Using Game Theory to analyse the diffusion of shore power

by

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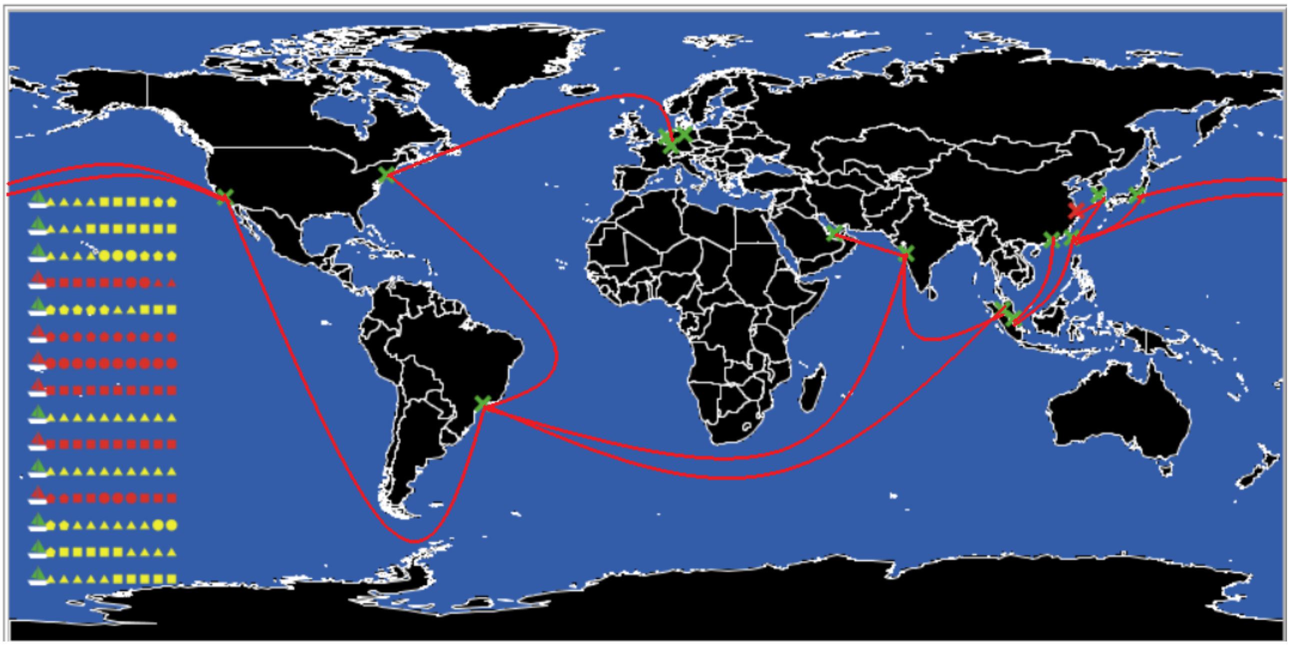
to obtain the degree of Master of Science
at the Delft University of Technology,



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SAMSKIP LOGISTICS

Preface

During my Master thesis, I found out what the essence of doing research is. It's not about finding problems but about asking the right questions. When Samskip arrived with the issue of Shore Power, they wanted to know what it would mean for them and how much it could bring them. With the idea that there was proper research in it, I started asking around, talking around and reading a lot. It took a long time before the right questions were finally formulated, and the spinal cord of my research was firmly on paper.

This research has taught me things in many different areas. Before I started, I wanted to teach myself a new skill and not just build on what I already know. In this research, I have immersed myself in the world of Game Theory, Agent Based Modeling and ports in general. I found out how many different sides there are to sustainable investments like shore power and what is needed to implement this.

From the TU Delft, I would like to thank my committee for the support they have given me and the structure they provided over the past months. From the committee, I would especially want to thank Rob Stikkelman. Each weekly meeting, which occurred twice a month, helped in shaping a simple problem into the fully-fledged research it is now and forced me to think about aspects I did not feel like thinking about. But the meetings can best be described as; half an hour of natter and every now and then something remarkable bright.

Personally, I would like to thank my flatmates for taking care of me over the past months. They distracted me more than necessary but helped me out more than they needed to do. It gave the whole process, which was largely accomplished in isolation, enough airiness to pull me through. Without them my head would be full and my stomach empty.

Lastly, I would like to thank my parents. In the seven years of my study they've taken care of me and motivated me throughout this journey. An excellent combination of good wine and sound advice has guided me in the right direction. Thank you all.

D.E. van der Meer
Delft, August 10, 2020

Executive Summary

Over the last few decades, ports, and the activities carried out there, have expanded enormously. Due to increasing globalisation, the demand for the transport of containers, bulk, passengers and other goods has grown enormously. There is a downside to this growth, ports and ships are responsible for 3% of global CO_2 emissions. This number can grow up to 8% in the coming years. Emissions from ships around ports are only a small part of the total emissions but are highly concentrated and close to residential areas. There are many solutions to this problem, such as the use of MGO, LNG or scrubber systems. This research, initiated by Samskip B.V., focuses on the solution of Shore Power. Shore Power has properties that can ultimately reduce emissions and costs. However, large-scale implementation is still lagging. Barriers can be identified on three different levels. The first level is Shore Power between shore and ship, and high costs and technical complications hamper this. Shore Power in a port encounters problems due to the complex network of shareholders and the lack of clarity as to who should be responsible for the costs. The last level is about Shore Power between ports. Ports find themselves in a chicken and egg story because they depend on each other in the efficiency of their investments and do not want to be the first to invest. The interaction between multiple ports is what this paper will investigate.

Ports are interdependent in terms of Shore Power because they are connected in a network and ships navigate between many ports. The choices of a port or shipping company affect the profitability of other ports and shipping companies. Game Theory underpins this situation and suggests a Nash Equilibrium. A game has been designed that mimics the current situation for ships and shipping companies and will further investigate the Nash Equilibrium. This game makes assumptions about reality, has players, rules, utility functions and more.

To analyse and manipulate the game, it is modelled from the ground up, using a quantitative modelling process. Essential data and participants have been processed using different model building blocks. These building blocks consist of Agent Based Modeling, decision-making mechanisms and profit utilisation behaviour. This quantitative model is completed with the conceptualisation of the Shore Power environment and implemented in a Netlogo programming environment. The different blocks ensure that the model is flexible and adaptive to future changes.

The model designed in Netlogo proves that there are two Nash Equilibria in all possible combinations of player choices. Payoff tables for the players also confirm this finding. The two equilibria can be found at the point that no one chooses Shore Power and at the point that everyone chooses Shore Power. The point where everyone chooses Shore Power is under certain circumstances more favourable for all players. A conclusion from this is that ports and shipping companies are currently not stimulated to use Shore Power. This choice is based on the idea that other parties do not swap strategies either. They make this choice even though collectively, there is more to be gained when they change strategy.

In the game theory, players in a Nash Equilibrium will never switch strategies. They never switch because a that yields them less utility. This research formulates strategies to ensure that this less favourable Nash Equilibrium disappears and players do not end up in it. The strategies are as follows:

1. Using emission prices
2. Forming Coalitions
3. Obligations by Policy
4. Payment of Subsidy

This research also formulates properties that can be added to game theory that show that in the long run

players can still switch between the two Equilibria. The model tests this by reviewing the rationality of players, as well as the non-cooperative aspect of game theory. Based on these two properties, the model has been revised.

The results are divided into a practical side and a theoretical side. The practical part indicates strategies that increase the implementation of Shore Power, and the theoretical part indicates changes to the game theory. First of all, it appears that the prices of the fuel used in ships and the electricity are decisive in the profitability of Shore Power. With the current price of €300/tonne of fuel, it is never a wise investment for ships. When the price rises to €500/tonne, it is feasible for many ships. Using emission prices increases the potential value of Shore Power investments. When this is taken into account, parties will be more likely to abandon the use of auxiliary engines. Another critical factor is the presence of the right infrastructure in ports. The presence increases the number of hours ships can use Shore Power, and the investments will be recouped faster. The right move for ports and local authorities is to take responsibility for this infrastructure. The responsibility gives a kick start to the network and the implementation of Shore Power, and with the right business model, these investments can be earned back within ten years.

Besides the strategies that support the practical part of this research, this research has also analysed specific characteristics of the game theory. As mentioned before, two equilibria are present. According to classical game theory, players stick to their strategy. In the model, adjustments have been made that revise the rationality and non-cooperative aspects of the players. Revising the rationality has changed the outcome but also made it less reliable. The non-cooperative aspect has been removed by allowing players to cooperate when their utility can be increased together. The model shows that players seize this opportunity, which in total has a positive effect on the network and the implementation of Shore Power.

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List of Acronyms

SP Shore Power

GHG Green House Gasses

AE auxiliary engines

AMP Alternative Maritime Power

SPI Shore Power Infrastructure

SPE Shore Power Equipment

TEU Twenty feet Equivalent Unit

SECA Sulfur Emission Control Areas

IMO International Maritime Organization

MGO Marine Gas Oil

LNG Liquefied Natural Gas

HFO Heavy Fuel Oil

ULSFO Ultra Low Sulphur Fuel Oil

VLSFO Very Low Sulphur Fuel Oil

Chapter 1

Introduction

Ports and the activities they conducted have primarily contributed to the welfare of the world. Ports are the concentration of trade, logistics and production, and their network connections have experienced unprecedented growth over the last decades: many ports in the world have benefited from the increase in international trade. The globalisation and the booming economies of Asian countries elucidate this expansion.

Within ships the combustion of fossil fuels, particularly in diesel engines, airborne exhaust emissions. Due to the significant amount sulfur in the fuel, inadequate combustion of the low-quality fuel and high pressure and temperature inside the combustion motors, they emit harmful gasses and particles like; CO_2, SO_x, NO_x and $PM_2.5$. These emissions have an impact on the environment and human health (McArthur & Osland, 2013). The port and shipping industry accounts for over 3% of the global anthropogenic carbon emission. With the prognosticated and current growth rate, this could increase to 8% by 2050 if no measures are taken (Buhaug et al., 2009).

The emissions of ships near ports account only for a small part of the overall emissions. However, because ports attract multiple ships at the same time, they are highly concentrated with the exhaust in the proximity of populated areas (Corbett et al., 2007). In the ports of Long Beach and Los Angeles, 11% of $PM_{2.5}$ and 72% of SO_2 total emissions were emitted because of hoteling (Group, 2012); hoteling load is the electricity a vessel needs in the port. Corbett et al. conclude that port emissions, compared with seagoing shipping, have a higher impact on public health.

