anonymous survey has been conducted by sending it to the wave developer population via email. Like in the semi-structured interviews, certain rules by Robson (2011) have been respected; such as the avoidance of long, multiple barreled, leading or biased questions, as well as avoidance of jargon. Fixed choice questions and development/fill in answers were offered to be used. Both the interviews and the questionnaire have quantitative elements embedded in them in order to build a better understanding of the sector and involvement of wave developers. Mainly the quantitative data gathering was focused around the following subjects:

- Price/cost per kWh and durability/lifespan of deployed devices to create a comparative scale towards other renewables and conventional energy sources.

- Numbers of employees and field experiences in years to assess experience and exposure to the specific market complexity.

- Initial investment in order to assess the importance of the financial input.

### 3.2.2 Analysis of Survey Data

The analysis of the survey data, like the data from the case studies, had two elements. First, there were mainly questions of qualitative nature in it. These were analyzed using the same thematic coding process as in the qualitative case study in order to see how far the developers in Scotland and Sweden differ from their global competitors. However, following the sequential exploratory approach, the survey has primarily been designed to deliver quantitative data in the second sequence part of the study to have a comparable set of data to the quantitative data of our case studies. The descriptive statistics have been conducted like in the case studies using minitab. The results can be seen in ***table 5.5*** in chapter 5.

## 3.3 Other qualitative information

While case studies and the questionnaire survey represent the two most important (in that order) empirical data gathering means, the research has been further enriched with a third method approach. During literature review, it became clear that there was a necessity to consider the perspective of the investors and financial advisors in the market. The purpose of this was to better assess what these actors consider and analyze in the emerging energy markets and more specifically, renewables and wave power. Also known as the Big Four, PricewaterhouseCoopers, Deloitte, Ernst & Young and Klynveld Main Goerdeler and Peat Marwick International (**KPMG**) are professional network services in accounting, consulting and financial advising (Christodoulou, 2011). These companies were contacted via official channels with emails, but only KPMG conducted an interview (KPMG [online], 2016).

Furthermore, the Swedish Energy Agency (Energimyndigheten) and the Scottish Energy Ministry were also contacted via official channels. The purpose of this process was to get a better understanding of the official governmental standing for each of the countries under study, market overview and receive information on wave development projects and actors in these respective markets (Energimyndigheten [online], 2016;The Scottish Government [online], 2016).

## 3.4 Collection of Data

As a result of the sequential exploratory design of this study, this research paper uses different types of data collection, as described in the first sections of this chapter.

As part of the qualitative research, multiple case study companies, business experts and researchers have been interviewed using semi-structured face-to face as well as email interviews. The basis for the interviews was a guide that helped to cover all topics that needed to be addressed, but modification and additional questions have been used in the development of the conversation. The face-to-face interviews have been conducted in either personal or video conference meetings. Further, governmental entities, especially the Energy and Climate Change Directorate in Scotland and Energimyndigheten in Sweden, have been interviewed by email interview-questionnaires. This has been conducted, because in a new technology like wave power, they are the ones who drive the change as well. In these procedures certain rules of thumb have been considered. Robson (2011) points out that it is important for the interviewer to listen more and speak less. This enables the researcher to collect more data and influence the interviewee less. Further, the questions have to be very clear, straightforward without being threatening or leading too much. Simple yes or no questions have to be avoided. Finally, it is important to show the passion for the project and not to seem bored. In this research project, these guidelines have been respected (Robson, 2011).

For the quantitative study, the survey, a structured questionnaire has been sent out to 139 wave developers worldwide; which were all developers in the EMEC list that provided an email-address. The survey has been conducted by sending it to the wave developer population via email. Like in the semi-structured interviews, certain rules by Robson (2011) have been respected; such as the avoidance of long, multiple barreled, leading or biased questions. Jargon has been avoided as well (Robson, 2011).

The wave power sector has been chosen due to the fact that a technology that can help to harness the energy of the oceans of the world has a high potential to solve issues connected to the energy crisis in a sustainable way. It is very much supported within the European Union (**EU**), especially in Scotland and Sweden, which are the countries in focus in the qualitative part of the study (EMEC [online], 2016, 1).

## 3.5 Ensuring quality

"*Because a research design is supposed to represent a logical set of statements, you also can judge the quality of any given design according to certain logical tests*." (Yin, 2014, 45)

According to Yin, there are four tests that can be used to ensure the quality in empirical social research (Yin, 2014, 46):

- Construct validity
- Internal validity
- External validity
- Reliability

*Construct validity* means that the measures that are used are the right choice for the concepts that are studied. This is difficult to establish in qualitative case study research, but can be strengthened by different means. First, the concepts in this study need to be clearly defined. Second, measures that can be used with the concepts need to be found. It is possible to increase construct validity further by using multiple sources of evidence, establishing a chain of evidence and by having the draft of the case study reviewed by key informants. This research paper used different sources of evidence like multiple case study companies, governmental data about the industry and a survey that integrated competitors to the case study companies to support the data. The use of the exploratory sequential design also helped to establish a chain of evidence. Most important to strengthen construct validity in this paper was to clearly connect the problem and aim of this study with the theoretical concepts, methods and empirics used to address them. Therefore, the connections have been explained at the beginning and end of each chapter (Yin, 2014).

Next elements are internal and external validity, which played no central role for this study. First, *internal validity* means that a study is "seeking to establish a causal relationship, whereby certain conditions are believed to lead to other conditions, as distinguished from spurious relationships" (Yin, 2014, 46). According to Yin (2014), this is only necessary to ensure in explanatory or causal studies, not in exploratory or descriptive studies like the sequential exploratory approach used in this paper. Second, *external validity* defines how much this research can be generalized, which is not the goal of this thesis (Yin, 2014).

Finally, there is *reliability*. This means that the study, for example the data collection, leads to the same results if conducted by other researchers. Reliability shall minimize errors and biases in this research paper. For this reason, the procedures have been documented in a protocol as well as database (Yin, 2014).

To further increase the quality of this paper, different data collection methods have been used to lower the weaknesses of each method. Face-to-face interviews have the advantage of dynamic interactions, but needed to be transcribed, send to the participants and demanded a lot of time. This method was not available in every case. Email interviews and online questionnaires are good means to reach an international population as it has been needed in this study. However, they are much less dynamic and can deliver less information than face-to-face interviews. In each method the aim of the study and the research questions have been integrated to make sure they were covered by data (Robson, 2011).

Neuman (2009) stresses on four obstacles to reliable field data:

- Misinformation
- Evasions
- Lies
- Fronts

Misinformation can occur when participants or researchers unintendedly provide false information due to uncertainty and complexity. Misinterpretation is also connected to this. Out of several reasons like confidentiality, information is not always revealed. Evasions are therefore elements that need to be considered in research. Closely connected are lies and fronts which can occur. These obstacles might happen in any social research and can affect the quality of it (Neuman, 2009).

A discussion of the quality ensurance of this paper is presented in ***section 6.4***.

## 3.6 Data analysis

During the process, collected data has been described and summarized. Social research, especially qualitative, is interpretive and subjective. This indicates that there is not only one way to analyze the data. To provide more structure to the analysis chapter, a framework analysis has been used in this study. This framework analysis means that the thematic coding approach and quantitative data collection, the empirics, have been in connection with the three theoretical concepts used in this paper to answer the three research questions. Although this could have been done by a bottom-up or inductive approach, a top-down or deductive reasoning has been used, starting with the theory and having a look at the empirical data from this perspective. The intention to analyze the data was to find enabling factors to strengthen the competitiveness of Ocean Wave Power; as defined in the theory chapter. For this purpose, different cases, both new approaches as well as older, not competitive projects from the past have been analyzed, to find both supporting factors as well as possible barriers. The information has been rather common for all participants, because the unique information about the technologies that have been used were not central to this paper (Neuman, 2009; Robson, 2011; Yin, 2014).

## 3.7 Ethics

Ethical and political considerations play a certain role in research. It is important to know how to treat participants not to cause too much stress, anxiety or other possible negative impacts. First step to ensure this is to make completely clear to the participants what kind of research they are involved in. Although ethics can be seen as situational relative and therefore depending on context, the rights of the participants have to be respected. No one is obliged to take part in research and informed consent can improve the relationship between researchers and participants. It also has the risk of lower participation rates. These aspects have been considered in this research and the character of this study has been made clear to all participants. Anonymity for the participants in both case study as well as survey has been offered. The participants have further been encouraged to ask clarifying questions if and when needed (Robson, 2011).

Up to this point, the problem, aim and research questions have been connected to the theoretical perspectives and methods used to address them. The next chapter will provide the empirical background for the different sources of empirical data, the cases, survey population and additional sources.

# 4 Background for the empirical study

The thesis has so far covered the problem in focus, the aim this research project has and connected the research questions to the theoretical perspectives and chosen methods to gather empirics to answer them. In this chapter, the background for the empirical study is presented. The background of the case study companies (**section 4.1)**, survey population (**section 4.2**) and additional sources (***section 4.3***) is essential to understand why theses sources where used. It also helps to understand the significance of these sources to address the research questions. Additionally, due to the strong connection of this topic to the technicalities of wave devices and different units, an appendix has been added that further explains the technical background for this study (***appendix 1***). Of special importance is the cost measurement Levelized Cost of Energy (**LCOE**), which is the net present value of the unit cost of electricity over the lifetime of a generating asset, device or plant. It is also further explained in ***appendix 1***.

To answer the question of *How is the wave power supply chain organized in Scotland and Sweden?,* it was not enough to study the wave developing businesses which are in focus in the case studies. Additional governmental sources in both Scotland and Sweden were needed to make sure to catch a holistic picture and not focus on one end of the supply and value chain only. The two other research questions *Why is wave power not competitive in Scotland and Sweden so far?* and *How can wave power become a competitive renewable energy source in Scotland and Sweden?* demanded different sources of evidence as well. To understand competitiveness of wave developers in Scotland and Sweden, it is not sufficient to talk to the developers only. The theoretical perspectives Competitive Strategy, Supply Chain Management and Economics of Innovation and Technology all need a broader picture in which several stakeholders and actors in the market are considered. It is not enough to look at the technology developers in Scotland and Sweden only. The most important other actors in the energy market considering the renewable energy supply chain are competitors, governmental bodies and investors. Competitors are also of high importance for the Competitive Strategy the wave developers in Scotland and Sweden are choosing. The biggest competitors for the businesses in the case studies are not the other developers in Scotland and Sweden only, but also other developers worldwide. This is why the global survey population was needed to gather data about competitors. Governmental bodies were essential to understand the different approaches within Scotland and Sweden, because they had holistic information about the different approaches in both countries. Finally, to become competitive, wave developers have to convince investors to provide capital. For this, the big advisory company KPMG has been interviewed; which provides advice to investors worldwide and in our two countries in focus. The following sections **4.1, 4.2** and **4.3** present the background of all the necessary actors to understand their significance for the empirical data **chapter 5**.

## 4.1 Case studies

The aim of this research paper was to explore enabling factors to make Ocean Wave Power a commercially competitive renewable energy source in Scotland and Sweden. The most important sources for this endeavour were the developing businesses that exactly try to make wave power competitive. Therefore, these developers were to be identified. Following the method approach of this thesis, case studies have been conducted about these companies, both considering available data like electronic mass media communications and interviews with employees, chief executive officers and researchers of this companies. The empirical background and available data guided the interviews (see ***appendix 3***) and thus directly influenced the empirical data and enabling factors explored in this paper. There were several cases studied in both Scotland and Sweden.

Scotland

The United Kingdom has long been seen as leading in the development of wave power. According to the European Commission database, the United Kingdom can be considered the world leader in wave power research with experimentations starting back in the 1970's. Several projects off the coast of Scotland have started and stalled due mainly to governmental funding cuts, rough seas and other natural conditions like salty waters that wear out equipment (EU Commission Eco [online], 2016). The conversation that leads to analyzing the competitiveness of wave power in Scotland, consequently the UK, has led many developers to sense the potential huge prize for grabs. According to the European Commission eco-innovation database, about 25% of the UK's energy demand could be potentially met through wave power. By some estimation, this figure is what actually is being covered by the coal-fired generators which would lead to lowering greenhouse emissions (*ibid.*). Consequently, if wave power becomes a viable energy source, it could affect other European markets and countries that can have geographical accessibility.

The companies studied herein are both developers who failed in the past (*Aquamarine Power*, *Pelamis Wave Converters* and *Wavegen Limited*) as well as new approaches in Scotland that try to learn from the past (*EMEC* and *WES).*

*Aquamarine Power* is the first former project based in Edinburgh that has been considered in this study. Even though its story begins in 2001 at the Queen's University in Belfast where Professor Trevor Whittaker's Research and Development team began to research flap-type wave power devices with the purpose of reducing the cost of energy, it was founded in 2005 and also operated at the EMEC's plant in the Orkney Islands (Aquamarinepower [online], 2016). Contrary to Pelamis, Aquamarine developed the Oyster wave power technology with the purpose of capturing energy found in near-shore waves (EMEC [online], 2016, 4). As further explained in ***appendix 1,*** the Aquamarine's Oyster concept is an oscillating wave surge converter. EMEC classifies it as buoyant, hinged flap attached to the seabed with depths varying 7-10 meters and up to 400-500 meters away from shore. When the company shut down its program and ceased trading in 2015, its latest device Oyster 800 was grid-connected since June 2012 at EMEC's Billia Croo test site (EMEC [online], 2016, 2).

*Pelamis Wave Converters* was formed in 1998 with the purpose to manufacture and operate wave energy converters (EMEC [online], 2016, 2). While based in Edinburgh, this company operated at the EMEC's wave test site at Billia Croo, northern Orkney Islands of Scotland. In this site, the company developed the P1, which became the world's first offshore wave power converter to successfully generate electricity into a national grid (*ibid*.). Through a series of cooperation projects with EMEC and ScottishPower Renewables, between 2004 and 2008, Pelamis deployed an ambitious strategic program structured through a series of weather states, each with progressively higher wave heights (EMEC [online], 2016, 3). Even though the company had designed ''a progressive management of risk for the technology and the ability to find and handle any unexpected technical issues'', in 2014 it went into administration with WES at present sole owner of its assets (BBC [online], 2016; EMEC [online], 2016, 1).

*Wavegen Limited* was founded in the early 1990's off the Isle of Islay, Scotland as a wave energy company and technological developer in the sector (Herald Scotland [online], 2001).

After almost a decade of research and development, the company became world known for its first wave energy device to go on a full commercial scale grid connected. The LIMPET was a shoreline device expected to produce power from an oscillating water column (Inverness Courier [online], 2011). However, it was only in late 2011 that the LIMPET was put into operations, before Voith Hydro Wavegen Limited, the new controlling company, closed down abruptly (Inverness Courier [online], 2013).

*EMEC* is a test and research center with a primary focus on wave and tidal power technological development based in the Orkney Islands, Scotland. This center is considered to be the first and only of its dimension and with purpose to provide support to developers both wave and tidal energy converters. Since its foundation in 2003, EMEC is seen as an institution that provides services in research, consultancy, meteorological, engineering and other standardization processes in correlation and function to the marine industry (EMEC [online], 2016, 1). EMEC was established by a grouping of public sector organizations and was publicly funded by the Scottish Government, Highlands and Islands Enterprise, The Carbon Trust, United Kingdom (**UK**) Government, Scottish Enterprise, the European Union and Orkney Islandss Council until 2011, when the center became financially self-sufficient due to itsactivities (EMEC [online], 2016, 2). Further on, in 2014 the Scottish government established *Wave Energy Scotland* with the purpose of being a leading technological development institution. Its objective aims to have, by 2025, at least one commercially viable wave power technology (*ibid.*).

Sweden

Sweden is the second wave power market under study in this paper. It is a very good country to develop renewable energy solutions. In 2013, it already hit its renewable energy goals. Following the European Union action plan to increase the share of renewable energy in the energy mix, it had a target of 49 % by 2020; by 2013 it already had 52.1 % (EU Commission, 2015). The country drew its conclusions from the oil crisis in the 1970's. Oil had a share of more than 75 % of its energy supplies in those years. Today, it is only 20 % and Sweden is further striving to more renewable sources (Swedish Institute [online], 2016). Further, it is a country which has expertise in hydropower. It has a very high share of hydro electricity production and wave power is closely connected to hydropower. Sweden has also a strong academic infrastructure which also dedicates considerable resources in renewable energies (STandUP for Energy [online], 2016). The reason for choosing Sweden is therefore that it is a huge contrast to Scotland. It neither has the pressure to develop renewable energy solutions to reach environmental goals by the EU, nor has it the perfect conditions for wave power plants. The country invests in the technology anyway and has different incentives for this than Scotland; most of all the opportunity to develop a technology that can be exported to other countries (Swedish Institute [online], 2016). This makes Sweden a fitting country for this research (The World Bank [online], 2016). The cases in focus were *OceanHarvesting, the project Offshore Väst/Ocean Energy Sweden, Seabased Industry AB* and *Waves4Power* (Ocean Energy Sweden [online], 2016; Ocean Harvesting [online], 2016; Offhore Väst [online], 2016; Seabased [online], 2016; Waves4Power [online], 2016, 1).

The first Swedish company that has been studied is *Ocean Harvesting* Technologies AB in Karlskrona. It has been founded in 2007 with the purpose to develop solutions for wave energy conversion. In contrast to the other three cases in Sweden, this company is providing technology to wave power device developers, not the complete device itself. The company also supports other developers in terms of cost, efficiency and power capture (Ocean Harvesting [online], 2016).

*Offshore Väst* is the arm of the SP Technical Research Institute of Sweden that has the goal to develop the offshore segment and to ensure that the industry, researchers and public authorities work together. The organization is owned by its members who are different companies, universities, public authorities and research institutions, but it is also funded by Vinnova, the Swedish Governmental Agency for Innovation Systems and West Götaland Regional Development Fund. The focus in the west of Sweden is basically due to the fact that this is where Sweden's offshore sector is the strongest. The main purpose of the organization is to strengthen the competitiveness of the Swedish offshore segment. The platform Ocean Energy Sweden has been especially created for the wave power sector to further support collaboration and commercialization of this technology (Offshore Väst [online], 2016, Ocean Energy Sweden [online], 2016).

*Seabased Industry AB* is a company that was founded in 2001 in the Ångström Laboratory at Uppsala University, Sweden. At the beginning, it had the purpose to be an innovation and patent holding company. This innovation focused from the beginning on ocean renewable energy. Over the years, the company's strategy changed. The present goal is to develop into a supplier of wave energy parks. Starting at the home market of Sweden, the company wants to reach a production level in series and with future strategy to target the world market (Seabased [online], 2016). Seabased is supported by Sweden's biggest energy company Vattenfall. This support increases the project's opportunities in the energy market (see ***appendix 2*** to get an idea about the technology).

*Waves4Power AB* is a company in Västra Frölunda that develops wave energy systems The idea to find ways to harvest wave energy started already in the 1970's and was further developed in the following decades (Waves4Power [online], 2016, 2). Between 2008 and 2010 the research finally resulted in a full scale ocean tested prototype called WaveEL-buoy. In the process of its development Waves4Power AB has been founded (Waves4Power [online], 2016, 2). The company is close to reach the goal of commercializing its wave power technology in 2016 and for this purpose it is building a wave power demonstration site in Norway which is produced in Sweden (Waves4Power [online], 2016, 1).

## 4.2 Wave Developers' Population

The wave developers' population in the survey represented competitors of the case study budinesses worldwide and were needed to get information about competing developers in other countries and quantitative data to see how competitive the Scottish and Swedish developers are on a global scale. The anonymous questionnaire survey had a focus population of 139 companies worldwide. This population, names, location and contact information has been appropriated from the European Marine Energy Centre in Scotland (EMEC [online], 2016, 3). These companies include wave developers, business managers and officers, researchers, device designers and engineers, which are fully or partially engaged in the process of building, deploying, harvesting, connecting segments through the supply network for wave in numerous areas of the world. The population represents the most comprehensive data list of businesses in the wave power sector worldwide.

## 4.3 External Wave Stakeholders

The source for additional qualitative data from governmental bodies and investors were the advisory company *KPMG*, *The Directorate of Energy and Climate Change* and *The Swedish*

*Energy Agency*. To understand the importance of these actors for this study, the background of each is further explained in this section.

*KPMG* is an international professional service company with Amsterdam, The Netherlands, as its home seat, but with a vast worldwide presence in the global markets (Christodoulou, 2011). The firm operates in audit, tax and advisory services, where the energy market in general represents an important feat in their portfolio with a special interest in the global renewables market. Their services encompass competitive program transformations, supply chain strategy and data analysis (KPMG [online], 2016). Furthermore, the company contributes to the energy markets through operational optimization with technology as a major impact factor and advising break through strategies and business models (*ibid.).*

*The Directorate of Energy and Climate Change* is a division within the Energy Ministry in the Scottish Government with the mission of increasing sustainable economic growth. The Directorate has been commissioned to work the transition towards a low carbon economy for Scotland (The Scottish Government [online], 2016). Similar to its Swedish counterpart, the Directorate ranges its responsibilities in sustainable energy, reduce carbon emissions, support clean and efficient energy programs / projects in its aspiring renewable program (*ibid.).*

*The Swedish Energy Agency*, Energimyndigheten in Swedish, is an institution under direct supervision of the Swedish Government and a subordinate to the Ministry of the Environment and Energy. With its slogan ‘’ …working for a sustainable energy system, combining ecological sustainability, competitiveness and security of supply’’, the agency is a leading institution in spreading knowledge towards energy efficiency and awareness (Energimyndigheten [online], 2016). Through its governmental directives, the agency finances projects, research and designs for renewable energy technologies and supports energy cleantech commercialization *(ibid.).*

All three empirical sources and their backgrounds resulted from the problem, aim, research questions, theoretical and method approaches of this thesis. These backgrounds were essential to understand the significance of the empirical results, which are presented in chapter 4.

# 5 The empirical study/results

The empirical data gathered in this study has been collected with the purpose to address the aim to explore enabling factors to make Ocean Wave Power a competitive renewable energy source in Scotland and Sweden. Guided by the three theoretical concepts, the method approach and the empirical backgrounds of the different sources in focus, the interview guidance was designed to both have the theories and research questions in mind. This way, the collected data helped to answer *How is the wave power supply chain organized in Scotland and Sweden? Why* is wave power not competitive in Scotland and Sweden so far? and How can wave power become a competitive renewable energy source in Scotland and Sweden?

The following sections present the results from the case studies (***section 5.1***), the survey (***section 5.2***) and additional sources (**section 5.3**) following the thematic coding approach for the qualitative data and the simple descriptive statistics in minitab for the quantitative data. The qualitative results represent phases 1, 2, and 3 of the thematic coding approach. Phase 4, the development and deployment of a thematic map of analysis, and 5, the deployment, interpretation and comparison of the different aspects of the data and how it plays into the theoretical framework, are logically connected to chapter 6 and presented there.

In *phase 1*, the interviews were transcribed and read. This way, thorough knowledge of the data was established and first themes noted; which were connected to the three theoretical perspectives in this paper, because the interview guidance was designed based on the theories, aim and research questions. In *Phase 2* initial codes have been generated through interaction with the data and similarities in the extraction of codes have been created. These codes were the factors that influence the supply chain and competititveness of wave energy, because the survey and interviews were designed to address the research aim. Finally, in *phase 3*, themes have been further recognized and categorized. Additionally, all data relevant to potential identified themes have been gathered and the initial codes and themes revised. This procedure led to the factors herein presented by the different empirical sources, following the empirical background from chapter, which was also essential to conduct the qualitative and quantitative data collection. ***Table 5.1*** provides an overview about the different empirical sources:

**Table 5.1** The Empirical Study

| Empirical source | Country | Name | Represented case/source |
|---|---|---|---|
| Semi-structured interview | Scotland | Arne Voegler | Aquamarine, Pelamis, Wavegen |
| Semi-structured interview | Scotland | Jonathan Hodges | Wave Energy Scotland |
| Semi-structured interview | Scotland | Joe Thompson | EMEC |
| Semi-structured interview | Sweden | Mats Leijon | Seabased |
| Semi-structured interview | Sweden | Mikael Sidenmark | Ocean Harvesting |
| Semi-structured interview | Sweden | Pierre Ingmarsson | Offshore Väst/Ocean Energy Sweden |
| Semi-structured interview | Sweden | Ulf Lindelöf | Waves 4 Power |
| Semi-structured interview | Sweden | Kenneth Sörensen | KPMG |
| Mail interview | Scotland | Julie Steel | Energy and Climate Change Directorate |
| Mail interview | Sweden | Maria Olsson | Energimyndigheten |
| Survey | Global | Anonymous | Wave Developer Population |

(Source: Own illustration)

***Table 5.1*** shows the different interviewees of the case studies, survey and additional empirics; the country they represent, the contact at the case study companies, KPMG and the governmental bodies as well as the survey population.

## 5.1 Case studies

Following the sequential exploratory approach, the collection of quantitative data through case studies, especially through semi-strucured interviews, was the first sequence of this study. The thematic coding approach to utilize the empirical results following the first three phases described in the introduction of chapter 5 resulted in three themes:

1. Strategic factors for the wave power industry
2. Supply Chain factors for wave power
3. Innovative & Technological factors

That these themes connect the aim of this study, to find enabling fators, with the three theoretical approaches Competitive Strategy, Supply Chain Management and Economics of Innovation and Technology is no coincidence, but a logical result of the research design and the interview guidance that was influenced by the research approach.

***Table 5.2*** illustrates the data gathered through the thematic coding approach with the case studies in both Scotland and Sweden. The empirical background of each case significantly influenced the interviews and both together led to the *30 enabling factors* after phase 1-3 of the thematic coding approach. These factors have been identified to hinder or to have the potential to promote the businesses in the industry towards competitiveness and are strong indicators towards a commercial future. Each factor is further described below in connection to the findings associated to each country.