Additionally, one can see that there is a great deal of willingness to become more sustainable based on international treaties, the most prominent example of which, of course, is Paris 2015. This agreement was presented at the climate summit in Paris on 12 December 2015. By 2050, or soon after, CO_2 emissions must be completely phased out in order to limit global warming. In the agreement, the upper limit of 2 degrees of global warming compared to the pre-industrial era was laid down for the first time in a legal instrument. Also, it lays down the objective of limiting global warming to 1.5 degrees. Furthermore, the use of fossil fuels must phase out quickly, as this is a significant cause of excessive CO_2 emissions. An often mentioned weakness of this treaty is the failure to mention both aviation and shipping, which is something that has a notable impact on shore-side electricity. However, this treaty does show the general trend and the thinking that is prevalent among a large part of the world's population.

Among others, these examples are the reason that ports have to become more sustainable. There are several measures that ships and ports can undertake. Ships that have plants with hybrid propulsion or power supply can reduce 10% to 35% of the emissions and fuel consumption (Geertsma, Negenborn, Visser, & Hopman, 2007). The hybrid propulsion requires optimum use of batteries and advanced energy management strategies to safe power and reduce fuel over time. There are three other well-known abatement options examined below, which are MGO, Scrubber and LNG (Zis, Angeloudis, Bell, & Psaraftis, 2016).

MGO

Marine gas oil (MGO) is a pure distillate oil. The sulfur content of this oil is 0.1% or lower. Because of the low sulfur content, this is the only fuel that marine engines can use in ports or other regulated waters. The Engines do not need notable modifications for MGO usage. Most marine vessels will use MGO besides another more polluting fuel and require a second tank for fuel storage. MGO has different characteristics, like a lower viscosity. In order to prevent damage, lube is needed additionally in the fuel pumps. Because of the characteristic differences, it does influence the performance of the engine. Because heavy fuel oil (HFO) is less processed, it is the cheaper option of the two. In the future, MGO will increase in price even more due to the increasing demand for low-sulfur alternative fuels (Notteboom & Vernimmen, 2009). The constant price increase of MGO makes other options more attractive.

Scrubber Systems

Burning fuel emits gasses from engines into the air like sulfur. In a scrubber system, the sulfur oxides (SO_x) are filtered through water which results in sulfates (SO_4). There are multiple ways of washing out the SO_x with water. Where the water originates from determines the type of scrubbing. One can use freshwater, seawater as well as a combination of those two in hybrid scrubbing systems. In the Baltic sea or Alaska, the alkalinity of the seawater is too low, which requires the use of freshwater (Henriksson, 2007). In other seas or oceans, the alkalinity of the seawater is sufficient for the scrubbing system to function. These scrubbing systems are built on new ships, or it is an option to retrofit older ships which is the more expensive option, and it requires some space which reduces the vessels capacity. Using scrubbers in freshwater can reduce $PM_{2.5}$ emissions by 30% and SO_x by 97% (Zis et al., 2016).

Liquefied Natural Gas

The third option is the use of LNG (Liquefied Natural Gas). Naturally, it exhausts less sulfur, and so it complies with the mandates. To use the gas for the propulsion of vessels, one needs a dual-fuel engine. The use of LNG has increased in the last ten years. Where LNG carriers were the only one in the past who would use LNG as propulsion, nowadays many ports offer facilities for LNG bunkering. The efficiency, as well as the low costs and most importantly, the lower emissions, makes this a plausible option. The exhaust mandates that require fuel to change will make LNG play a significant role as it is expected to outweigh retrofit costs. However, there are not enough facilities where they offer LNG bunkering, making it a less favourable option (Holden, 2014). Furthermore, LNG does not comply with the long-term vision of the climate agreement of Paris, which makes it an even less attractive option for investments.

Shore Power

The final measure is the main focus of this research. This measure reduces emissions inside ports and uses shore power instead of the electricity generated by the AE (Auxiliary Engines). This abatement option is getting more popular. An overview generated by the World Ports Climate Initiative in 2015 showed that many ports have already installed a shore power infrastructure (SPI) as can be seen in table 1.1.

Samskip is one of the companies in the Port of Rotterdam that want to make use of Shore Power but have many questions towards its implementation. This research is initiated and conducted on their behalf. In the next section, the problem that arises when looking at shore power is mentioned and is the starting point of the thesis research.

1.1 Problem Description

As mentioned above, the solution that is proposed as an abatement option that does comply with the sulfur regulations and the long-term vision on sustainability is Shore Power (SP). Although the benefits of the technology are clear and convincing, so far it did not lead to large-scale-diffusion. Many practical problems arise when looking deeper into the technology. The relatively high capital cost for retrofitting ships and berths are a problem, as well as the costs and emissions of the power that is supplied by the local grid can harm the potential financial and emissions abatement benefits. Besides these, there are logistical problems. One of these problems is the risk of creating costly queues at berths and technical issues, like the voltage and frequency differences of vessels as well as the high peak power demand for local grids. These are all issues that act as barriers towards the diffusion of this technology in the market. On the contrary, SP has many benefits that can act as enablers towards the implementation inside ports and vessels. Investigating the benefits and disadvantages of this technology is one of the goals of this thesis.

One has to note when analysing the situation of whether or not to invest in shore power, that this question employs criteria other than return and financial risks. This situation is a so-called 'socially responsible investment' (SRI) (Tsai, Chou, & Hsu, 2009). These social consequences have to be incorporated somehow in the big,

Table 1.1: The ports that installed Shore Power up to 2017

Year of Introduction	Port name	Country	Capacity (MW)
2000	Gothenburg	Sweden	2.5
2000	Zeebrugge	Belgium	1.25
2001	Juneau	U.S.A.	9
2004	Los Angeles	U.S.A.	60
2005	Seattle	U.S.A.	12.8
2006	Kemi	Finland	N/A
2006	Kotka	Finland	N/A
2006	Ouli	Finland	N/A
2008	Antwerp	Belgium	0.8
2008	Lübeck	Germany	2.2
2009	Vancouver	Canada	16
2010	San Diego	U.S.A.	16
2010	San Francisco	U.S.A.	16
2010	Karlskrona	Sweden	2.5
2011	Long Beach	U.S.A.	16
2011	Oakland	U.S.A.	7.5
2011	Oslo	Norway	4.5
2011	Prince Rupert	Canada	7.5
2012	Rotterdam	Netherlands	2.8
2012	Ystad	Sweden	6.25
2013	Trelleborg	Sweden	4.6
2014	Riga	Latvia	N/A
2015	Bergen	Norway	N/A
2015	Hamburg	Germany	N/A
2015	Civitavecchia	Italy	N/A

financially driven corporations like ports and have to be weighed against quantitative consequences. What stands out before the research takes off is the fact that not many ports have implemented SPI so far in their supply chain while the technology has been around for some decades now. A low implementation rate indicates an impasse and this research has to study the situation and environment of the question as mentioned above.

Ports are the environment of the SP problem which immediately raises concerns regarding the decision making stakeholders have to do on the topic. Ports have complex structures which are managed and organised differently across the world. Several factors can influence the decision making like; Location of a Port, types of cargo, the socio-economic structure of a country and the level of privatisation (Brooks, 2009). This structure has to be integrated into the decision making, and the analysis must take these factors into account. Actions that influence the performance of a port require investments and agreement by the stakeholders. Stakeholders will be referred to as agents. In this context, an agent is an entity that can act or affect the port system (García-Morales, Baquerizo, & Losada, 2015). Between these agents, there are often conflicting interests like; Environmental protection, Resident interest and overall economic development versus port development (de Langen, 2006).

The environment in the port can be described as a system, and the agents as autonomous decision-making entities. The agents can make decisions like using their AE, adapting their ships to shore power and cooperate with other agents. Installing shore power installations requires set-up costs for the ports; the same goes for adapting ships to these installations. The agents in the port depend on each other for the effectiveness of these investments. The port has to make agreements with multiple companies based on their shared ambition. On top of that, grid operators have to adapt their systems to provide shore power. These relations between agents can be simulated in a repetitive competitive environment, and through computational power, it can predict behavioural patterns (Bonabeau, 2002). The simulations can be used to understand the current situation in ports better.

As can be read, the implementation of SP involves difficulties. There are unknown barriers and enablers; the environment is complex and can influence the decision making of the stakeholders who have conflicting interests. To better understand this situation, one has to map it and probably simulate it to be able to conclude on causes and possible solutions. The main problem of this research is that there are no easy applicable ways of describing and analysing this situation according to a proven theory. The first step is fully understanding state of the art by reviewing the literature and draw conclusions and perspective from there. This process can be read in the next section.

1.2 Literature

The search for the right literature is an iterative process in which one regularly update the search terms do have a better fit with the actual research. This section tries to capture this process. It will show the search terms and the results it generated with lead to an overview of the literature. The terms were aimed at peer-reviewed and published articles. The engines and databases used are Google Scholar, Scopus and Web of Science.

Aforementioned, the subjects of this research are among others; Shore Power, Ports, Sustainable innovation and Network decision making. The search terms had to capture the essence and boundaries of the research. The search terms used can be read in table 1.2. Building a structure for the literature review helped in creating insight into the situation and classifying the problem. The search terms often resulted in many hits. Sorting on relevance and filtering on at least some citations lead to interesting articles. In Google Scholar, the magnitude in hits did not generate a problem because the most relevant articles were often displayed on the first page. The search in the databases resulted in important articles. The references for these selected articles were used to discover the rest of the literature. This iterative process repeated.

Table 1.2: Literature review - Search terms

Try	Search terms	Database	Hits	Action
1	"Green Ports"	GS	919	Wanting to see the current state of green ports but too many hits. Tried with alternative search term.
2	"Sustainable Ports"	GS	428	Still to many hits. Tried to specify the search terms.
3	Environmental AND Innovation AND Ports	WoS	72	Selected article on stakeholders and environmental innovation in ports
4	"structure Ports"	Scopus	42	Selected articles on governance structures in ports and an article on different stakeholders in ports.
5	"Shore Power"	GS, WoS, scopus	-	Generated too many hits WoS and Scopus. GS gave articles for the state of art of SP.
6	Cold Ironing	GS	1540	Selected an article on the socio-economical benefits of SP
7	"Shoreside Electrical Power"	GS	93	Selected an article on challanges of interconnecting.
8	"alternative maritime power"	GS	340	Selected an article on AMP barriers in China.
9	"Shore power" AND characteristics	Scopus	24	Not the right results.
10	"Shore power" AND barriers	Scopus	3	Selected an article on the barriers of SP implementation in Djibouti.
11	Shore Power Management	WoS, Scopus	-	Not the right results.
12	"Shore Power" AND installation	GS	3540	Selected an article for SP standards and SP deployment problems.
13	"Shore Power" AND "decision making"	WoS, Scopus	-	Not the right results.
14	"Shore Power" AND Standards	Scopus	26	Selected an article for SP standards.
15	"Shore Power" AND Networks	Scopus	32	Not the right results.
16	"Modelling Ports"	Scopus	22	Not the right results.
17	"Simulation Ports"	Scopus	2	Not the right results.