**Table 5.2** Enabling Factors in Scotland and Sweden

| WAVE POWER INDUSTRY: SCOTLAND & SWEDEN | | | | | | | |
|---|---|---|---|---|---|---|---|
| | SCOTLAND | | | | SWEDEN | | |
| FACTORS | Strategic | Supply Chain | Innovative & Technological | | Strategic | Supply Chain | Innovative & Technological |
| Affordability of Technology | X | | X | | X | | X |
| Chain Network & Facilities | X | X | X | | X | X | X |
| Challenges with Technology | X | | X | | X | | X |
| Collaboration | X | | X | | X | | X |
| Communication/Education | X | | | | X | | |
| Controllability of the device | | | X | | | | X |
| Data Availability | X | | X | | X | | X |
| Device Performance | | | X | | | | X |
| Device Survivability | | | X | | | | X |
| Environmental Activism | | | X | | | | |
| European Union | X | X | | | | | |
| Field Experience | | | X | | | | X |
| Financing | X | | X | | X | | |
| Fossil Fuels - Market Competition | X | | | | X | | |
| Institutional Infrastructure | X | | | | X | | |
| Investment & Risk | X | | X | | | | X |
| National Government Policies | X | | | | | | |
| Natural Geo-Physics Conditions | | X | X | | | X | X |
| Nuclear - Market Competition | X | | | | X | | |
| Renewables- Market Competition | | | | | X | | |
| Scale of Devices | X | | | | X | | |
| Scottish Market Approach | X | | | | | | |
| Sector Specificity | X | X | | | X | X | |
| Source Availablity | X | | X | | X | | X |
| Stage Focus | X | | | | X | | |
| Stakeholders' Perspective | X | | | | X | | |
| Swedish Market Approach | | | | | X | | |
| Systems Thinking | | | | | X | | |
| Trust | X | | | | X | | |
| Undeliverable Expectations | | | X | | | | X |

(Source: Own illustration)

The factors presented in ***table 5.2*** can be applicable to all three themes in different stages and significance throughout the process. However, it is imperative to recognize that the (X's) in the table represent the relationship in a level of crucial/immediate importance and relevance. This means that the factor has been specifically and repeatedly (by several sources) mentioned in the corresponding theme and is therefore interpreted as an important factor within that theme. Since these themes are strongly connected to the theoretical perspectives of this study, this is important for the connection of theories and empirical results in the analysis chapter 6. The factors are essential to be able to answer the research questions in this paper and are the main contribution to the field of business administration.

**Affordability of Technology** is herein used to mean the total expenditures (initial investments, maintenance cost etc.) in connection with the LCOE. This is associated with the technological process from design to deployment. It illustrates the timeframe to develop technology, the funding process as well as building a system of trust values and interrelationship with other stakeholders. Scotland has shown former projects (see Pelamis and Aquamarine) failing due to the affordability of the technological scale. While these were precious experiences, they were also quite expensive as well as created an aura of skepticism around the industry. Sweden on the other hand has shown a more conservative approach historically speaking. Developers have deployed their projects in a more controlled operational setting while testing on small scale devices.

**Chain Network & Facilities** represents the supply structure for wave throughout the board. In both countries, results have shown that it is a crucial factor for all three themes. From device designing, transportation and testing plants, to real sea conditions within facility stimulation to grid connections and power production, the network is the physical infrastructure of the whole sector. Scotland's EMEC testing plants are a facilitation for developers that necessitate to test their concepts in controlled and real conditions sites. Sweden does not have a testing facility such as EMEC, although there are small testing facilities present. The case companies operate their testing phases through private contractors or other offshore partners.

**Challenge with Technology** is meant to understand the engineering process of R&D as well as the operational maintenance, adaptations due to sea conditions and historical patterns. There are a few hundred device concepts today in the world that come with a series of basic-to-severe challenges. While at EMEC, the vast majority of these devices is tested through different projects, Sweden has seen an undeliberate focus on one-to-two type devices.

**Collaboration** has come across as one of the factors to share and exchange valuable information between developers, research institutes and network players towards a common or individual product. The concept is meant as either pro bono or pro rata in a sector where IP is highly valuable and one of the few tangible assets. In this regard, Scotland is enriched by the facilities and research through EMEC and WES which acts as a project management entity as well as an intellectual property network. Sweden is represented in this regard through the SP which is a governmental body to facilitate research and funding. However, both countries have a past of non-collaborative structure and culture, which can be seen to have shifted in the recent years with major learning achievements. It is important to notice here, that there is a considerable number of developers that choose to be privately funded and to insource all production within in Scotland and Sweden.

**Communication/Education** has been identified as a barrier and an opportunity to improve technical knowledge exchange between stakeholders involved in the sector. This study has experienced the fact that while each subsector of the industry is represented by highly motivated and proficient professionals, there is a lack of understanding of each others' perspectives and priorities. This is true to some extents in both Scotland and Sweden, while there are differences across the board on how each country addresses issues.

**Controllability of the Device** is a rather complex operational factor. It is meant to address the validity of the process through which a particular device is tested in production and then later on in real sea conditions. It is also part of the challenges of technology and the validation before going into water. In both Scotland and Sweden, controllability has to do with boosting device harvesting performance as well as connecting it to the grid to feed the chain. The more efficient the technical controllability system the better the production pattern that leads towards commercialization of the power produced.

**Data Availability** is strictly related to communication of field information and strategic operational experience. In Scotland, WES acts as data gathering and sharing entity for former or present projects accordingly. In Sweden, the system of IP is stored within the developers themselves which in turn keeps the data unavailable for market easy accessibility.

**Device Performance** is the factor that describes the ability of the potential devices to constantly supply power for a competitive price per kWh. It has not been surprising that this factor has been mentioned in the innovative and technology theme in both countries.

The oceans are a very challenging environment for wave energy harvesting solutions. **Device Survivability** is therefore a key in the innovative process to ensure the devices can withstand the challenges. This is the case for all developers.

**Environmental Activism***,* although not a direct study objective, has resulted as an indirect strong factor towards the development and/or hindering of wave projects. In the past, Scotland has experienced pressure from activists and organizations that have lacked adequate information on specific enterprises in regards to its technological devices. On the other hand, Sweden's data show little or no interest from environmental urging.

**European Union (EU)** is particularly envisioned in Scotland as a vital pillar of resource and legislation providing. It is seen as an international regulatory and financier of projects towards the Horizon 2020 agenda. On the other hand, Sweden almost in unison comes across as quite alienated towards EU involvement in internal policy. This is strictly connected to the fact that developers in Sweden hold in particular regard their IP which the EU would claim were they to finance the project.

**Field Experience** is a factor strictly related with data availability and maturity of ground operations. As presented, wave power case studies cover an array of companies, from moderate developers to mature consolidated sector players. This factor is strongly smoothened through the EMEC – WES infrastructure in Scotland, while Sweden sees companies from going solo, to multi-layered/actors projects under the direction of SP.  Also, the factor is highly related to the cost reduction over standardization and optimization of processes as dictated by experience and previous failures.

**Financing** has resulted in one of the pillar factors of the wave power industry development and livelihood. As an emerging industry, wave embeds finance through all the strategic and development phases, which in turn continues to dictate enabling processes towards producing power. Finance should be herein seen as risk/operating capital injection in the industry. However, empirics results show that the level of finance accredited to wave is highly discriminatory compared to other renewables and even further so, from fossils. Furthermore, Scotland shows a high need for funding into research and development as well as field deployment. On the contrary, Sweden reflects sufficient to abundant funding through governmental entities which push for collaborative formulas. This means that funding in Sweden is higher if projects are run/conducted in collaborating teams of developers.

**Fossil Fuels** are perceived as the most probable market competitor for renewable sources overall, and wave in particular. Not only is this seen under a market share dimension but also in the maturity and levels of engagement fossils have in our society. Both in Scotland and Sweden, the credo for wave is to challenge the market claim fossils have on the planet overall and in the energy culture that both countries represent.

**Institutional Framework** has been identified as a factor on different dimensions as; engaging start up/small developers, creating legislative and financial infrastructures to facilitate and encourage development, as well as to regulate and incentivize countries into participation. However, data from both countries show that regulation and institutions would need to keep a distant and a non-dominant position in order not to hinder originality and not to create tight structures. In the current development stage in which wave is, a strict framework could conflict with the many device designs out in the market. Furthermore, a system of top-down structuring could be counterproductive.

The factor **Investment & Risk** has been mentioned as a factor that combines the inherent risk of the technological development with the willingness of investors to provide money for the wave energy industry. In Scotland, there is an institutional strategy to derisk the investment of the technology, while in Sweden the risk of investment has been primarily connected with the developing companies.

**National Government Policies** describe the influence policy systems have on the sector while subsidizing the development or providing a stable political infrastructure. This has been a highly strategic factor in Scotland, where different influencing structures like the UK and EU membership and long term supporting programs, have been seen as nonexistent.

**Nuclear - Market Competition** refers to the competitive pressure through nuclear power. In Scotland, the huge governmental support for the nuclear industry has been accompanied by lower support for the renewables industry. Although, it has uncertain commissioning/decommisioning costs. In Sweden, it has rather been seen as a complementary solution for a market that is using all different kinds of energy sources.

A very important factor in connection with the competitive situation of wave energy is **Natural Geo-Physics Conditions***,* which is an essential unique factor. It describes the special site-specific differences, which defer much more in wave than in other energy sources. In both countries, this has been a very important aspect for the supply chain - with cable lines and connecting points onshore - and the innovative and technological theme with different wave conditions that demand different device solutions.

The factor **Renewables- Market Competition** refers to the role other renewable sources like wind or solar, have for the wave power industry. In both countries, other renewables are rather seen as complementary. However in Sweden, offshore wind has been identified as a strategic competitor for connection points onshore; which is a factor for the strategic development of the renewable energy supply chains.

**Scale of Devices** is herein included to illustrate the strategic development that wave power device deployment is at current stage. Historically speaking, former projects in Scotland have started testing and developing on big scale devices which on later years have shifted towards smaller designs. By big scale it is meant not physical structure of devices, but also the expected/forecasted production output in mega/kilo watts. Sweden presents data towards the latter model, while progressing towards bigger devices and deployment as future project advances.

**Source Availability** refers to the geographical position of a country and access to sea/ocean waters for harvesting waves. It is connected to the factor *Natural Geo-Physics Conditions*. However, it specifies if there are potential commercial sourcs at all, while geophysical conditions specify the geophysics of existing resources. Considering its position in the north of the Atlantic, Scotland has access to more wave mass per year with high density and power. Sweden on the other hand, suffers from accessibility to considerable wave patterns and has projects that deploy away from its national waters.

The **Market Approach** *(either* **Scottish** *or* **Swedish***)* refers to the different marketing strategies the wave industry has. Here, differences between the two countries have been identified. Scotland learned from failures with the Pelamis and other projects in the past and established WES to provide support for different developers to present and test their different approaches. Furthermore, in Scotland, almost all different device types can be found in development. In Sweden however, there is a huge trend towards collaboration between developers and there is the device type 'point absorber' (see attachment 2), that is primarily under development. The goal is rather to focus on finding a technology to export rather than to use it for the home market.

**Sector Specificity** describes elements of the wave energy sector that are different to other sectors. This was mentioned in the strategic and supply chain theme in both countries. Two elements of this factor have been of special significance. First, unlike in the automotive industry for example, failure is not recognized as a logical part of the development process, but rather as the ending criteria for some technological approaches. When devices broke, they have been identified as useless. In car development, tests in which cars break are essential elements of the development process. Second, special equipment is needed to maintain and reach the power stations. Vessels are most likely needed in many device types and some devices can slightly change their location due to their movements in the water.

An element that has been identified as missing in the past and that is sometimes challenging is **Stage Focus**. This means that there is a clear, logical development approach. Phase gate processes have been established in both countries to monitor the development of the devices and to support a scientific method approach. This means, different development stages are defined with certain characteristics and indications; which are controlled throughout the development process. A good example can be seen in the TPL and TRL concept in ***appendix 2.*** There are problems connected with these stages; like missing data capturing or stagnation in the process. However, a clear and defined development process is a strategic factor in both countries.

To enable the industry longterm in Scotland and Sweden, the **Stakeholders' Perspect***ive* is to be considered. As seen in the factor Communication/Education, there are different understandings and interests between different stakeholders like governments, investors, supply chain utility companies or developers. In order to develop the sector efficiently, all these stakeholders need to be aligned to work together.

**Systems Thinking** has been an important factor identified in Sweden. This basically refers to the importance of having the whole picture in the innovation process, and that there is not a primary emphasis on one factor. Test sites, for example, are indeed as a very important element in the development infrastructure, but it is still only one piece in the whole innovative system.

The need to gain **Trust** back from investors or other stakeholders, was mentioned in almost all interviews that have been conducted in Scotland and Sweden. The failures of big wave power projects in Scotland in the past and the viscious circle of promising too much, failing, the need to promise more the next time as well as the rising likelihood of failure on a second try, has led to a loss of trust in the whole sector.

Highly connected with the trust factor is **Undeliverable Expectations**. In the innovative theme, it has been identified as crucial to design realistic development plans in both countries. (Pesonal messages[2])

Concluding the qualitative data, Scotland and Sweden delivered many similar factors, with slight differences as identified. Following the aim of this study, to explore enabling factors to make Ocan Wave Power a *commercially competitive* renewable energy source in Scotland and Sweden; it had to be ensured that it was also clear to the competing developers of the second source of empirics, the survey, what was meant by commercial and competitive. While it was possible to clarify in face-to-face interviews, it had to be defined to the survey population what these terms meant. Therefore, as a direct result of the case studies – the empirical background as well as the interviews - the terms “competitive” and “commercial” in ***table 5.3*** have been developed for the survey

**Table 5.3** Competitive and Commercial

| → | COMPETITIVE | COMMERCIAL |
|---|---|---|
| 1 | Survivability | Price / kWh |
| 2 | Accessibility / Availability | Economic & Transportation Costs |
| 3 | Financial Feasibilty | Environmental Impact |
| 4 | Maintenance / Conservation | Constant Power Supply |

(Source: Own illustration)

To reduce complexity for the survey, ***table 5.3*** shows four central elements for each term which have been used. These have been repeatedly mentioned in the interviews and additional sources provided by the cases concerning the two terms. They have especially led to the quantitative elements that have been addressed in the survey (***see appendix 3***).

The *qualitative* case studies in the first sequence of the exploratory approach also led to the identification of useful *quantitative* elements for the second sequence of the study, the collection of quantitative data. ***Table 5.4*** illustrates this data for the case studies.

[2] (Arne Vögler, personal message, 2016-03-02; Joe Thompson, personal message, 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01).

**Table 5.4** Quantitative Data Case Studies

| Quantitative Data Case Studies | | | | |
|---|---|---|---|---|
| Quantitative Element | Minimum | Maximum | Mean | Range |
| Cost per kWh (in € cents) | 20 | 60 | 35 | 40 |
| Device Lifespan (in month) | 0 | 36 | 24 | 36 |
| Initial Investment (in Million €) | 9 | 19 | 14 | 10 |
| Number of Employees | 6 | 50 | 19 | 44 |
| Years of Studying Wave Power | 2 | 35 | 16 | 33 |

(Source: Own illustration)

***Table 5.4*** shows the quantitative data calculated in Minitab that has been collected from the case studies in the second sequence of the study. This resulted from the conducted interviews, but was to a huge extent influenced by the empirical background as described in ***section 4.1.*** The cost per KWh had a range of 40 € cents, reaching from 20 to 60 € cents. Some of the devices in the case studies have not been in real ocean water conditions yet. The longest time period a device has spent outside of test environments was 36 months. A minimum of € 9 million was necessary as initial investment to get the device operational. All case studies had a mean of 19 employees and a mean experience of studying wave power of 16 years. However, it has to be stated that not all cases wanted and could deliver all the quantitative data needed. (Personal messages[3]).

In order to develop an understanding of how competitive these numbers are, these and other quantitative data have been asked for in the survey, to the competitors of the Scottish and Swedish developers. These results together with the qualitative elements are to be presented in the next section.

## 5.2 Wave Developers' Survey

The Survey was a source of both qualitative and quantitative data for competing developers worldwide to our case studies in Scotland and Sweden. For the qualitative data, the same thematic coding approach was used as for the semi-structured interviews. ***Table 5.5*** illustrates results from the wave population as illustrated in ***section 4.2*** (empirical background) above.

[3] (Arne Vögler, personal message, 2016-03-02; Joe Thompson, personal message, 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01).

**Table 5.5** Enabling Factors Survey Population

| WAVE POWER INDUSTRY: | | | |
|---|---|---|---|
| FACTORS | Strategic | Supply Chain | Innovative & Technological |
| Affordability of Technology | | | X |
| Chain Network & Facilities | X | X | |
| Challenges with Technology | | | X |
| Collaboration | X | | X |
| Communication/Education | X | | |
| Data Availability | | | X |
| Device Performance | | | X |
| Device Survivability | | | X |
| Field Experience | | | X |
| Financing | X | | X |
| Fossil Fuels - Market Competition | X | | |
| Institutional Infrastructure | | X | |
| Investment & Risk | X | | |
| Market Approach | X | | |
| National Government Policies | X | | X |
| Natural Geo-Physics Conditions | | X | |
| Renewables- Market Competition | X | | |
| Scale of Devices | X | | X |
| Sector Specificity | X | X | X |
| Social Impact | X | | |
| Source Availablity | | X | |
| Stage Focus | X | X | X |
| Stakeholders' Perspective | X | | |
| Systems Thinking | | | X |
| Trust | X | | |

(Source: Own illustration)

In ***table 5.5***, the enabling factors that resulted from the survey can be observed in the same logic as in ***table 5.2***. The population response was conservative with 17 out of 139 contacts approached via email, while individual feedback was of satisfactory relevance and content. Further below, like in the qualitative data of the case studies, each factor is described in connection to the findings from the questionnaire. There are similarities as well as differences in comparison to Scotland and Sweden. While the similarities can be assessed as a common trend for the specific factor, the differences can be identified in consideration to the crucial/immediate relevance towards the themes. Since all a detailed explanation of the similarities and differences would break the limits of this thesis, only the most important differences are presented in the next paragraph.

**Affordability of Technology** was perceived as needed to have an affordable technology cost. **Chain Network & Facilities** does not identify the chain as a major player to be concerned with, but that improvements and adaptations are needed. **Challenges with Technology** is only applicable to the Innovative & Technology theme with the same challenge as the case study countries. The concept of **Collaboration** resulted in high acceptance and positive remarks, with skepticism reflected on IP protection and regulatory framework suggestions. **Communication** resulted in a very similar approach with collaboration where investors need to be brought unto the same knowledge as developers and vice versa. This could be done through demonstrating unit to view emerging projects and prove their merits.

**Data Availability** reflected in responses that showed missing infrastructure to rely on. Just like in the case study data, patentability of products and technology is seen to hinder collaboration and affect individualistic work. **Device Survivability** is a key problem in the responses. The same can be claimed for **Device Performance** and it preserves the same approach as Scotland and Sweden. **Fields Experience** is a factor that shows high unfamiliarity in real conditions due to the fact that several developers have only testing data. **Financing**, undoubtfully, is seen as a vital factor to the development of industry. This can be done through feed-in tariffs and general governmental funding. **Fossil Fuels** prove to remain the strong market competitor for wave. Also considering that existing fossil infrastructure (see United States of America) make it highly cheaper and also subsidized. **Institutional Infrastructure** shows a trend to establish and support collaboration. However, in comparison to Scotland and Sweden where established governmental institutions are participatory, the survey results show high reliability and collaboration with universities. **Investment & Risk**, the limiting of risk from the development, has been used in the strategic theme of the survey. There were also different **Market Approaches** identified that were considering collaboration as part of the solution. However, from several responses in the survey, the study recognizes that different countries can offer different models to approach the market. An example of this is the Danish association to address the wave industry by pressuring and lobbying for legislation. **National Government Policies** have been mentioned as of central importance; especially in the form of feed-In tariffs. There was also the result that in some countries it is the government that manages the development actively. Not surprisingly, **Natural Geo-Physics Conditions** have also been seen as a crucial factor in the wave energy industry. **Renewables-Market Competition** has rather been seen as complement by the survey population. **Scale of Devices** represents the concepts of downscaling testing and production as difficult and rather against it. Further, investment opportunities are referred to when addressing the need to enter the market small scale. Unsurprisingly, there was also awareness for **Sector Specificity** and the need for a **Stage Focus** and the consideration of **Stakeholders' Perspective**. Like in Scotland and Sweden, **Systems Thinking** and the need to build **Trust** back from investors or other stakeholders was stated as well. A new factor that was not central in the case studies, but that has been addressed in the survey data was **Social Impact.** This especially refers to the impact the change from a more centralized, fossil fuel and nuclear based energy market to a more decentralized, renewable energy market has for communities (Karagjozi & Parker, 2016)

As can be seen, the qualitative results of the survey data were rather similar to the results from the conducted case studies. Therefore, the competitors see comparable enabling factors as identified in Scotland and Sweden. Central for the survey in the second sequence of the sequential exploratory approach, however, were the quantitative elements. These are presented in ***table 5.6***.

**Table 5.6** Quantitative Data Survey

| Quantitative Data Survey | | | | |
|---|---|---|---|---|
| | | | | |
| Quantitative Element | Minimum | Maximum | Mean | Range |
| Cost per kWh (in € cents) | 2 | 57 | 18 | 55 |
| Device Lifespan (in month) | 0 | 600 | 170 | 600 |
| Initial Investment (in Million €) | 1 | 175 | 19 | 174 |
| Number of Employees | 1 | 10 | 3 | 9 |
| Years of Studying Wave Power | 2 | 38 | 12 | 36 |

(Source: Own illustration)

As can be seen in ***table 5.6***, the mean years of study have been 12, ranging from only two to a maximum of 38 years. Therefore, the participants in the survey had a rather long term experience in the field. The developers are mainly working in small teams with three employees in average; starting with only one single developer up to a team of 10. In the device's lifespan there were huge differences. While some devices have not managed to operate in a real ocean environment, there were devices that have been in the water for up to 600 months. The mean lifespan has been 170 months. In regard to the cost per kWh, there was therefore also a wide range between € 0.02 up to € 0.57. The mean cost was € 0.18. It has to be mentioned, that the high majority of these costs are estimates by the participants. Finally, the initial investment needed reflected the diversity of the different approaches as well. The mean of the initial investment in the answers has been about € 19 million, but the needed investments lay within a wide range starting from € 1 million up to 175 million needed to initiate the technology into operation (Karagjozi & Parker, 2016). These results reflected the huge variation in approaches worldwide and fit very well into the results from the case studies in Scotland and Sweden.

The next part will present the results further empirics from the governmental institutions and KPMG contributed to this study.

## 5.3 External Wave Stakeholders

From the additional empirical sources, only qualitative data was collected in the first sequence of the sequential exploratory approach. Again, the thematic coding approach was used to process the data. In addition to the case study and survey data, the interviews with the ministries and KPMG helped to get a perspective from outside the wave energy sector. As barriers, it could be seen that there is little experience with wave energy outside of the industry and that main challenges are seen in survivability, reliability and life cycle costs. Although limited amounts of funding have also been seen as hinderness, the importance has been stressed on that these limits are necessary to support collaboration. Especially the Swedish Energy Agency has developed an ocean energy strategy based on this to support the industry. The enabling factors that could be seen from the advisory perspective were a bit different from the developers' perspective. As a marketing tool, the society trend towards sustainability could be used to promote the technology; when society is convinced by the technology, this will make it investable and businesses will likely pick up the trend accordingly. A critical element of this has been seen in patentability. Further, factors have been seen in the natural environment, the quality of the labor market, a functional legal framework and research space and access to capital. It has been especially pointed out that there is a vast amount of capital existing; the sector has to find strategies to get its share. Then there are factors like scalability, resilience and maintenance that need to be further addressed. It has been seen of central importance to align all the stakeholders towards a more progressive process. (Personal messages[4]).

The empirical findings presented in this chapter were the result of the research design in connection with the problem, aim, research questions, theories and methods used in this paper. Based on the empirical background of the different sources, 30 enabling factors were identified as result of the primary qualitative focus in the first sequence of the sequential exploratory approach. Further, to be able to answer the research questions about how wave power can be competitive, quantitative data has been collected in the second sequence of this research approach. All these elements together helped to address the research questions in chapter 6, where the analysis and discussion has been conducted.

[4] (Kenneth Sörensen, personal message, 2016-02-17; Julie Steel, personal message, 2016-03-01; Maria Olsson, personal message, 2016-03-03).

# 6 Analysis and discussion

The paper so far presented the problem and aim of this research paper. Starting with the research questions, theories, methods and empirical sources have been chosen to gather empirical data to be able to answer these questions. In this analysis chapter, the research questions are answered by combining the theoretical framework with the collected empirical data. ***Section 6.1*** answers research question 1, ***section 6.2*** research question 2 and ***section 6.3*** research question 3. In ***section 6.4*** as discussion of the findings and the quality of the study will close the chapter.

In order to answer the research questions, however, the missing two phases of the thematic coding approach had to be conducted for the qualitative data. In *phase 4* a thematic map of the analysis has been developed out of the qualitative empirical results presented in chapter 5. It reverses the order by clearly stating the crucial factors for each of the three themes. The result is illustrated in in ***figure 6.1***.