The first step is to look at the current situation in the ports. By evaluating which problems are occurring, one can understand why sustainable innovations like shore power are necessary. The next step is taking a look at why it is complex and challenging to implement shore power. The final part of the literature analyses shore-power while making a distinction between the different levels. The first level is an analysis of a ship and a quay and the difficulties that occur there. The second level is how a port can deal with shore power problems, and the third and final level is creating an overview in the shore power problems across multiple ports. Which papers were selected can be seen in table 1.3. This literature study aims to identify a knowledge gap on which the rest of this research can elaborate.

Table 1.3: Literature review - Selected papers

Paper	Athor(s)
A study of the potential of shore power for the port of Kaohsiung, Taiwan.	Tseng & Pilcher
Costs and benefits of shore power at he port of Shenzen	Wang et al.
Critical bariers to the introduction of shore power supply for green port development	Radwan et al.
Identifying barriers in the diffusion of renawable energy sources	Eleftheriadis & Anagnostopolou
Identifying the unique challenges of installing cold ironing at small and medium ports	Innes & Monios
Key factors and barriers to the adoption of cold ironing in Europe	Arduino and Ferrari
Payback period for emissions abatement Alternatives	Zis et al.
Shore Side Electricity in Europe: Potential and environmental benefits	Winkel et al.
Stakeholders, conflicting interests and governance in port clusters	de Langen
State of Shore Power standards for ships	Peterson et al.
Technical design aspects of harbor area grid for shore to ship power.	Kumar et al.
The governance structure of Ports	Brooks
The shore ower deployment problem for maritime tranportation	Wu & Wang

1.3 Introduction to innovation in ports

This section analyses the current state of ports and their sustainability innovations. It will generate answer on what these innovations are, and these are so hard to implement.

1.3.1 Shore Power

One of the measures proposed by different studies to reduce the emissions inside ports is to use shore power instead of the electricity generated by the AE (Auxiliary Engines). Shore power is also called cold ironing, shore-side electricity, onshore power supply, alternative maritime power and shore-to-ship power supply (Chen et al., 2019). Through SP a berthed vessel can use shore-side electricity to supply onboard systems like ventilation, lighting and communication from electricity. The vessels can continue their ship operations while being connected to onshore power without emitting GHG. The connection from the local grid to berthed vessels comes about through substations at the port (Wang, Mao, & Rutherford, 2015).

The reduction of emissions in ports is the most important benefit of SP. There have been numerous studies on SP and other environmentally friendly options. Three different SP scenario's were calculated in (Khersonsky, Islam, & Peterson, 2007) and (Ferrara, Uva, Nowlin, & Side, 2011) and all the options emitted less GHG. Most studies tried to calculate the potential emission reduction effect by comparing the power needs and the energy mix, like the research in the port of Kaohsiung (Tseng & Pilcher, 2015) or the port of Mytilene (Kotrikla, Lilas, & Nikitakos, 2017). In European ports, the effect of SP would be significant in terms of GHG and other air pollutant reductions. Eight hundred thousand tons of CO_2 will be saved from going into the atmosphere by 2020. This reduction of CO_2 estimates the anticipated health benefits to €2.94 billion (Radwan et al., 2019). A general study that summarised 13 pieces of research displayed that SP could reduce emissions across ports in America, Asia and Europe between 60% and 80% (Wu & Wang, 2020).

Although the benefits are always present, the effectiveness of SP depends on the energy mix. Most researches do not take the emissions in consideration that are exhausted during the extraction, transportation and consumption of the energy for SP (Peng et al., 2019). When using a mixture of LNG (Liquefied Natural Gas), coal and nuclear for the energy mix, the reduction of emissions are still around 50% for CO_2, SO_2 and NO_x (Zis et al., 2016).

1.4 Implementing innovations

Shore power has benefits that contribute to a sustainable port. Innovations like these and in general have become an increasingly import factor in maintaining competitive advantage (Porter, 1990). However, there are problems with the implementation of shore power on different levels. This section will capture the problems that occur on these levels as well as the benefits provided by SP and will analyse the methodology and findings.

There are eleven barriers stated that hinder the implementation of shore power (Radwan et al., 2019). These barriers can be analysed on the different levels mentioned above. For example, the costs of retrofitting the ship and electricity are difficulties that occur in connecting a ship to the quay. These barriers came from expert interviews. This study applies a Fuzzy set theory to identify critical barriers and quantify qualitative data.

1.4.1 SP between Ship and Quay

The first section analyses the situation between a ship and a quay. There are specific difficulties, to which ships have to adjust. On the other hand, they can gain specific benefits. The literature used comes from section 1.3.1.

Different aspects are relevant to analysing this situation. This research investigates technical and financial barriers. To start with SP initial investments have to be made. It is necessary to retrofit a ship to create a connection between the local grid and the electrical systems. The costs of retrofitting are around $400,000 for Ocean-Going Vessels (OGV)(Arduino, Carrillo Murillo, & Ferrari, 2011). The costs vary heavily on the size of the vessels. In a more recent study, the costs for the largest vessels (more than 100,000 GT) was up to $750,000. Adapting smaller vessels is possible for $300,000 to $700,000; this also depends on the type of vessel. Besides the ships, there are also initial investments for the ports. Connecting the SPE of ships to the port requires an expensive retrofitting process which creates SPI (Wu & Wang, 2020).

After these investments, one can save fuel and reduce emissions. Calculating the cost-effectiveness of these options requires one to calculate the emission generation and the fuel consumption for each scenario. With an activity-based methodology, the cost per ton of abated pollutant was calculated (Zis et al., 2016). Zis et al. found out that the payback time for a vessel retrofitting costs is dependent on the electricity price, time spent at ports and the price of fuel. The other research is from (Eleftheriadis & Anagnostopoulou, 2015) who used quantitative methods to identify the energy demands of ships and compared the costs to emission savings. A 10-year unsubsidised scenario in the most realistic case will not generate a positive NPV after ten years. After the investments, there are maintenance costs. The World Ports Climate Initiative (WCPI) calculated that the maintenance cost is 5% of the initial investment annually. The supply of the electricity price to berthed vessels dramatically depends on local policy (Initiative, 2016).

Radwan et al. Found out thru a fuzzy cognitive map approach that a significant barrier for the implementation of SP is the power requirement. This power requirement is the total power required and the capacity of the national grid to prevent grid overload. This requirement ensures that total power in a port is sufficient and stable (Acciaro, Ghiara, & Cusano, 2014). The challenges of electricity capacity are the possible overload and the unknown total capacity requirements for all the vessels and the risk of destabilising. There is not much research done on these topics.

Another issue is the non-harmonised frequencies and voltages in different shipyards, which means that the systems of ships require different electricity input (Innes & Monios, 2018). Most vessels have an engine and systems that run on a frequency of 60 Hz. Through a converter, it is possible to solve the disparity of 50 to 60 Hz (Winkel, Weddige, Johnsen, Hoen, & Papaefthimiou, 2016). Solving this disparity comes at a higher cost, but it will be hard to arrange a standard in this field. For the different levels of voltages, it is possible to use a transformer to ensure the right voltage levels. A solution for the frequency issue is the use of battery storage based supply. This innovative concept could support the vessels in cold ironing (Kumar, Kumpulainen, & Kauhaniemi, 2019). There is also a standard developed for the voltage

Main Takeaway

The main takeaway is that the costs are a big issue at the moment. From multiple papers, the conclusion is that there is no financial incentive to invest in retrofitting the vessel or the shore-side. The shore-side has to be subsidised to make it feasible. However, since there is an environmental motivation behind shore power, one must bear in mind that the focus should not lay primarily with return on investment. It could be interesting to take the financial barrier away and see which other barriers are essential. The power requirements are a relevant question, as well. Making SP a more cost-efficient option requires more ships to use the installations. Whether or not it is feasible to get the power requirements and how this will influence the stability of the local grid. Another relevant issue is the difference in voltage and frequency. This difference could benefit from international cooperation between ports and establishing a standard. The literature on SP cooperation can be read in level 3. Other barriers can be read in section 3.

1.4.2 SP between Ships in Port

Zooming out of the quay and a ship, an overview of the port arises. This section analyses the different structures of ports and their stakeholders. This section also examines the barriers of SP implementation on this level and the local benefits of SP.

On a broader scope, it is hard to implement SP in ports. Ports have different structures which make it complex to design an approach. There are four different port model structures: The service port model, Tool port model, Landlord port model and The private service port (Brooks, 2009). The models vary in how much local authority owns the land, and if the infrastructure is leased or owned by operating companies. For each port, it makes the decision making analysis different. On top of that are the many different stakeholders in each of the models. These stakeholders often have conflicting interests which influence the port development on various ways(de Langen, 2006). While the collaboration between multiple and independent stakeholders is challenging, the density of stakeholders in ports gateways can boost innovation (Rowley, 1997). The intersection of the need for SP as an innovation and the collaboration between stakeholders is where the interest lies.

This intersection manages carefully which barriers for the implementation of SP can be identified (Radwan et al., 2019). The result of which leads to one of the barriers for SP implementation in ports which are the managerial aspects. The balancing needs of different stakeholders, coordination between various departments, managing the cultural change towards SP and the sensitivity of electricity pricing are all critical issues (Tseng & Pilcher, 2015). There are so many actors involved who need to be balanced by the management: Port operators, shipping companies, electricity supplier, local community and port authorities (Zanetti, 2013).

The barriers and benefits of SP make it a complex issue and hard to implement. The right way to analyse such a situation is analysing the current environment in simulations. There are no authors in the literature that design simulations for SP but many studies are conducting in optimising ports. In a case study, the impact of the construction of a quay in the port of Antwerp was assessed by a discrete event simulation model (Thiers & Janssens, 1998). Bottlenecks in the port of Trabzon were detected as well as investment alternatives through simulation-based models (Demirci, 2003). These models also helped in evaluating Berth allocation policies in different ports (Huang, Kuo, Wu, & Kuo, 2012). The other port analysis one could do is with stochastic optimisation were several decision variables act as a utility function, and the objective is to maximise that. The downside is that harbour systems could be very complicated. To honestly evaluate the alternatives would require many simulations (Solari, Moñino, Baquerizo, & Losada, 2010). Even Monte Carlo simulations are used for port planning and management to deal with the number of elements in a port (Izaskun Benedicto, García Morales, Marino, & De Los Santos, 2019).

One last issue in ports for the implementation of SP is the interdependency of the stakeholders. Shipowners do not retrofit their ships until ports have installed SPI and ports will not install SPI when ships are not ready. This "Chicken and Egg" dilemma needs to breached (Winkel et al., 2016). On the other hand, many ships are already SPE ready. 40% Of the ships entering the port of Shenzen were already retrofitted and came from ports in North America and Europe (Wang et al., 2015).

Main Takeaway

The main takeaway is the decision making in the port is complex for management because of all the different stakeholders. The benefits set out in section 1.3.1 are clear. Unfortunately, only a few ports benefit from it. All the involved stakeholders should come together to make suitable business model (Kumar et al., 2019). It is unlikely that his will happen because ship owners have to make investment costs and are not directly benefiting from the emission reduction. Shipowners will, because of this reason, not be the first ones to retrofit their ships when ports are not ready. More insight on the port level could be gained by simulating the stakeholders and the decision variables; this could be seen from the literature. However, the port system has to be simplified.

1.4.3 SP between different Ports

The benefits of introducing SP to a port are present but not sufficient for large scale diffusion across ports in the world. It would be beneficial to analyse the literature on a higher level to understand the SP issue and create insight. This level entails the cooperation between ports on the implementation of SP and which barriers are present. An issue at the moment is the different connection systems ships would require although the high voltage shore connection (HVSC) standard was developed (Parise et al., 2016), which is a standard for specific situations. Ships still use different voltages and frequencies. The power requirement of vessels, depending upon onboard power supply equipment, is either 11kV, 6.6kV or 440 V (Peterson, Chavdarian, Islam, & Cayanan, 2007). This difference increases the costs in an already not cost-effective situation. Most port authorities and ship operators have difficulties with the different specifications for connecting the shore-side electricity with the ship services (Khersonsky et al., 2007). A standard for this situation could increase the cost-efficiency.

On top of that, with the demand for standards, there are more benefits to be gained from cooperation. When more ports build SPI, Ships equipped with SPE will have the opportunity and will use SP more often. The costs for shipping companies will be reduced because it is cheaper for ships to use SP electricity than their AE after the initial investment of retrofitting the ship. As a consequence of this cost reduction, more shipping companies will install their ships with SPE which will lead to more ports installing SPI because it could be a source of income to supply vessels with onshore power. This process will be repeated and will benefit the SP implementation (Wang et al., 2015). The network effects of SP are qualitative and thus, hard to calculate. One study considered this effect in a shore power deployment problem (Wu & Wang, 2020) by designing a mathematical model. This model starts with a situation without retrofitted ships and ports to analyse the influence of subsidisation decisions from the government.

Main takeaway

The network effects of SP in ports are essential but not enough investigated. This effect touches on something important that ports need to cooperate and are better together. SP is an expensive investment; many expert interviews showed that all the stakeholders are willing to start with SP, but the main focus of every company is to remain competitive globally. This focus leaves some room for investigations. The implementation of SP would be much different without the investment barrier in which every company remains competitive in its pricing. Alternatively, how would the network effects influence the speed of implementation of SP through different ports in the world?

1.5 Knowledge gap

Out of all the literature reviewed in the previous section arise some important aspects of SP, and it identifies a knowledge gap. The knowledge gap leaves room for the conducted research in the rest of this thesis. SP is too expensive, as is stated in multiple types of research. Nevertheless, SP is an environmental improvement in polluting ports, and in the end, it will be installed. What is lacking in the literature is how the situation would look like if the financial barrier would be ignored and which barriers at that moment would be key in the SP implementation.

What is clear is that sustainable innovations like SP are complicated because of the many stakeholders in ports. There are many analysis and simulations on optimising port supply chains but not on the decision making of the stakeholders in the port. The different stakeholders have different interest and are stuck in a "Chicken and Egg" dilemma of who is investing first. Taking the first step of retrofitting a port with SPI should encourage ship owners to retrofit their ships. Multiple ports in the same region could encourage each other. Because all ports are connected in some way, the players can gain network effects. What the effects of these initial investments are on ship owners and other ports are not researched precisely. The percentage of ships using SP will go up, and the costs for both the shipowners as the port will go down. When the costs come done on an individual level, it should reach a threshold in which it is favourable to use SP. Investigating the effects would require an extensive analysis on the stakeholders (both ship owners and the port authorities) and the decision they make based on multiple criteria as well as how these decisions influence other stakeholders.

What is clear is that shipping companies and ports around the world should collaborate. With globalisation and increased market competition, collaborations between firms in R&D or product development becomes more prevalent. Collaboration could be sharing knowledge and facilities but also setting standards. Conflict and collaboration between stakeholders can be investigated by the principles of Game Theory (Arsenyan, Büyüközkan, & Feyziotlu, 2015). This paper used these principles to analyse the collaboration efforts and the network effects of SP. The theoretical framework and the methods used can be read in chapter 2 and section 3.4.

Chapter 2

Theoretical Framework

This chapter describes the theoretical framework of the research. The framework used, is game theory. The first section gives an overview of the theory. Examples of different game types are given in the second section. Lastly, the connection to SP is given.

What can be read in section 1.5 is that the cost of retrofitting ships and ports for SP installations is not cost-effective in the current conditions. Both ports and shipping companies can increase the effectiveness of their own and other investments by participating and investing in SP technologies. They are both stuck in this position of not wanting to be the first. It should be possible to break through this situation by cooperation and initial investment. A possible way of describing this situation is with game theory. What it is and how it can create insight in this situation is explained in this section.

There are multiple methods to solve financial investment issues or create insight into decision-making dynamics. This research uses Game Theory. There are two reasons why it helps full and necessary in this project. The first reason is that in the SP environment, there are multiple autonomous entities. These entities have to make decisions. An excellent way of giving these entities motive and reason is setting up utility functions. The outcome of these functions should explain the behaviour of all the different players in the network. Secondly, the outcome of the decisions from the players is dependent on the decisions from the other players. An example of this is the chicken and egg scenario described in the previous chapter. These decision-making dynamics are often seen in Game Theory and should give insight into the current port environment.

2.1 Overview

In short, the study of mathematical models of cooperation and conflict between rational and intelligent players or stakeholders is what game theory entails. A scene in which at least two stakeholders are involved is called a game in game theory jargon. In the same style, a stakeholder is referred to as a player. While game theory originates from mathematics, it branched out towards applications in biology, physics, economics, engineering, political science and much more. Applying game theory has the consequence that one assumes the specific characteristics of the players. The characteristics are that all the players are intelligent as well as rational. Intelligence in this context means that the players in the game have the same knowledge and understanding as to the designer of the game theory model. All the players are in the same position; hence all the information is available to all those involved. Furthermore, all the players know the game theory model and recognise that other players know this model as well. The rational characteristic assumes that players make decisions that are in line with their objectives. The objective is for every player to maximise the expected value of the outcome. This payoff is measured in utility. How a player can maximise its utility differs each game (Myerson, 2013).

Example of a game

Situations in which rational stakeholders can make decisions that influence each other can be analysed by mathematical techniques provided by game theory. The practitioners of game theory study hypothetical examples and quantitative models to try to understand conflict and cooperation. These examples are simplistic, although often unrealistically simple, they generate insight by capturing the core of the issue, which is easier to grasp than imitating the complex situations of real-life scenarios. With regards to ports, the game theory might describe a situation in which stakeholders positions are clearly and quantitatively described, in the real world it is never as evident, but it does help to understand competitive situations.

The distributed nature of game theory is its strength. The autonomous players participate in multiple rounds. The rounds divide the game, and the players optimise their role based on the context. The normal or strategic form gives the essential elements of a game (Jackson, 2011).

1. The set of players is $N = 1, ..., n$.
2. Player i has a set of actions, a_i, available. These are generally referred to as $pure$[1] strategies. This set might be finite or infinite.
3. The set of all profiles of strategies or actions denoted by $a = (a_1, ..., a_n)$.
4. Player i's payoff as a function of the vector of actions taken is described by a function $u_i : A \rightarrow \mathbb{R}$,where $u_i(a)$ is i's payoff if the a is the profile of actions chosen by player i.

It is always relevant for a scientist or the game designers to make predictions about the strategy chosen by the players. The difference in payoff determines the action of the player. The dominant strategy is allocated to the highest payoff in combination with the strategies by other players. A dominant strategy makes predictions much easier. There is a difference between dominant strategies. When at least the same utility is provided by a strategy for all the other player's strategies and greater for some, it is a (weakly) dominant strategy. Which looks like;

$$u_i(a_i, a_{-i} \geq u_i(a_i^{'}, a_{-i})$$

for all $a_i^{'}$ and $a_i \in a_i$. When on top of that $a_i^{'} \neq a_i$ holds; the strategy always provides greater utility no matter what the other player's strategy is. The name of this strategy is called a strictly dominant strategy.

Nash Equilibrium

As mentioned above the players in game theory are assumed to maximise their profit, disregarding the competitors, by choosing the strategy, based on the information available, that offers the best chance on this result. In other words, they behave rationally. The designers of the game will analyse the actions of all the players and mathematically deducing the best outcome for that specific player. The objective of the designers, or researchers, is to find a solution by locating a position, which is not necessarily the most optimal, where all the players end up in equilibrium by executing the strategy that has the best fit with their personal goals. This situation is the famous equilibrium named after the even more famous mathematician John Forbes Nash. In a Nash Equilibrium, the following situation is described: " *Suppose that each player is rational, knows his payoff function, and knows the strategy choices of the others. Then the players' choices constitute a Nash equilibrium in the game being played*"(Aumann & Brandenburger, 1995). Considering that each player is rational and knows the strategy of others, the players' strategy must be optimal, and indeed, one arrives at the Nash Equilibrium.