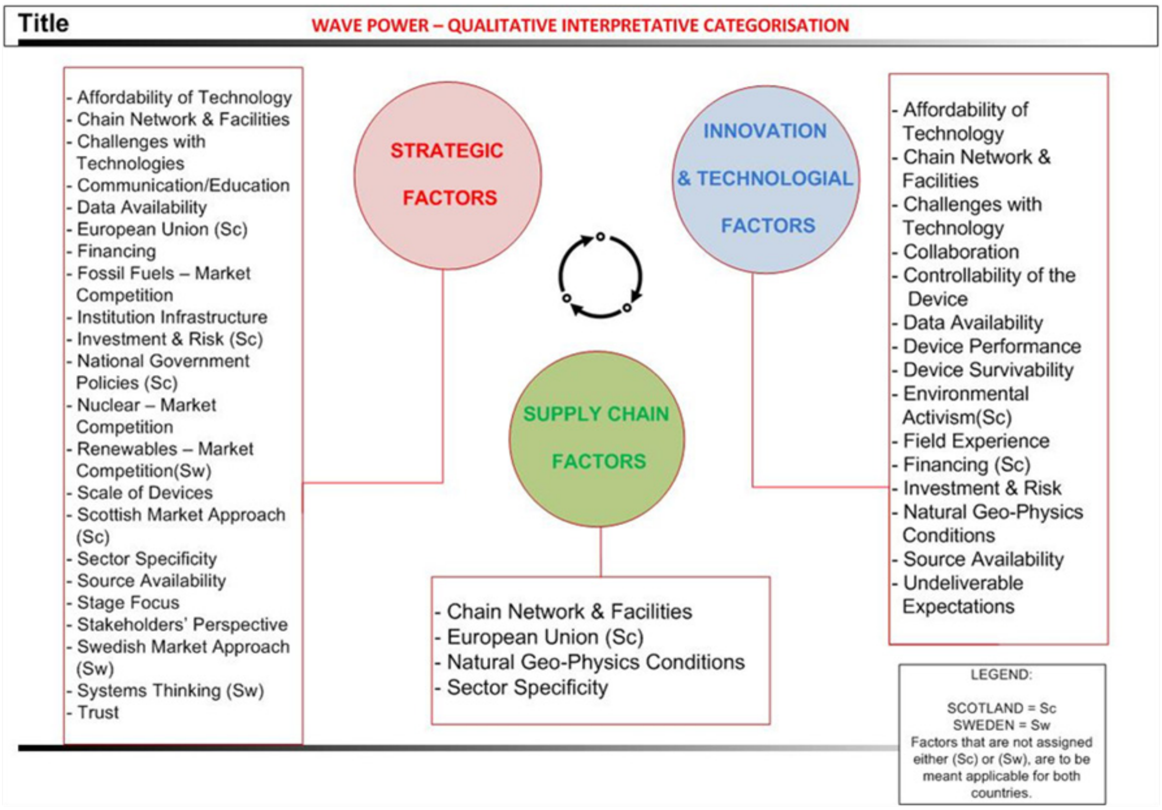
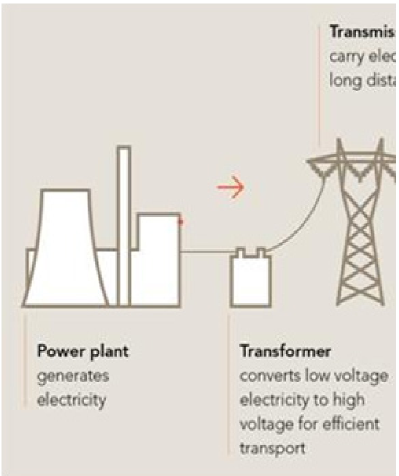



**Figure 6.1** Thematic Map of Analysis (Source: Own illustration)

The map in ***figure 6.1*** portrays the thematic analysis with themes accompanied by the identified enabling factors. In the final *phase 4* of the thematic coding approach, the deployment, interpretation and comparison of this data was used to answer the research questions. This means, different aspect of data were considered and how they play into the theoretical framework. The data is described and the most important aspects summarized to demonstrate the quality of the analysis.

## 6.1 RQ I: *How* is the wave power supply chain organized in Scotland and Sweden?

The power supply chain in Scotland and Sweden has not developed an independent concept of infrastructure for the wave industry. However, the supply network theoretical model is quite similar to the other energy sources as illustrated in figure 5 in chapter 2.2.1. Differences can be noticed in the weak part of the chain network, which is identified as power plants, cables and connecting points on shore (see ***figure 6.2***).




(Source: EEX [online], 2016)

**Figure 6.2** Weak Links in the Chain

- Power plants are either a single device or a composition of several more complex devices working together in a specific network. Both Source Specificity and Source Availability demand diverse solution and operational structures in regard to geographical position and environment.
- Cables are connecting and transmitting devices in order to link power plants with hubs, transformers and substations. They become especially crucial when power plants are situated in off shore locations.
- Connecting points on shore are substations that act point of reference between power plants and transmition lines or existing power supply chains on shore.

An element that needs consideration in all three supply chain elements mentioned above, is the need for standardized equipment to have an efficient cost structure in the market. As far as it is considered possible, the standardization of equipment would assist the market to become more competitive and also facilitate the mechanical, technical and network operations. Furthermore, there are general issues with the supply chain of renewables energy sources. First, the existing infrastructure is considered to be outdated and amortized in the current situation. Second, the conventional concept of energy supply is to have centralized power production which is later transported towards peripherical end consumers. Therefore, the distribution lines are also designed to transport power only in this direction. However possible it may be, changes need to be done to reverse this transportation concept. Third, Source Availability is a strong characteristic of wave power due to its geographical position away from populated areas and existing supply systems. Hence, the source is localized rather than centralized. This creates a further need for substation to reverse the transportation system as mentioned in the second point. Last major aspect refers to energy storage related issues. Wave power generated storage is yet to be developed and integrated in the system. There are however a few pioneering concepts in the making at present. Although all three empirical sources pointed explicitly out that the Supply Chain Network is not the dominating issue in wave power becoming competitive, there are several factors that need addressing throughout as identified above. The wave energy supply chain is thus not organized yet, but it can be through the adaptation, integration and the necessary updates to the links as addressed above.

## 6.2 RQ II: *Why* is wave power not competitive in Scotland and Sweden so far?

Wave power has not reached competitive levels in these two countries due to several strategic factors that have affected the market development, the supportive operations network and technological efficiency. However, different reasons can be identified for each country. Scotland enjoys the status of a country with source availability which has been active in the wave power industry for a moderately long time. The strategic approach to start testing and operating on large scale devices/projects, has been proven to be wrong, thus undermining Trust in the industry and investors. On the other hand, Sweden did not reflect the same large device projects. The wave source is limited thus creating a focus on a different energy portfolio mix. First, as introduced earlier, strategy towards competitiveness is a framework to a precise direction for a firm or an industry. The wave power industry, from its beginnings in the 1970's, has been portrayed by non strategic consistence and comprehensive structure to direct it and further develop it (Porter, 2004a, p. 215). A comprehensive strategy has to do majorly with a structural change, which focuses on technological innovation and adaption from various origins and forms (Arora *et al.*, 2001; Fagerberg *et al*., 2005; Hall & Rosenberg, 2010). Thus, wave power in Scotland, in the following years from its beginnings, has suffered several setbacks in structural characteristics. These setbacks have heavily hindered the wave industry in technological uncertainty, strategic ambiguity, high initial/entry costs, supply/grid/operations networks and financing structures. Furthermore, wave power was characterized by a system of non-existent rules of the game in relationship to strategic planning. Hence, this made the strategic approach rather inexperienced and slow-to-react towards necessary transformations and adaptability. Second, both Scotland and Sweden have had an emerging industry approach towards wave power as an energy source. An emerging industry shows low levels of market need, as well as investor and developer unawareness, thus reflecting an unfamiliar behavior towards wave. This trend has kept awareness away from the economic opportunity that introduces wave as a relevant renewable energy source (Porter, 2004a, b). Third the commercial outlook and prospect was another underlying factor in hindering competitiveness. The sector lacked a sound economic feasibility framework thus, missing a clear income strategy and return on investment roadmap. This scenario created a delicate and precarious situation with investors and developers; which in turn created uncertainty around risk and financing. Strategic decision-making was often a byproduct of what the investors' needs were, rather than focused on the necessary time-consuming technological optimizations (Personal messages [5]) Last, as already identified in the text, several factors are strongly suggesting towards the failure of *why wave power is not competitive in Scotland and Sweden*. These factors have come into play throughout the years at different stages and nuances, contributing to the whole setback account. The thematic map of factors and themes further demonstrates these factors.

Three quantitative data connected to competitiveness resulted from empirics. First, an aspect that illustrates the historical uncompetitiveness is the levelized cost of energy (LCOE) for the different energy sources. Based on the LCOE principle, ***table 6.1*** shows the 2011 costs for competing energy sources compared to the quantitative data collected in this study:

[5] (Arne Vögler, personal message, 2016-03-02; Joe Thompson, personal message, 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01).

**Table 6.1** Costs of Competing Energy Sources

| **Source** | **€ Cents/kWh** |
|---|---|
| Coal | 2,8 |
| Gas | 3,6 |
| Hydro | 2,3 |
| Nuclear | 2,4 |
| Solar | 5,3 |
| **Wave (Range)** | **2 - 57** |
| Wind | 3,0 |

(Source: Forbes [online], 2016;

Karagjozi & Parker, 2016; Personal messages [4])

The gathered data from the empirical study shows that wave energy still is on the high end of the presented averages ***table 6.1***. At present, the data shows that wave power is far off from these averages; often with conflictual ranges of cost per kWh (Karagjozi & Parker, 2016; Personal messages [6]).

A *second* data was identified that is related to the initial investment required. This inititial investment represents the capital needed to make the devices operational. There has been a wide range of investment needed between € 1 to 175 million. This wide range shows the complexity of the industry in terms of device types and scale (***appendix 1***, Karagjozi & Parker, 2016). To get a clearer relative picture for this investment need, a look at decommissioning costs for nuclear power plants is useful: According to an OECD report from 2016, these costs are uncertain, but very likely to sum up to *billion* Euros in the Sweden and especially the UK (OECD [online], 2016).

*Last*, like the required initial investment, the lifespan of the devices varies considerably between a few months and a few years; most of which still in testing environments. In the long run this has to stand competition with, for example, onshore wind, where wind turbines have an approximate lifetime of 20 years (Karagjozi & Parker, 2016; Wizelius, 2007, 158). These quantitative aspects show the stage of immaturity and early development. They are direct results of the present stage, and they need to be developed in order to assist the development of the industry.

Wave power has not been a competitive energy source in Scotland and Sweden due to the several factors listed above. The empirical results from the survey and the external wave stakeholders show that this is not only the case in Scotland and Sweden, but in other areas of the world as well.

## 6.3 RQ III: *How* can wave power become a competitive renewable energy source in Scotland and Sweden?

In order to assess the future of wave power, a particular focus must be on the concept of what makes the wave industry in both countries, competitive. The following section illustrates the SWOT analysis approach to identify core competencies, potential strengths and surrounding market environment, while responding to sector threats and weaknesses. In addition, the analysis sheds light on exploiting opportunities and strategically envisions the industry.

[6] (Arne Vögler, personal message, 2016-03-02; Joe Thompson, personal message, 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01)

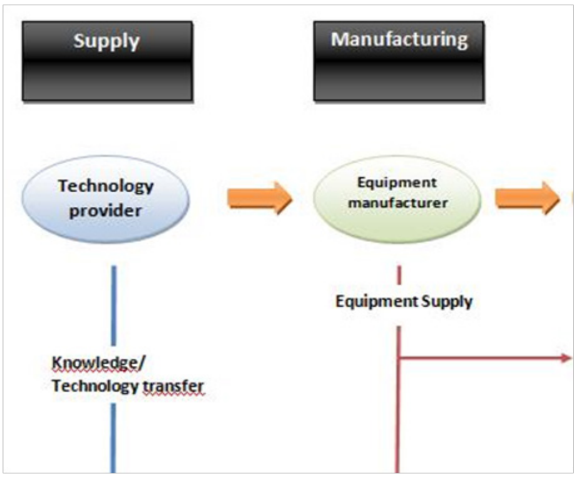
"*If the engineers are the same, the money is the same, seven days of the week, wave would beat wind and solar! It would beat hard on solar and a bit lighter on wind.*" (Mats Leijon, personal message, 2016-05-04)

The **strengths** of wave energy are that it is abundant and widely available; especially considering that large populations reside near coastal areas. It has a huge potential to supply the energy demand in Scotland and Sweden as well as worldwide; therefore, wave power plants are an interesting export product in both countries. Wave energy represents a clean renewable source and is highly efficient when it comes to energy conversion. It can be captured up to a 100 % and has greater potential than wind (30 $MW/km^2$ compared to 10 $MW/km^2$). Compared to other renewable energy sources it can also more constantly, and predictable supply energy through a variety of ways to harness it. Thus, it creates an agenda on less dependency on fossil fuels (Conserve Energy Future [online], 2016; Rafael Waters, personal message, 2016-02-15).

As we address the enabling factors, clear and challenging **opportunities** can be identified as well. First of all, the wave industry can learn from other market competitors like fossil fuels and other renewables in regard to marine deployment and infrastructure, experience in dealing with geophysical conditions and transportation and operation in hazardous natural environments. However, there is opportunity in creating a diversified energy portfolio based on renewable sources only in contrast to conventional ones. Logically this leads to the concept of collaboration, which is not only between different renewables, but especially in the wave industry amongst developers, engineers, scholars, governments and investors. Both, Scotland and Sweden show efficient programs at present (like EMEC, WES and Offshore Väst) that are operational. This practically proves the concept presented in the theory of collective invention presented in the theoretical framework of Economics of Innovation and Technology. Collaboration in joined initiatives can act as a system of checks and balances in order to avoid wasting resources in radical innovation that can hinder the commerciability of a product. Furthermore, institutional infrastructure is the next natural and logical step in helping collaboration and bringing stakeholders' perspectives together. In this regard, national governmental policies, as illustrated in Sweden, where subsidies are higher for joined projects, have a huge potential to assists the market through subsidies and moderate legislation. Individual developers as well as institutions should develop a stage focus approach which in turn would guarantee guidelines to an efficient roadmap and lower investment risk. Through a solid strategy plan, there is the opportunity to build effective communication bridges between stakeholders.

"*The power resource in the ocean is enormous. If you find a way to harvest that, it would solve the entire world's energy needs, but it is not easy"* (Arne Vögler, personal message, 2016-03-02)

To address **weaknesses** is to directly address the focus of this study. Needless to say, the factors identified are at present contributing to the several weaknesses that the wave industry has in Scotland and Sweden. Hence, the study regards them as enabling necessary factors to nullify weaknesses and develop the industry. The thematic mapping identifies these weaknesses to be part of the three themes at different stages of the process (see ***figure 6.3***).