In the Nash Equilibrium, finding the location is the task of the scientist. This location is described in a strategy or set of strategies. This set is named the strategy coordinates for the players. In this equilibrium, any unilateral strategy or decision change can not yield any incremental improvement to one or any of the players. The prospect of no incremental change in utility means that none of the players is stimulated too, considering the other players and opponents, deviate from the current strategy. If these properties are present in the strategy or set of strategies of the players, these specific payoffs and coordinates of the game are called the Nash Equilibrium (Myerson, 2013).

Game theory distinct multiple equilibria, depending on the strategies of the players. When the strategies of all the players are pure, the equilibrium is called a pure strategy Nash Equilibrium. One the contrary, one arrives at a mixed strategy Nash Equilibrium when the strategy of one or multiple players is mixed. Locating the Nash Equilibrium is possible when the payoff and the strategies of the players are known. The first step is revealing the strategy or set of strategies from each player among the other players. The second step is analysing the best strategies and responses for all the other strategies and responses. Proving the Nash Equilibrium is done in the final step by finding the specific payoffs and coordinates where a deviation of the strategy for one player does nothing with the strategy of the other players which is right for all the players.

The existence of this equilibrium is due to human behaviour and rationality. With static rules and full understanding of the game and rules by the players, the outcome of games is predictable. When players move in a

[1]The term "pure" indicates that a single action is chosen, in contrast with "mixed" strategies in which there is a randomization over actions

Nash Equilibrium, they will be worse of; this makes it predictable and self-enforcing. The prisoner dilemma is the most famous example of this situation. This dilemma exists in normal game types. The most well-known game types are described in the next section.

2.2 Type of Games

Within the theory, a game is a collection of strategic interaction of the actions that the players can take. There are, however, multiple classes of games each with their properties. The different essential properties of games are described below, and an overview can be seen in fig. 2.1 (Hayes, 2020).

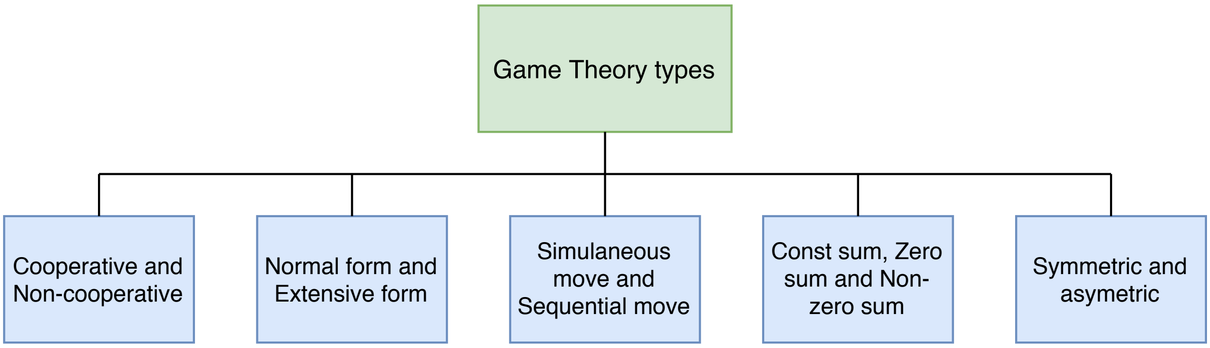

Figure 2.1: Game theory; game types

Cooperative and Non-cooperative games

As can be seen in fig. 2.1, there are many different game theories. However, cooperative and non-cooperative are the most common theories. They differ depending on the player's actions. A player can make a decision and is interpreted as an individual or multiple individuals that act as a group. Cooperative game theory describes the cooperative groups. Coalitions form between players, and it is essential how these are formed and how the payoff is allocated between them.

How these communities form depends on a behavioural model. In any other cases, games form these communities. The goal of these matching games is creating a more significant utility function and optimizing it inside a coalition. On the other side is the non-cooperative game, which describes rational players who interact with each other and strive for their own goals. According to their context, the players maximize their utility by optimizing their strategies, doing so whilst not joining other players in coalition or strategy agreements.

Normal form and extensive form games

The difference between these two types of games has to do with how they are described. The normal form game has a description of the game in matrix form or table. This form assists in finding the equilibrium or the dominant strategy. The most famous example of the form game is the prisoners' dilemma in which players can cooperate or defect, and the payoff of their strategy in combination with the other player's strategy is displayed in a table. There are many variations of this game, like the Cournot duopoly that are based on the same principle. When events in a game can occur by chance, the extensive form is often used. A decision tree is used to help with the description. This form is more focused on timing. In the decision tree, a complete description is included of the order of moves of all the players.

Simultaneous move games and sequential move games

In the Game theory players can have actions or strategies. The timing of these actions can differ in the game types. When a player chooses his or her action before the other players, the game is called a sequential game. An essential aspect of the sequential game is that the players who make their decision afterwards have to be aware of the previous choices. With the information about the previous choices, the time difference becomes a strategic effect. Time is an essential aspect in the sequential game; hence the time axis that is often present. These games are often represented in decision trees (Brocas, Carrillo, & Sachdeva, 2018) and are therefore usually extensive games as well. The most well-known example of a sequential game is chess.

On the contrary, is the simultaneous move game. In this game, the players choose their actions without being informed on the strategies of the other players. The usual way this game is played is that players make their decisions at the same time. An example of this game is Rock paper scissor (Pepall, Richards, & Norman, 2014). However, it can be that players make choices sequentially, but are not informed about the decisions of the others, which still makes it a simultaneous move game. Another difference with the sequential game is that these games are represented in matrices and do not have a time axis.

Constant sum, zero-sum and non-zero sum games

The outcome of the actions of the players results in a payoff. This payoff can be positive, negative or does not change the utility of a player. The sum of the payoff of all the players can have different outcomes and specifies these game types. The situation in which the positive or negative payoff for players perfectly balances out the positive or negative payoff by the other participants is the mathematical representation of a zero-sum game. In a zero-sum game, the collective of gains subtracted by the collective of losses should sum to zero. Cutting a cake is an example of a zero-sum game. After a cake is divided into eight equal pieces, a player decides to add another part to his piece. This player will gain utility. Other players will receive less cake and lose utility. The sum of the utility is zero upon the condition that all the players value a piece of cake equally. The minimax theorem can often solve these kinds of games (Binmore, 2007).

On the other hand, is the non-zero-sum game. The sum of the gains and losses of the participating players can be more or less than zero. A non-zero-sum game can be both competitive and non-competitive, whereas a zero-sum game is strictly competitive. With a dummy player, this game type can be transferred into a zero-sum game. The last option is a constant sum game, in which the outcomes remains constant independent of the actions of the players.

Symmetric and asymmetric games

Lastly, this section covers the symmetric and asymmetric games. When the strategies of the players are all equal, the game is symmetric. Symmetric means that the payoff of a particular strategy is only depending on the strategies employed by the other players and not which players are employing it in the first place. If the payoff of the strategies would not change when the identities of the players switch, the game is symmetric. There are many variations of the symmetric game (Cheng, Reeves, Vorobeychik, & Wellman, 2004). Opposed to this game is the asymmetric game in which the players adopt different strategies. In these scenarios, the outcome of the same strategy differs for different players.

2.3 The SP problem

Game theory is used as a theoretical framework to describe SP problems. In order to do so, the problem turns around, and the first step is explaining the SP environment in game theory jargon. The players are the shipping companies and the port authorities. Both these players have the decision making power to retrofit either their ships or ports with SP installations. They are both rational and intelligent and try to maximize their utility. The utility is essentially profit for the stakeholders. In a game, the utility should be brought down to simple factors which can be calculated. Doing so will motivate the strategy and the decisions of the players. In a port, there is one port authority and multiple shipping companies. There are multiple ports, each with the players, as mentioned earlier.

Throughout the game, all the players are connected in networks. They are aware of the strategy of the other, and the shipping routes between different ports connect them physically. Although the players are connected, they do not act as a group and do not make group decisions. Each player tries to reach their objective. The SP problem can thus be described as a non-cooperative game. The other characteristics of the game are self-explanatory. The players do not have to make their decisions simultaneously but can do it throughout the full-time span of the game and are aware of the strategies and decisions of the other players, which makes the game a sequential move game. The description of the payoffs can be boiled down to a matrix which is a characteristic of the normal form. Lastly, the payoff for the same strategy can change for each player, and the sum of the payoff for all players is non-zero. These characteristics result in the following game theory type for SP as can be seen in fig. 2.2.

2.4 Conclusion

As can be read in this section, game theory as a theoretical framework can be used to create insight into the problem. The problem remains the implementation of SP. There are benefits to be gained when all the players,

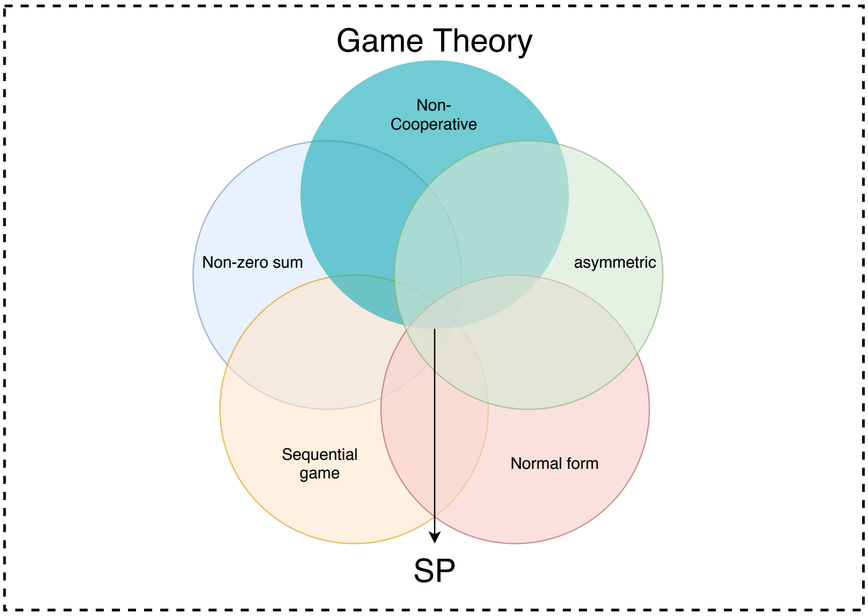

Figure 2.2: Game theory; SP scope

which are the shipping companies and the port authorities, would switch their strategy and implement SP. However, when only one player does this, the obtained payoff is not enhancing the utility. The SP situation can be described as a non-cooperative, normal form, non-zero sum, sequential and asymmetric game. Because the game is non-cooperative, the players can only influence their strategy. Their strategy is not switching to SP because it does not boost utility. The players are aware of the strategy of the other players, which is also not switching.

It can be concluded that at this point, all the players' strategy is optimal, and one has arrived in a Nash equilibrium. This research aims to investigate whether or not such an equilibrium can be broken by implementing cooperative aspects of game theory or boosting one side of the network, which should kick start the implementation of SP for other players. The first step is proving that the players are in a Nash Equilibrium. The second step is investigating the impulses delivered to a part of the network. The methods used for proving this are elaborated on in the next chapter.

Chapter 3
Research design

The previous chapter gave an introduction on the ports and SP as well as a literature review on the current state of the technology. It exposed the barriers and enablers of the implementation and gave this research a direction. With game theory as a theoretical framework to analyse the SP problem, the rest of this research can be mapped out. This chapter describes the objective of this research. Afterwards are the research questions that function as a handhold during this process. Thirdly, is the research approach which is phased plan on how and when this research will answer the main questions which were mentioned earlier. Lastly, the methods that are used to solve the issues are described in the final paragraph.

3.1 Research Objective

Overcoming the aforementioned challenges, this research should create insights into the problem of SP. Using game theory as a framework, it should create knowledge on the topic of game theory as well as practical knowledge about Shore Power. This research will prove the chicken and egg situation as an equilibrium problem that was mentioned in section 1.5 and use game theory and simulations to improve that static situation. After proving the equilibrium, this research will formulate strategies that can enhance the SP implementation and this should function as advise towards Samskip and the port.

Scope

There are many aspects of shore power and theory that this research will focus on, but there are other aspects and theory just outside the focus. The theory used is game theory to describe the situation of SP. The technical issues will not be investigated; the financial issues do lie within the scope. The port authorities and shipping companies will be a part of the SP environment. Eventually, simulations should create knowledge on the game and prove the equilibrium. This scope is visually represented in fig. 3.1.

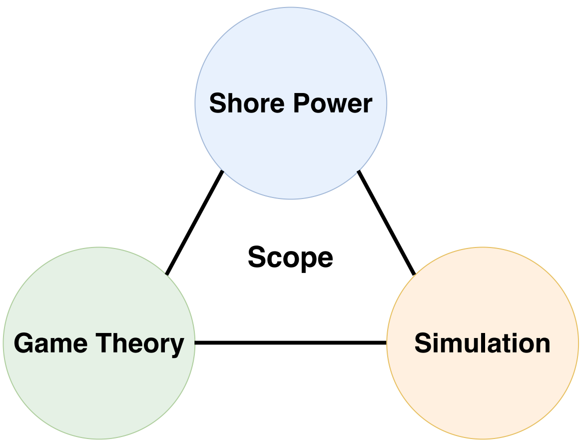

Figure 3.1: Research Scope

3.2 Research Questions

The following research question and sub-questions have been formulated based on the literature review, knowledge gap and theoretical framework:

Why are Ports and Shipping companies in a Shore Power Nash Equilibrium and how can the situation improve?

This translates into the following sub-questions:

1. **How can the situation of Shore Power implementation be described, using game theory as a theoretical framework?**
   (a) What are the assumptions of the game?
   (b) Who are the players in the game?
   (c) How can the game be played?
2. **How can the properties of Shore Power function as input for the designed game?**
   (a) What are the utility functions for the stakeholders?
   (b) How can the properties of Shore Power be quantified?
   (c) What are the generalisations needed for this game to function?
3. **Why are the Ports and Shipping companies in an equilibrium regarding shore power without an incentive to upset it?**
   (a) Can the designed game be used to prove the equilibrium?
   (b) Is there an equilibrium, using the game to prove it?
   (c) What are critical elements in this equilibrium?
4. **Which strategies can be formulated to disrupt the equilibrium and enhance the implementation of Shore Power?**
   (a) Which strategies can be formulated on the base of game theory?
   (b) Which strategies can be formulated based on the stakeholders?
   (c) Which strategies can be formulated on the base of the simulations?
5. **What is the impact of the strategic disruptions and what advise can be formulated out of the effects?**
   (a) How can the strategies be formulated as input in the game?
   (b) What are the effects of the strategies on the outcome of the simulation?
   (c) What advice can be formulated from the strategic interference?

3.3 Research Approach

The research question formulated in the previous section is going to be answered throughout this thesis in different chapters. So far, the introduction, literature review and the research design are done. The yield of these chapters is the research questions and the methodology, on which the next section will elaborate. The next chapter focuses on the agents in the SP environment. Each stakeholder receives a place in the network, together with their ambition and influence they have on the environment. This chapter will also introduce which stakeholders will be interviewed throughout this research.

The game design of chapter 5 describes the assumptions, players and the rules of the game and answers the first sub-question. It will do so using information from the literature review and information from the conducted interviews. Chapter 6 conceptualises the designed game. It again uses information from the literature review and interviews to address value to elements in the utility equation. The issue here is quantifying qualitative values. Solving this will answer sub-question 2.

With the information of the game design and the conceptualisation, it is possible to simulate the SP game. After verifying the game with test runs, it should be able to confirm the potential Nash equilibrium of the stakeholders. These simulations and the result answers sub-question 3. The designed strategies in chapter 8 are formulated by input from the stakeholders in the interviews, by critical elements from the simulations and well-known theory from the game theory. These strategies should answers sub-question 4.

Chapter 9 will test the results from the strategies formulated in chapter 8. The first step is transforming the strategies into input for the game. After this is done, it will compare the results of the game with the different strategies to the first situation without strategies and in equilibrium. Doing so, will measure the effectiveness of the formulated strategies and offers to advise towards ports and shipping companies like Samskip. This chapter answers sub-question 5.

The answers of sub-question 1 to 5 answer the main research question of this thesis. This is done in chapter 10 and 11, which contain conclusions and recommendations. An overview of the research approach is visualised in fig. 3.2.

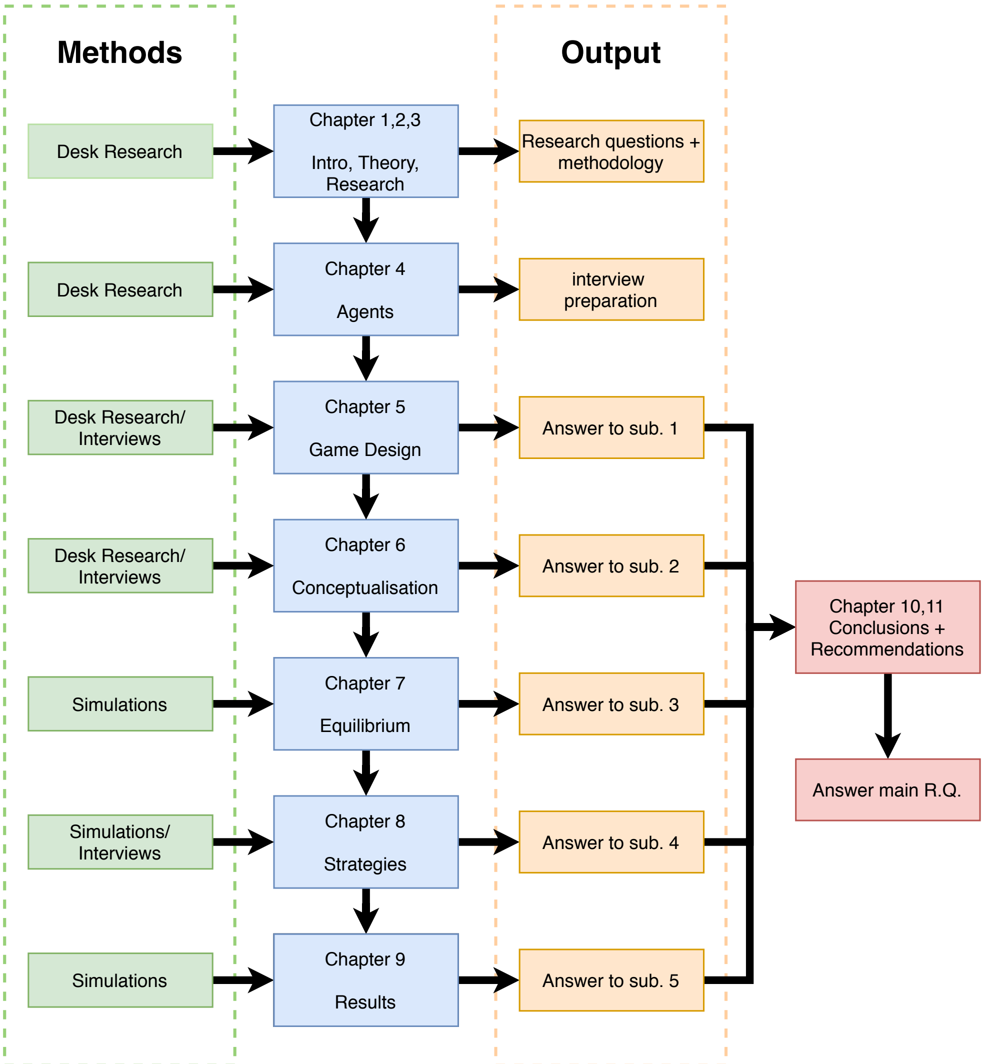

Figure 3.2: Research Structure

3.4 Methods

The methods described in the research approach and used throughout this thesis are described in this section. The three main methods are the desk research, Expert interviews and Simulations.

3.4.1 Desk research

Desk research shapes the outline of this research and answers multiple sub-questions. This kind of research searches, analyses, and evaluates relevant secondary data. The literature review primarily used peer-reviewed and published articles. In the following chapters, relevant sources, to discover state-of-art data, are more than only academic literature. A deviation in the article requirements is necessary to acquire the most relevant information about the stakeholders and properties of SP. Chapter 1 to 6 all use input from desk research, and a large amount of this research is invested in desk research.

3.4.2 Interviews

The Expert Interview is often used in an Exploratory phase. The network of the Port of Rotterdam and the factors to the diffusion of Shore Power is so far unknown. That makes the expert interview a great method to gain fast access to this unknown field. An expert is a person who is responsible for the implementation or development of strategies, policies or solutions and a person who has more information about certain processes or person (Ullrich, 2006).

There are several advantages to this method. Obtaining specific information is less time consuming compared to other methods. The experts are well networked and highly motivated people, which means that they are more often willing to cooperate and can introduce new possible interview candidates. Lastly, the information gained by these interviews is often specific knowledge which is hard to obtain through other methods.