(Source: Own illustration based on: Wee *et al,* 2012, 5456)

**Figure 6.3** Supply and Manufacturing

Wave power is, by many regards, an emerging industry. As it has developed throughout the years, **threats** are identified in the technological concept related to design, deployment, operationability and maintenance. Referring to the energy supply chain, the threat can mainly be seen in supply and manufacturing as can be seen in ***figure 6.3***. Technology providers and equipment manufacturers are facing threats strictly related to the affordability, controllability, survivability and performance of their units. This has to do, not only with financing these operations, but also the threat that comes with natural geophysics conditions. Lastly, smaller developers face threats connected to limited field experience which is a mean to data availability and knowledge capture (Personal messages [7]).

From the empirical gathering from Scotland and Sweden, this study has taken a strong perspective on stage focus and systems thinking. Systems Thinking refers to the importance of having the whole picture in the innovation process, in mind and that there is not a primary emphasis on one factor. This structure should be able to absorb and effectively engage innovative ideas, individual initiatives from developers and strive to align stakeholders' interests. By creating an organism that focuses on stages, the wave power industry can have a solid roadmap process and secure the vital necessary financing. Weber *et al.* (2013, 4) point out that the two concepts of the nine TRL and the nine technology TPL can be a guidance for a phase gate process that helps to define the strategic capital needs and determines the progress towards commerciality (see ***appendix 2***). Furthermore, stage focus also stresses on the high importance of staying focused on the road map to the principle project, while avoiding opportunities and distractions along the way. An essential characteristic that has resulted from former development failures in Scotland is to focus on small scale prototypes initially, while scaling up later in the process. An almost identical lesson could be learned from the competitive wind sector. This developed over the years through a phase gate process from small to big scale. The advantage of this approach is that it is possible to generate a return on investment in early stages of technological development. Also, development and advances on a small scale build a gradual trust system between developers and investors, while enriching the value network that different stakeholders have. Empirical data in this study have shown that trust can make or break the market or push for collaborative projects like in the modern Swedish experience. Lastly, the stage focus mentality creates a systems thinking that focuses around technological development, while revisiting and reshaping the strategic umbrella around the market. Once these two major pillars of the wave power

[7] (Arne Vögler, personal message, 2016-03-02; Joe Thompson, personal message, 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Karagjozi & Parker, 2016; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01).

industry are solidified the market will update and adapt the supply network infrastructure (Personal messages [8]).

The process of strategic planning and decision making is crucial to make wave power a competitive renewable energy source in Scotland and Sweden. By identifying solidified strengths and surrounding market environment, the industry can use them to respond to weaknesses and own threats. Also, by exploiting opportunities a means to turn threats into strengths is gained, and the ground for strategic processes can be developed.

## *6.4 Discussion*

### 6.4.1 Reflection

The analysis combined the empirical results from the business perspective of this study with the three theoretical business concepts Competitive Strategy, Supply Chain Management as well as Economics of Innvation and Technology. This way, the three research questions about how the supply chian is organized, why wave power is not competitive so far and how it can become competitive from a business point of view could be addressed. The vacuum identified in business literature could be filled with respect to the aim of this study to explore enabling factors to make Ocean Wave Power a commercially competitive renewable energy source. The concept of *Competitive Strategy* was enriched with the business view on why businesses operating in the wave power industry were not competitive in the past and how they could become competitive in the future. Some of these implications are also useful for the development of *Supply Chain Management*. However, the main contribution here is to see how the wave power supply chain can be organized, where the weak links are and how these can be managed. Finally, *Economics of Technology and Innovation* have been further developed from a wave power business perspective to see how the collaborative approach and developments of technology concerning clear systems thinking and stage focus can enable businesses to create the wave power industry. Considering the answers to the research questions helps to develop the industry in Scotland and Sweden and can be guidance for policies to support the competitiveness of businesses that develop this renewable energy source in the future. (Arora *et al.,* 2001; Blanchard, 2010; Cruz, 2007; Everett *et al.,* 2012; Ivanov & Sokolov, 2010; Porter, 2004a, Porter 2004b, Wee *et al.,* 2012). An unintended byproduct of this study was the concept of services for the market from wave power developers. This means that well solidified and established developers as well as governmental institutions can commercialize data availability or process refinement blue prints, for example. This process would serve the market of smaller developers or new entries; which is a central part of Competitive Strategy. Furthermore, it would give collaboration as essential in EIT a boost based on a well structured and transparent pro rata system to enhance communication and joint projects.

### 6.4.2 Validity and Reliability

In order to discuss the quality of this empirical social research project, four tests according to Yin (2014) as explained in the method chapter ***section 3.5*** have been conducted that referred to construct, internal and external validity and reliability. *Construct validity* has been

[8] (Arne Vögler, personal message, 2016-03-02; Joe Thompson, personal message, 2016-05-13; Jonathan Hodges, personal message, 2016-03-01; Karagjozi & Parker, 2016; Mikael Sidenmark, personal message, 2016-04-08; Mats Leijon, personal message, 2016-05-04; Pierre Ingmarsson, personal message, 2016-04-26; Rafael Waters, personal message, 2016-02-15; Ulf Lindelöf, personal message, 2016-04-01)

strengthened by clearly connecting each part of the study to show that the measures were the right choice for the concepts that were studied. All parts of the paper, from the problem formulation and aim to the theories and methods used, have been designed to fit together and to address the research questions. *Internal validity,* seeking to establish a causal relationship, has not been of central importance for this exploratory study with descriptive statistics. Therefore, this test did not influence the quality of this study in a negative way. Same is the case with *external validity*, the generalizability of this research. This research projet does not intend to be generalizable, but to explore the business perspective of wave developers in Scotland and Sweden. *Reliablity,* the ability of other researchers to have the same results when conducting it the same way, has been strengthened by a profound documentation of the procedures in protocols and by making the interview guidance and survey available in ***appendix 3.*** However, it cannot be completely ensured that the researchers do not influence the qualitative studies at all. For all four elements of the quality ensurance, especially construct validity and reliability, this research project supported the quality.

### 6.4.3 Limitations and Further Research

Primarily three limitations of this study have been identified during the process. First, the design of the study puts emphasize on the business perspective of developing businesses. Therefore, other perspectives from big energy providers and system or grid operators could be valuable perspectives for futher research. Second, the quantitative data in the second sequence of the sequential exploratory contained estimates for the levelized cost of energy. This was due to several factors like confidentiality or the early technological stages some of the developers operate in. Future research projects that collect the data when the developers have reached higher stages of the TRL and TPL might lead to more solid data. As a third limitation, the responses in the survey were with 17 out of 139 rather few. This was due to several reasons. Most essential were email addresses on the developers' webpages that have not been in operation and the busy development stages many wave developers are in at the moment. Future research can enhance the feedback quota by calling every respondent to ask for an email address that is in use. Out of financial considerations, this has not been conducted in this thesis due to the survey population coming from all places around the world. Further research can especially focus on the renewable energy source offshore wind power, which faced comparable problems in its development and could have useful implications for the wave power businesses in Scotland and Sweden.

# 7 Conclusions

This thesis examined the strategy and competitiveness of wave power in Scotland and Sweden; as this business perspective was lacking from existing business literature. The problem behind this project was that wave power is not a competitive renewable energy source in Scotland and Sweden yet. The aim of the study was to explore enabling factors to make Ocean Wave Power a commercially competitive renewable energy source in both countries. To answer the research questions *How is the wave power supply chain organized in Scotland and Sweden?, Why is wave power not competitive in Scotland and Sweden so far?* and *How can wave power become a competitive renewable energy source in Scotland and Sweden?,* this study used the theoretical perspectives of *Competitive Strategy*, *Supply Chain Management* as well as *Economics of Technology and Innovation*. The method that was used to adderess the research questions was the sequential exploratory approach, Robson (2011); in which mainly qualitative data and a small amount of quantitative data was collected from three different empirical sources. These were to the biggest extent business case studies on wave power developing projects in Scotland and Sweden. Their perspective was enriched by surveying a broader wave power population and by wave energy stakeholders. Combining the theoretical concepts and the methods, this study contributed to business literature by providing for the first time an analysis of enabling factors that have the potential to help wave power to become a competitive renewable energy source in Scotland and Sweden in the future.

Following the sequential exploratory design of this research project, the first sequence was mainly the collection of qualitative data. Therefore, several business case studies have been conducted, which were enriched by semi-structured interviews. As second sequence, the quantitative data was collected. For this purpose, a survey was conducted with a global wave developer population. Together with data from wave energy stakeholders, this data was used to address the aim concerning the competitiveness of wave energy in the two focus-countries. Scotland has been chosen due to a long history in wave power projects and modern proactive operations. Sweden is one of the top countries for renewable energy and is also active in the modern market developments. Both countries represent a transparent and easy infrastructure access to study. Scottish businesses were studied through the cases Aquamarine, Pelamis, EMEC, Wavegen and WES; while Swedish developers were explored with Ocean Harvesting, Offshore Väst, Seabsased and Waves4Power.

The research primarily resulted in answers for the three research questions. *How is the wave power supply chain organized in Scotland and Sweden?* - It is not operating yet, but it can be through adaptation of necessary updates to the weak links power plants, cables and connecting points on shore. Other offshore energy sources; like wind power or oil and gas; can function as role models for the wave industry. The key to the two research questions*, Why is wave power not competitive in Scotland and Sweden so far?* and *How can wave power become a competitive renewable energy source in Scotland and Sweden?,* were found in 30 strategic, supply chain and technological and innovative factors. These are responsible for the missing competitiveness and are essential to making it competitive. Addressing these factors, the main qualitative factors levelized cost of energy, duration of device and initial investment can compete with other energy sources in the future.

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**Personal messages**

Hodges, Jonathan
Research and Business Development Manager, Wave Energy Scotland Initiative
Skype interview, 2016-03-01

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Leijon, Mats
CEO, Seabased
Personal interview, 2016-05-04

Lindelof, Ulf
VD/CEO, Waves4Power
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Olsson, Maria
Avdelningen för förskning och innovation, Energimyndigheten
Mail interview, 2016-03-03

Sidenmark, Mikael
CEO, Ocean Harvesting
Skype interview, 2016-04-08

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Mail interview, 2016-03-01

Sörensen, Kenneth
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Thompson, Joe
Data Technician, EMEC
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Vögler, Arne
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Waters, Rafael
Researcher, Institutionen för teknikvetenskaper, Elektricitetslära, Uppsala Universitetet
Personal interview, 2016-02-15

# Appendix 1: Technical Background

This paper studies a topic that is highly connected to technology. Therefore, it is essential to have the technical background to understand the basic devices that are tested in the wave power industry as well as a few basic physics behind it, to be aware of what the different scales of power production are that are part of the empirical data, analysis, and discussion chapter of this paper. The following two sections will therefore introduce this basic technical data.

<u>Physics of wave power</u>

'' *Waves are created when wind moves over the ocean surface. Even small ripples on the ocean surface gives the wind an opportunity to off load some of its energy on to the waves, causing the wave to grow bigger as the wind is acting over the ocean surface over long distances – the fetch. The longer the fetch and the stronger the wind the bigger the waves. As waves can travel for hundreds and even thousands of kilometers with virtually no loss of energy, they act as an energy reservoir charged by the wind. The wind in turn is created when the sun heats the surface of the earth unevenly, creating air movement, first vertically when hot air rises up and then horizontal air motion – wind – is created to fill the void from the rising air.*" (Waves4Power [online], 2016, 3)

<u>Wave power device types</u>

In the wave power industry, there is not only one technology device that is tested, but many that are developed to find ways to harvest wave energy in general, but that also consider the different settings at different places in the world. EMEC names basically eight main device types (Cruz, 2007; EMEC [online], 2016, 4):

1. Attenuator

This device floats parallel to the wave direction. It is therefore riding the waves and is using its two arms to harvest the energy.

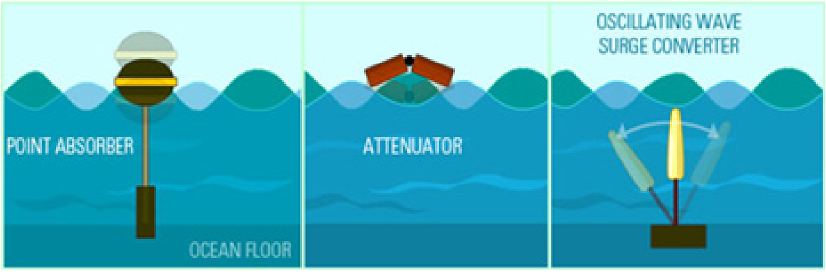
2. Point Absorber

A point absorber moves at or near the water surface. This enables this device to absorb energy from all directions. On top, there is a buoy. Its movements relative to the base are converted into electricity. There are different point absorber systems which can often be distinguished by their take-off system.

3. Oscillating Wave Surge Converter

As the name already points to, this form of device harvests energy from the wave surges and water particles which move within them. The arm on the device works like a pendulum and responses to the movement of the waves.