3.4.3 Simulations

A basic research method in analysing the SP implementation in ports is designing a game and simulating this game in a computational environment. The literature does not show many examples of a game theory simulation. Because of a lack of samples, this game and simulation are built from scratch. Designing such a game and eventually running it is one of the main challenges and at the same time learning aspects of this research. The steps of this process can be seen in fig. 3.3

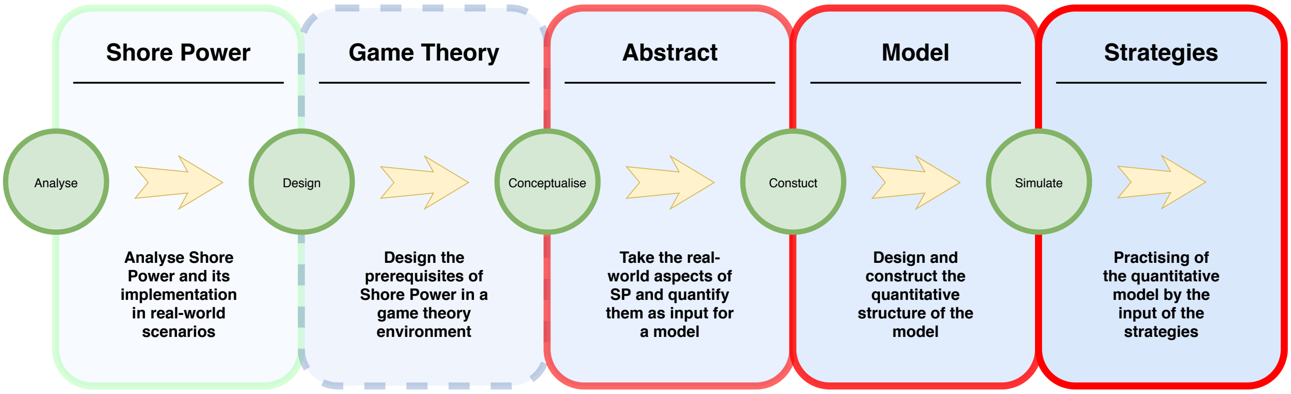

Figure 3.3: Modelling steps

The first step in this process was to analyse the current situation of SP. This was done in desk research. chapter 5, Gives the rules of the designed game. With botch chapters, the model can be made in Matlab, and the simulations can be run. These simulations help to answer sub-question 3, 4 and 5 in chapter 7, 8 and 9.

Chapter 4

Agents in the Port Environment

This chapter takes a look at stakeholders in the port environment. It will analyse who is responsible and what is required and which stakeholders are capable of influencing the SP implementation. In the first section a general overview is given. The second section describes which of the previous mentioned stakeholders will be used in the game according to Game Theory. Lastly, a more specific case study is done on the stakeholders in the Port of Rotterdam. This is discussed in the third section.

4.1 Stakeholders in the Port environment

A port and all the companies, government and citizens surrounding it form a cluster. These clusters contain a diverse group of stakeholders. In this research a stakeholder is defined as an actor that is affected by or can affect the objectives of the firm it belongs to. All of these stakeholders have a varying interest concerning the port operations and objectives and have a varying level of influence on these objectives. One of the, if not the most important stakeholders in ports are the transport firms such as the shipping companies. The main interest of these transport firms is a limited costs with respect to the regulations. Emission standards, security regulations and vehicle tax are examples of these regulations. These regulations are directly linked to the competitive advantage they hold over their competitor transport firms in different ports and countries. So has each of the stakeholders its own interest and source of influence. In this section the most important stakeholders are described. This section is based on a research from de Langen (de Langen, 2006).

Government

The way ports are structured differs in each region or country and so does the level on government interference. This research does does distinguish between local municipalities and national government but are mentioned under the same section as these roles often intertwine between ports globally. The main interest of local municipalities is how a port can contribute to the economic position of that region. This includes the tax revenues as well as employment opportunities. The local government is also interested in the interface of a port or city and how the port can positively influence this transformation. On the other hand is the national government, which not only seeks economic contribution but a maximisation of welfare. The welfare enhances through limited negative externalities, low generalized transport cost and tax revenues. The limited negative externalities are for example the pollution of GHG for nearby located citizens. Often, national government has invested in the infrastructure of ports and environment around it. Through tax revenues the government tries to recover from these investments.

The influence of regional government comes through the investment in the ports and how the environment surrounding the port is structured. The muncipalities are often a public owner of the port as well as the owner of the land most infrastructure is build upon. An indicator of the influence of the municipality would be the level of ownership of the port and the land. Depending on the structure of the ownership the national government has the rights and sources of influence as the regional government. Furthermore it has the ability to create port laws and can review the level of taxation. These influences can directly impact the competitive position of the port.

Port authorities

The entity that has influence in the port and are responsible for decisions and the direction of the port is called the port authority. The main interest of the port authority is the optimisation of the core business of ports which is transport. The authorities optimize transportation by the quality of infrastructure and the level of generalized costs for transport. The logistic chain in the port is free from interference because of product quality regulation, security, safety and custom procedures. Although the authority has to object to laws and influence from the government, they have the most influence in the port compared to all the stakeholders. Throughout the port network they have an influence by the cargo they divert to other ports.

Shipping companies

The shipping companies are the customers and end-users in the port clusters. The goods and bulk they ship from and to ports is the core business inside this environment. For the shipping companies it is important to maximize their profits with each vessel operation. Therefore, their interest lies with lowering the transportation costs. The costs include a higher reliability, lower time at berth and damage control. Similar to the port authority, the shipping companies can influence the network by the cargo they divert to other ports, albeit limited to their own cargo. An other option they have is to lobby in branch associations to increase their influence.

Grid operators

Many tasks and system in the port cluster require power. Where most ships run their own engines to supply their systems from power and manoeuvre in and outside the port, the port system require electricity. This electricity is delivered by the local grid operator. In the case of installing SPI, the grid operator has to supply to shore-side electricity and the price the grid operator charges influence the cost-efficiency of the investment greatly. The main interests of grid operators are maximizing the profit of the delivered electricity as well as the the electricity more sustainable.

Local residents

In the vicinity of port clusters are local companies and citizens located. Disregarding the companies, this section focuses on the local citizens. Port clusters create employment opportunities and the locals interest lie with this job creation. Besides the labour market, the residents have an interest in minimal traffic congestion's and a limited reduction of life quality. This reduction would be accompanied with safety, noise and pollution through exhaust. Local residents often have a significant influence in the port albeit indirect. Procedures can prevent or postpone certain capital investments or port expansions. The local, or even national residents, can use their political power to pressure port authorities and governments.

4.2 Case study of Port of Rotterdam

In the game design, conceptualisation and strategies in chapter 5,6 and 8 is information given which originates from stakeholders in the Port of Rotterdam. Certain companies and organisations have been approached and are interviewed to create insight and interpreted the data used in the game. This section states which companies are approached, which information is given and how this information is processed. The following companies and organisations are used;

1. Municipality of Rotterdam
2. Port of Rotterdam
3. Samskip
4. Anonymous shipping company A
5. Anonymous energy company B

Of the list above, three parties are known. The Municipality of Rotterdam has a substantial share in the local port. They are partly responsible for a large number of consequences and risks in the port and are therefore also very interested in SP technology. The second party on the list is the port of Rotterdam itself. This party refers to the port authority. At the beginning of this chapter, this is mentioned as the Port Authorities. Contact was made with the Port Company to inform about the state of SP in the Port of Rotterdam and verify specific findings. Third, on the list is Samskip. Samskip is the initiator of this study. As a large logistics company with a fleet of around fifteen ships, it has to deal with the issues surrounding SP daily. It is therefore attractive for

Samskip to map out the financial feasibility of SP for them. In addition to all the necessary preconditions of this study, they also provided private information that has a lot of added value for the designed game.

These three parties have permitted to be mentioned in this report. The other two anonymous parties are both from the network of the Port of Rotterdam and have signed a consent form stating that they wish to be mentioned anonymously in this study. This form allows the shared knowledge to be included in this report, albeit anonymous. Anonymous transcripts of the interviews have been made and will eventually be stored in the TU Delft Database. The section below contains a summary of the interviews conducted with the aforementioned parties and presents the most important findings.

The most important thing is the current state of affairs. At the moment, little is happening in the field of shore-based power because no parties are responsible for the construction of the structure yet. One of the advantages of shore-side electricity is the reduction of emissions. So far, no party has to bear the costs of emissions (Port of Rotterdam, 2020). The absence of this responsibility reduces the attractiveness of the SP technology. It also makes it questionable to include the emission prices in the calculations. However, this could be a possibility in the long term, so it is beneficial to investigate the effects of this (Municipality of Rotterdam). For several years an initiative has been born under the name Shore Power B.V. This company is a collaboration of several parties in the port (https://www.heavyliftnews.com/heerema-to-take-shore-power-from-wind-at-rotterdam-calandkanaal-mooring/). The municipality has spent a subsidy of 2 million to stimulate this project (Port of Rotterdam). The port authority is experiencing many problems with the current situation. In particular, the limited nitrogen emissions per area and the noise nuisance for residents stimulate them to look for solutions. Next to the SP B.V. project, they are looking if European agreements can be made with other Ports to stimulate SP while not losing their competitive position.

SP B.V. is currently making a 20 MW installation in the harbour. This installation can be seen as a charging station with four connections. When four ships make use of this, the utilisation rate will be about 25%. The costs for this 10 MW installation are between 7 and 10 million (Shipping company A). A depreciation of 15 years is used for this installation. However, it is assumed that this installation will last for 30 years. It is customary for innovation to make conservative assumptions. This research is in between those two approaches and takes depreciation of 20 years. SP B.V. is fully responsible for the investment of the SP infrastructure. Through a subscription model it recovers these costs.

Samskip has also made a significant contribution to this research by providing information about ships in its fleet. Samskip's ships are a lot smaller than the gigantic cruise ships that occasionally berth in the port of Rotterdam but give a good indication of specific proportions. An average container ship of Samskip consumes 160 litres of fuel per hour when stationary in a port, which is MGO. The average power consumption is 600 kW. Finally, the ships of Samskip use several ports in Western and Northern Europe. In these ports, they are stationary for two to three thousand hours a year. The shipping companies in the port of Rotterdam all recognise the importance of more sustainable solutions. For example, they are all prepared to pay more for a sustainable way as opposed to more traditional methods. The estimated more price for sustainable methods is about 5% (Samskip, 2020).