To get a better idea about these first three device types, ***appendix figure 1*** offers a good illustration:



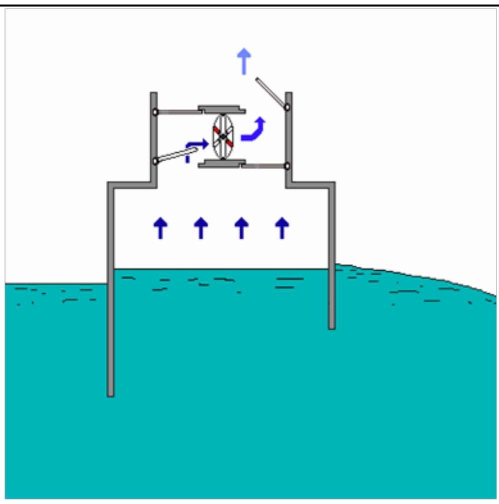

(Source: Eschooltoday [online], 2016)

**Appendix figure 1** Attenuator, Point Absorber, Oscillating Wave Surge

These three approaches in ***appendix figure 1*** are very common in the presented case studies. All studied Swedish wave developers use the point absorber approach; Pelamis Wave Power used the attenuator and Aquamarine focused on the oscillating wave surge converter (EMEC [online], 2016, 3).

4. Oscillating Water Column

Below the water line, this partially submerged, hollow structured device is open to the sea. Inside, there is a column of water and a column of air on top of it. When there are waves, the level of the water column changes which leads to a compression and decompression of the air inside. This air then flows to and from a turbine to the atmosphere. The turbine can rotate in both directions and produces electricity. This can be seen in ***appendix figure 2***:



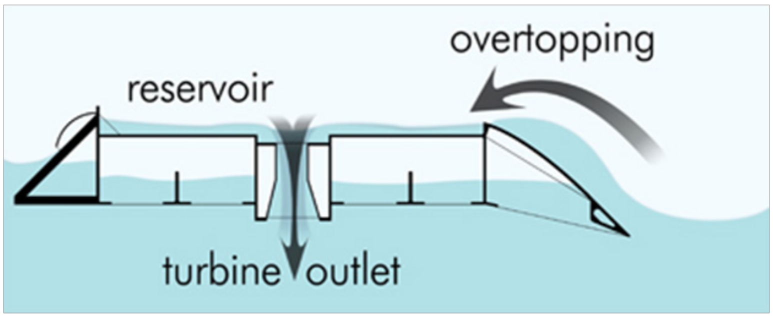
(Source: Caphysics [online], 2016)

**Appendix figure 2** Oscillating Water Column

This technology in ***appendix figure 2*** has been used by THE LIMPET by Wavegen, which had been commercially grid connected (Alternativeenergysourcesinfo [online], 2016; EMEC [online], 2016, 3).

5. Overtopping/Terminator device

This technology uses a storage reservoir which has water capturing devices on top. When the waves come, the water falls into the reservoir, passing a turbine that generates power. The water is then returned to the sea (see ***appendix figure 3***).



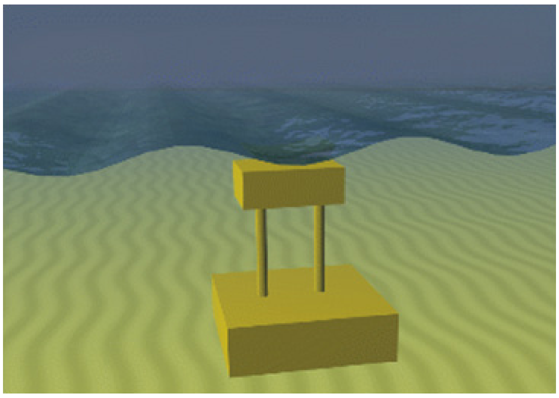

(Source: Hswstatic [online], 2016)

**Appendix figure 3** Overtopping device

This device in ***appendix figure 3*** has not been developed by any of our case studies in Scotland and Sweden, but it is tested in the UK (EMEC [online], 2016, 3).

6. Submerged Pressure Differential

These wave devices are usually connected to the seabed, close to the shore. The change in the sea level causes a pressure differential in the machine which is using pumps to transport fluids through a system. This way, power is produced. See ***appendix figure 4***:



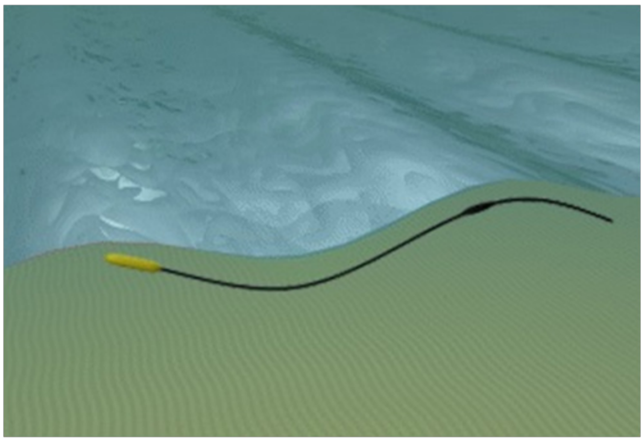
(Source: Kis-orca [online], 2016)

**Appendix figure 4** Submerged Pressure Differential

This device presented in ***appendix figure 4*** has not been used by our case wave developers; only five companies from the EMEC wave developer population use this approach (EMEC [online], 2016, 3).

7. Bulge wave

In case of the device that can be seen in ***appendix figure 5***, a rubber tube that is filled with water is moored to the seabed and heads to the waves. When waves occur, water enters through its stern and causes pressure that develops a bulge in the device that is travelling through the tube, driving a turbine that generates electricity.



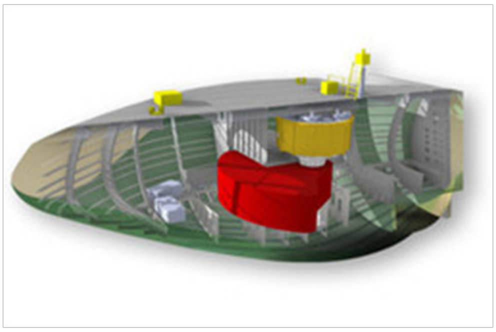
(Source: Waveenergyconversion [online], 2016)

**Appendix figure 5** Bulge Wave

The bulge wave device in ***appendix figure 5*** is not in development by our case companies and is only tested by one developer in the UK; which is the only one in the whole EMEC wave developer population (EMEC [online], 2016, 3).

8. Rotating mass

Rotating mass devices use two different motions, either of an eccentric weight or a gyroscope. Both motions are connected to an electric generator that produces electricity. See ***appendix figure 6***:



(Source: Rosspmiller [online], 2016)

**Appendix figure 6** Rotating Mass

This device in ***appendix figure 6*** has not been used by our case companies. There are three developers on the EMEC list that do research on it (EMEC [online], 2016, 3).

Most Swedish developers focus on the point absorber, one that has not been studied in this paper develops an attenuator. In Scotland and the UK all devices except of the submerged pressure differential and rotating mass have been developed or are still tested (EMEC [online], 2016, 3). ***Appendix table 1*** provides an overview about the different device types in our case studies:

**Appendix table 1** Case Device Types

| Case | Country | Device Type |
|---|---|---|
| Aquamarine Power | Scotland | Development of Oscillating Wave Surge Converter |
| EMEC | Scotland | Support of all kinds of device types |
| Pelamis Wave Power | Scotland | Development of Attenuator |
| Wave Energy Scotland | Scotland | Support of all kinds of device types |
| Voith Hydro Wavegen | Scotland | Development of Oscillating Water Column |
| Ocean Harvesting | Sweden | Development of Point Absorber |
| Offshore Väst | Sweden | Support of Attenuator and Point Absorber |
| Seabased | Sweden | Development of Point Absorber |
| Waves4Power | Sweden | Development of Point Absorber |

(Source: Own illustration)

***Appendix table 1*** shows: while EMEC and Wave Energy Scotland support all kinds of different wave power solutions, Offshore Väst in Sweden supports the two approaches of attenuator and point absorber in Sweden. The other case studies, Aquamarine Power, Pelamis Wave Power, Voith Hydro Wavegen, Ocean Harvesting, Seabased and Waves4Power are/were wave developers of one specific device type (EMEC [online], 2016, 3).

Basic technicalities

To have a better understanding of the devices' potential to supply electricity as studied in the analysis chapter, it is essential to understand what basic concepts like work, power, energy, terawatt, megawatt and kilowatt are (Unitjuggler [online], 2016).

First, it is necessary to see the interdependence between work and power:

Work is "the exertion of force overcoming resistance or producing molecular change" (Oxford Dictionaries [online], 2016, 2). As a formula (Physics Classroom [online], 2016):

Work = Force x Displacement x Cosine (theta)

Power is "the rate of doing work, measured in watts or less frequently horse power" (Oxford Dictionaries [online], 2016, 3). The formula is as follows (Physics Classroom [online], 2016):

Power = Work/time (i. e. kW/h)

Energy is "the property of matter and radiation which is manifest as a capacity to perform work". Mechanical energy has two different forms, potential and kinetic energy (Physics Classroom [online], 2016):

Potential energy = Mass of object (m) x acceleration of gravity (g) x height of the object (h)

Kinetic energy = 0.5 x mass of the object (m) x speed of the object $^2$ ($v^2$) (i. e. kW)

Having explained the simple concepts of work, power and energy, it is crucial to have an idea about the different scales of power, and energy. In this paper there are terawatt (TW), megawatt (MW) and kilowatt (kW) that are mentioned measurements of power; and million tons of oil equivalent (Mtoe) and kilowatt-hour (kWh) that are measurements of energy. The relation of power units is (Unitjuggler [online], 2016):

1 TW = 1,000,000 MW
1 MW = 1,000 kW
1 TW = 1,000,000,000 kW

Energy measures, which are equal to power multiplied by time, are for example (Unitjuggler [online], 2016):

1 Mtoe = 11,630,000,000 kWh
1 Mtoe = 11,630,000 MWh

It is helpful to have a look at total primary energy consumption to get a feeling for what a TW is. Primary energy sources mean sources that are "naturally occurring energy stores or energy carriers" (Everett *et al.*, 2012, 36). In 2012, the world primary energy consumption was 17.57 TW. Sweden consumed 0.07 TW and the UK 0.29 TW (Everett *et al.*, 2012, 43; Convert Measurement Units [online], 2016; EIA [online], 2016; Unitjuggler [online], 2016) Renewable energies have the potential to be in principle available for use for 117, 460.32 TW (Everett *et al.*, 2012, 9). This is 6,685.28 times the world's total primary energy consumption of 2012 (Everett *et al*., 2012, 9). Although it is not realistic to be able to harvest all of this energy; it is possible to cover a huge share of the world's total primary energy consumption (Everett *et al.*, 2012). Wave energy can realistically contribute with approximately 2 TW which is around 11 % of the total primary energy consumption in the world of 2012 (Murdoch University [online], 2016).

To develop an understanding of the smaller energy measures like MWh and kWh, further examples can help. MWh, the average electricity consumption per electrified household in 2014 was 3.4 MWh in the world, 7.8 MWh in Sweden and 3.9 MWh in the UK (WEC Indicators [online], 2016). According to the U.S. Department of Energy, a notebook computer with a wattage of 25 that is used for 8 hours on five days a week consumes 1 kWh of energy; a microwave oven with a wattage of 1500 needs 1.5 kWh for 1 hour usage a week; a coffee maker with a wattage of 1000 needs 1 kWh for 1 hour usage a week (US Department of Energy [online], 2016).

This basic understanding is helpful to grasp the opportunities that come with wave power devices and to clarify some of the results in the following empirical study.

Levelized Cost of Energy

The Levelized cost of energy (LCOE), often referred to as the Levelized Energy Cost (**LEC**), is calculated as the net present value of the unit-cost of electricity over the lifetime of a generating asset/device/plant. This can be seen in ***appendix formula 1.***

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

$I_t$ : investment expenditures in the year $t$

$M_t$ : operations and maintenance expenditures in the year $t$

$F_t$ : fuel expenditures in the year $t$

$E_t$ : electrical energy generated in the year $t$

$r$ : discount rate

$n$ : expected lifetime of system or power station

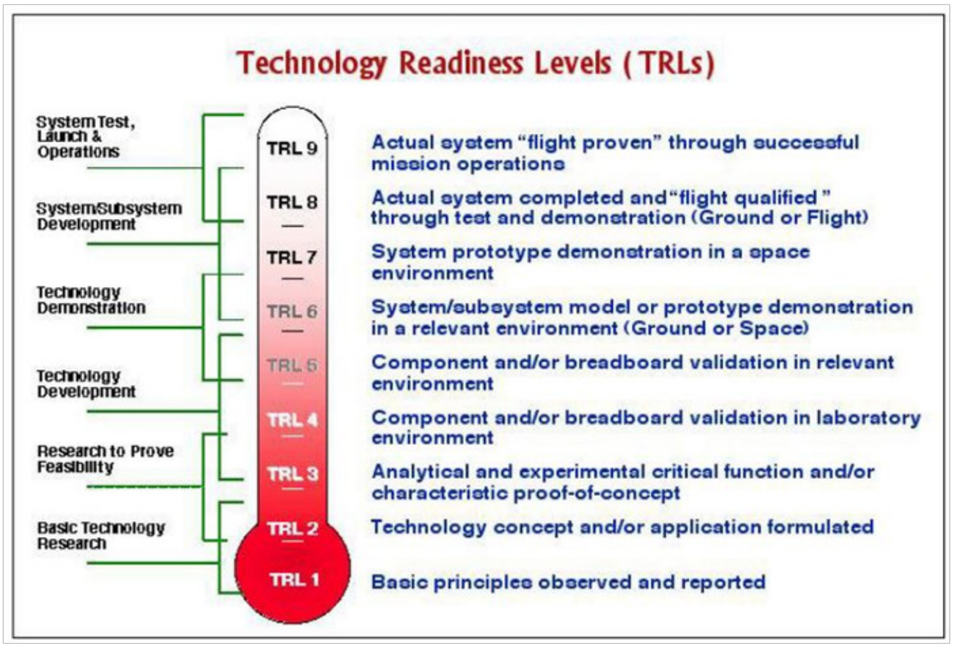
(Source: Nrel [online], 2013; OECD [online], 2016)

**Appendix formula 1** Levelized Cost of Energy

***Appendix formula 1*** incorporates an economic assessment including initial investment, operations and maintenance, cost of fuel, cost of capital and the role they play towards cost competitiveness. LCOE must be understood as the average price that the generating device must receive in market to break-even over its expected lifetime (Nrel [online], 2013; OECD [online], 2016).

# Appendix 2: Technology Readiness Levels and Technology Performance Levels

***Appendix figure*** *7* shows the usually used development steps, the technology readiness levels (Mankins, 1995):




(Source: Choonghsiafoundation [online], 2016)

**Appendix figure 7** Technology Readiness Levels

As can be seen in ***appendix figure 7***, there are several development stages that characterize technology development. This way, the stage of wave development can be analyzed using the needed infrastructure at each step and certain risks that come with it (Mankins, 1995). It also enables to understand where the wave energy development stands and what needs to be done to support further development.

Additionally to this, the concept of technology performance levels has been developed. Similar to the technology readiness levels, there are also nine performance levels in ***appendix table 2*** (Weber *et al.,* 2013, 3):

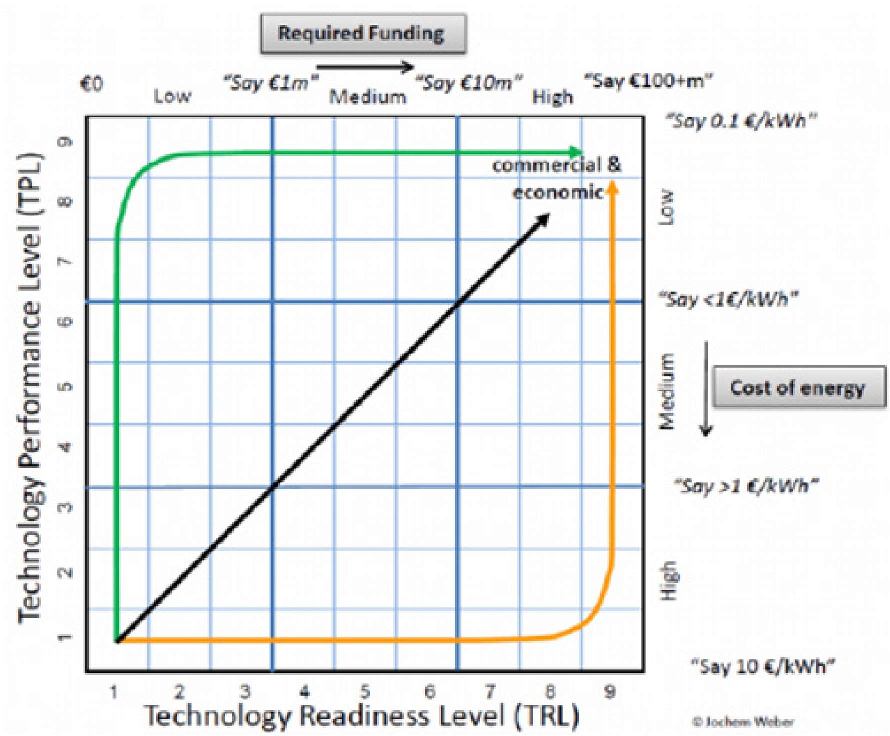
**Appendix table 2** Technology Performance Levels

| TPL | Category | Characterist. | TPL Characteristics |
|---|---|---|---|
| 9 | high | Technology is economically viable and competitive as a renewable energy form | Competitive with other energy sources without special support mechanism |
| 8 | | | Competitive with other energy sources given sustainable support mechanism |
| 7 | | | Competitive with other renewable energy sources given favourable support mechanism |
| 6 | medium | Technology features some characteristics for potential economic viability under distinctive market and operational conditions. Technological or conceptual improvements may be required. | Majority of key performance characteristics & cost drivers satisfy potential economical viability under distinctive and favourable market and operational conditions |
| 5 | | | In order to achieve economical viability under distinctive and favourable market and operational conditions some key technology implementation improvements are required. |
| 4 | | | In order to achieve economical viability under distinctive and favourable market and operational conditions some key technology implementation and fundamental conceptual improvements are required. |
| 3 | low | Technology is not economically viable | Minority of key performance characteristics & cost drivers do not satisfy potential economic viability |
| 2 | | | Some of key performance characteristics & cost drivers do not satisfy potential economic viability |
| 1 | | | Majority of key performance characteristics & cost drivers do not satisfy and present a barrier to potential economic viability |

(Source: Weber *et al.,* 2013, 3)

Having run through all levels of performance of ***appendix table 2***, the technology can finally reach a point where it is competitive to other energy sources without the need for special forms of funding or financial support (Weber *et al.,* 2013).

The TRL and TPL can be combined in a graph to see the dependence of required funding and cost of energy; leading to certain development trajectories as illustrated in ***appendix figure 8*** (Weber *et al.,* 2013, 4):




(Source: Weber *et al.*, 2013, 4)

**Appendix figure 8** Generic Wave Energy Converter Technology Development Trajectories

***Appendix figure 8*** shows: the further we get in the TRL, the more funding is required, and, logically, the better the TPL, the lower the cost of energy. The figure gives some examples for possible cost and funding dimensions as well (Weber *et al.,* 2013).

# Appendix 3: Interview Guidance and Survey

This appendix presents the *Interview Guidance* which was the loose structure of the semi-structured interviews and the survey, which has been conducted in Netigate (Netigate [Online], 2016).

**<u>Interview Guidance</u>**

- Why wave power?
- Describe your company's development in the last years.
- What development do you expect in the future?
- Do you cooperate with other research institutions?
    - Why?
    - Why not?
- What is needed in the supply chain? Are there differences to other renewable energy sources?
- How is wave power different to other renewable energy sources like wind or solar?
- Why is it more difficult for wave power than for other sources to get commercial?

- What is your approach to make wave power competitive?
- What are barriers?
- Describe these barriers
- What needs to be done?
- Why is wave power not competitive so far?
- How long does it take to make it competitive?
- Is there a positive development or rather a negative one?
    a. Which institutions support your research?
    b. Do you cooperate with other research institutions/developers/others?
    c. Do you feel that the wave industry is sufficiently regulated by a supportive infrastructure of standards?
        i. Why/Why not?
    d. Collective invention in technological advances driven by competing intellectual property interests, can be a force among wave developers (Handbooks in Economics, 2010). What are your thoughts on collective/cooperative invention?
    e. How do you see the concept of spreading the costs of invention and technological efficiency among multiple organizations through the collective/cooperative invention approach?
    f. Is there a legislative infrastructure that you use to exchange knowledge & data? If not, how would an international legislative infrastructure facilitate this process?
    g. Can you identify the development stages?
    h. What risks do you identify in each development stage??
    i. How do you approach them?
    j. How do you cope with uncertainty in the development process?
- *How* is the wave power supply chain organized in the UK/Sweden?
- *How* can wave power plants be a competitive renewable energy source in the UK/ Sweden?
- *What* are necessary steps to make wave power plants commercially competitive in the UK/ Sweden?
- *Why* is wave power not competitive in these two countries so far?

**<u>Survey</u>**

Dear Participant,

Please accept our gratitude for your contribution and appreciation on your professional opinion. This questionnaire is part of the Master Thesis Project by M.Sc. candidates Frencis Karagjozi & Gary Parker in Environmental Economics, at the Swedish University of Agricultural Studies in Uppsala, Sweden. This study aims at exploring enabling factors to make ocean wave energy a competitive renewable energy source.
The data herein aimed at being gathered has the purpose to create empiric evidence/suggestions on the wave power sector on an international scale.
The following questionnaire also offers the possibility to express your personal views on the market and eventual suggestions you might have. The answers will be handled with the greatest respect for the integrity of all parties involved. No results will be presented or disseminated in such a way that individuals, developers, companies, or projects can be identified.
The questionnaire is composed of 33 question in total, and we estimate an average time of

20-30 minutes depending on the length and depth of your responses. For your consideration and further facilitation, we would like you to consider the terms of *Competitive* and *Commercial* under the following framework:

1. **Competitive**

- Survivability
- Accessibility / Availability
- Financial Feasibility
- Maintenance / Conservation

2. **Commercial**

- Price / kWh
- Economic & Transportation Cost
- Environmental Impact
- Constant Power Supply

**We are grateful for your opinions & time!**

**PLEASE NOTE: WE SUGGEST THAT YOU AVOID CLICKING 'ENTER' THROUGHOUT THE QUESTIONNAIRE.** BY DOING SO, YOU WILL BE JUMPED TO THE END PAGE.
HOWEVER, IN THE EVENTUALITY THAT THIS HAPPENS, YOU CAN BACKSPACE INTO
WHERE YOU PREVIOUSLY LEFT OFF.

**1. General Information**

*"There is one major resource that has remained untapped until now: wave energy. Its potential has been recognised for long, and mostly associated with a destructive nature. No solution has yet been found to harness it. Or has it?"*
(Cruz, 2007, p. 1)

**Please provide how long you have studied wave energy? (Answer in years)**

**Please provide the number of employees you have.**

**Please describe your functional connection (researcher, developer, funder, etc.) to wave power research/work.**

**Please describe your perspective on wave energy in comparison to other renewable energy sources. (Economic, social, environmental aspects)**

**What is the realistic cost per kwh for your wave energy technology?**

**Which technological approach (model, device) do you use to harvest wave energy?**

**What is the longest lifespan of your device(s)? (Answer in months)**

**2. Strategic Decisions**
*''Competitiveness is here taken to mean the possession of the capabilities needed for sustained economic growth in an internationally competitive selection environment, in which environment there are other (countries, clusters, or individual firms, depending upon the level of analysis) that have an equivalent but differentiated set of capabilities of their own.''*
(Fagerberg et al., 2005, p.544)

**Is your project harversting wave energy on a commercial scale?**

**What needs to be done to be able to go commercial?**

**Which barriers exist?**

**What is the biggest supporting factor?**

**How much initial investment is needed to get your device/s operational?**

**How much development investment is needed?**

**Where do you see the biggest struggle in the cost structure?**
Generation costs
Deployment costs
Foundation costs
Chain Grid Costs

**Why is wave energy not competitive in your country so far?**

**Please describe in a few sentences how wave energy plants can be a competitive renewable energy source in your country.**

**What do you see as the next necessary steps needed to be taken by the involved stakeholders (company, state, or others)?**

**3. The Supply Chain Network**
*"A supply chain is only as strong as its weakest link."*
(Lysons & Farrington, 2006, p. 92)

**What are the main challenges that you have encountered to make wave power devices grid connected?**

**What changes are needed in the energy supply chain?**

**Where do you see the weak links in the chain?**

**Which link of the chain is the most important factor in the development of grid connected wave power plants?**

**What are the differences of wave energy chains compared to other renewable energy supply chains?**

**How is the wave energy supply chain organized in your country?**

**4. Economics of Innovation and Technology**
*''Collective invention occurs when competing organizations share knowledge about the design and development of new technologies"*
(Hall & Rosenberg, 2010, p. 575).

**Which institutions support your research?**

**Do you cooperate with other research institutions/developers/others? (Why/why not?)**

**Collective invention in technological advances driven by competing intellectual property interests can be a force among wave developers (Hall & Rosenberg, 2010). What are your thoughts on collective/cooperative invention?**

**How do you see the concept of spreading the costs of invention and technological efficiency among multiple organizations through the collective/cooperative invention approach?**

**Can you identify the development stages?**

**Is there a legislative infrastructure/professional platform that you use to exchange knowledge & data? If not, how would an international legislative infrastructure facilitate this process?**

**What risks do you identify in each development stage?**

**How do you approach the risks?**

**How do you cope with uncertainty in the development process?**

**Thank you for taking part in this survey!**

We are very passionate about the development of the wave energy industry and with this study
we hope to deliver a small contribution to the cause of making this sector competitive in the future. It is our ambition to further emancipate the academic circles into future substantial research in the wave sector beyond the humble interest levels shown thus far.
We look forward to reading your survey responses.

**Your time is very much appreciated.**

**Frencis Karagjozi & Gary Parker**

Contact for the survey: **frzi0001@stud.slu.se or gapa0001@stud.slu.se**
This survey is part of a Master thesis at SLU in Uppsala, Sweden. The final paper will be available at http://stud.epsilon.slu.se/cgi/search/advanced in the second half of 2016.

For further information, questions or suggestions mails are welcome at any time.

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