4.3 Players in the game

The stakeholders mentioned in the previous section are chosen based on their influence in port clusters as well as their potential involvement in the implementation of SP. With game theory as a theoretical framework, the implementation of SP is translated into a game. This game will have players chosen from the stakeholders out the previous section. These players are:

1. Shipping Companies
2. Shore Power Firm

The game that will be designed and elaborated later on in this research uses these players for a specific reason. Although all the stakeholders have to potential to influence the implementation of SP, their role is less crucial than the that of the Shore Power Firm and the Shipping Companies. While one can assumes that the port authorities have full authorization over the investment strategies of the port and local and national government have a lot to say and take an active role in port management throughout the world, adding these player will over-complicate the game and will not add to the scientific or practical contribution that this research has. Besides, Port Authorities and government don't feel the obligation to invest in the technology as of right now. When in the future they do want to get involved they can always support the Shore Power Firm. The stimulating effect that local residents can have by exerting their political pressure can be includes into quantitative formula's and doesn't require an extra decision making authority. The shipping companies and the Shore Power Firm are the ones who can choice to invest in SP or not. How this is shaped can be read in chapter 5.

4.4 Conclusions

The purpose of this chapter is to identify the various parties in a port and to emphasise which parties have the most considerable influence on SP. It looks at local and national governments, port companies, shipping companies and more. Shore power has investment costs on the ship side and the shore side. At the moment, it is puzzling that no parties are responsible for the shore-side electricity infrastructure. Discussions with the various parties in the port of Rotterdam revealed that a Shore Power B.V. would be a good alternative. Multiple parties can work together and share costs and benefits. In the port environment this agent is called the Shore Power Firm. It is introduced here to take the role as driving force of the SP technology and will be part of the game. The conversations that were held gave a general impression of the current situation in Rotterdam. The data provided will be further used in the game and will be presented in chapter 6. Strategies will also be formulated on the basis of the talks, which will be discussed in Chapter 7.

Chapter 5

Conceptualisation of Game design

In chapter 2 could be read what the fundamentals of game theory are and how it is used to describe the SP issue. In this section, an SP game will be designed. The assumptions, the players, the rules and the way it is modelled. As described in the research approach, this section will answer the first sub-question, which is formulated below. The sub-sub-questions are answered in the different sections of this chapter.

How can the situation of Shore Power implementation be described, using game theory as a theoretical framework?

1. What are the assumptions of the game?
2. Who are the players in the game?
3. How can the game be played?

5.1 Assumptions

Modelling a real-life decision-making situation is incredibly complex due to the amounts of variables and unlimited choices actors have. These variables are, in many cases, not relevant to capture the essence of the problem. Modelling the SP implementation issue in game design requires the situation to be simplified. The simplification is done by certain assumptions on the real-life situation that are listed below. The assumptions are made on the findings from the literature in section 1.2 and the theoretical framework of game theory in chapter 2 and more (Fris, 2016). An overview is given in the categories of General assumptions, Game types, Network between players and SP Characteristics. Eventually, they are used as foundations and requirements to model the game. It could be questionable to assume so much and simplify the real world. The most critical assumptions of each category are discussed and explained below.

General assumptions

1. Players are rational
2. Players are intelligent
3. Players are pursuing their external set goals
4. Payers have certain characteristics and are aware of the characteristics of the other players
5. Strategies have payoffs and players are aware of each other's payoffs

In the classical game theory, one always assumes that players are both rational and intelligent. Aforementioned in chapter 2 this means that players have all the information available and calculate everything to land on decisions which are entirely in line with their objectives. An often-heard criticism is that it is illogical to assume that players will correctly compute their payoffs in order always to maximise their utility. In this scenario, the players are big international companies in which small margin increases can lead to an impressive increase in profits, which makes it safe to assume the players are rational. Critics argue as well that the rationality does not always hold because players can make irrational decisions (Hagen & Hammerstein, 2006). An often-heard response is that this is the same for physics (Kelly, 2003). In physics situations in real life can differ from the theory, but the fundamentals can be used as a foundation and theoretical framework. There are however, aspects of choices which are hard to measure and could explain irrational behaviour; this is mentioned in the assumptions regarding the SP characteristics.

Another thing about rationality is that there is often a lack of consistency in the preferences or utility (Burns & Roszkowska, 2005). The game is simplified in such a way that the preferences like cost reduction and emission reductions are the main motives. These preferences will stay relevant for the coming decades. Lastly, the descriptive aspect of game theory has been questioned in the past (Savage, 1972). The critic was that game theory is, instead of descriptive, a prescriptive tool. Nevertheless, it is debatable that players would make behave inaccurate from the point of view of the model. This would mean that the decisions made would reduce utility. Even when players would make mistakes, over time, they will learn and improve (Fudenberg & Tirole, 1991).

Game types

6. Non-cooperative game
7. Sequential move game
8. Asymmetric game
9. Non-zero sum game
10. Perfect information game
11. Discrete game

In the classical game theory, it is assumed that the player is both a strategist and an egoist. Taking into account what the best response is towards the actions of others. Nonetheless, these decisions or responses are independent and completely autonomous. The situation is judged on the basis of the players own utility and is not concerned with the utility of others at all. This is captured in the classical rational player in non-cooperative games. In this game, the player evaluates outcomes as well as interaction with other players solely on the implications for itself. This characteristic of game theory is parochial and often criticised (Burns & Roszkowska, 2005). In real life, the social context is indeed essential. The social context includes; relational, institutional and cultural terms on which decisions are made. However, using the classical game theory as a framework does highlight the critical aspects of the implementation of SP currently. It could be argued that changing some aspects of the game is vital in enhancing the utility for all players. These insights are valuable, and strategies like these will be mentioned in chapter 8.

Within the game theory, multiple distinctions can be made on the game characteristics. An important distinction is about the payoffs and the rules for each player. When identities of players are changed, but the payoff remains the same, the game is symmetric. Within the SP, there are different players in each scenario. The ship owners differ from the Shore Power firms, but the ship owners also differ from each other. The number of ships can change as well as how old the ships are. These changes can change the payoff.

Lastly, the assumption of a sequential game has to be explained. Repeating what has already been explained in chapter 8; a game can be sequential or simultaneous depending on whether or not the players make choices at the same time or one chooses the action before the other(s). What matters here is if the players have information about the strategies of others. When there is the time between the action of players, but the one who has the last move is not aware of the other choices, there is no strategic effect, and it is a simultaneous game. Within the SP problem, all the players would immediately be aware if one of the players would make the switch to SP since these are mostly large public companies. The game will simplify these decision moments to a fixed date in a year where players can decide to switch. The decision making at that time is simultaneous. The next year the other players are informed of the other choices. Over the whole life span of the game, this is a sequential moving game.

Network between players

12. Ports are connected through ships and agreements between countries
13. Shipping companies are connected through overarching organisations
14. The more ships use SP, the more the costs are reduced for ports
15. The more ports use SP, the more the costs are reduced for shipping companies

The way players are connected with each other varies per player. Between ports, there are ships that continuously navigate between them, and there could be cooperation between counties. For example, the ports of Rotterdam, Antwerpen and Hamburg are all influenced by the European Union. Shipping companies are often connected, as well. Although the players are connected, they do not influence each other. The players remain rational and keep on making autonomous decisions in this non-cooperative game. The fact that these players are connected can eventually make a difference policy-based or in a cooperative matter. This will be investigated later on.

One of the reasons this research is conducted is on the premise that the costs for the use of SP for both shipping companies and ports will decrease when more ports and ships install and use it. These so-called network effects are crucial in eventually calculating the utility. However, these network effects are hard to quantify. On top of that, it is not logical that the decision of one port of shipping owner will influence the entire network. In the game relations between players have to be quantified based on how strong it is.

SP characteristics

16. The technical issues of standardisation are not included in this game
17. There is no logistical issue regarding SP when both ports and ships are equipped with SP it is always possible to connect them
18. The benefit of noise reduction is not included as a benefit of SP
19. Other characteristics of SP, including the fuzzy ones, have been attempted to quantify

The literature study in section 1.2 uncovered the barriers to the successful implementation of SP in ports. The second most crucial barrier next to the costs is the technical issues that both ports and ships have to cope with. These technical issues are relevant to investigate and to reference concerning the decision making of ports and ship owners. However, the technical issues are not correlated to the network effects, which is the crux of this research. Future research will have to demonstrate how these technical issues can be included in this game.

One important assumption is that of the logistical issues. In real life, it could occur that through complex logistics, a vessel can not be guided to a terminal where SPI is installed. Although both players made an initial investment, they can not reap the benefits in this case. Modelling this would not make sense because, in the final situation, where all the ports and ships are equipped with SP, this would not be an issue anymore. It is, however, a necessity to make an estimation of the lost benefits and to add this as a disclaimer to the conclusion.

Many characteristics of shore power are quantitative aspects. There are, however, also aspects that are qualitative. Benefits like the sustainable fulfilment it could yield, as well as the image which could benefit future business are fuzzy. These elements have to be quantified with fuzzy set theory to incorporate them into the utility functions. One qualitative element that will not be included in the noise reductions for neighbouring citizens. The reason being that this benefit is more related to inland shipping SP constructions.

5.2 Players

An overview of all the stakeholders is given in chapter 4. Not all stakeholders will participate in this game. For example, the municipalities or governments and or authorities that influence or control ports are not mentioned because the degree of control varies so much that it is easier to make an external company responsible for the Shore Power decisions.Besides municipalities, there are players that are part of the environment but do not have direct control of the implementation of SP. An example is the grid operator. Although the construction of the network is a requirement for power supply to ships, they will not stimulate or discourage the implementation speed of SP because of the passive role they have. The stakeholders that do have an active role in this game are categorised into two groups.

The two groups in this game are the Shore Power Firms and the Shipping Companies. The Shore Power Firms are a collection of groups that manage and make all the decisions concerning Shore Power in the port. In this game, it can be said the port authorities own the ports, however the firms take decisions regarding Shore Power. How this is funded is not relevant here. The other players are the shipping companies. The shipping companies own many vessels and have full control over how these ships are equipped and between which ports the vessels navigate. The assumptions regarding the players can be read in the general assumptions, and the strategies they have in the game environment are mentioned in the rules of the game.

5.3 Rules

In the previous sections, the players and the assumptions of the game are described. Before a game can be "played" a final element is missing: the rules of the game. This section will describe how this game will proceed by explaining, among other things, the choices players can make, when choices can be made and for how long the game will go on.

5.3.1 Strategies

The SP implementation problem stems from underlying problems of environmental pollution and cost reduction. There are several directions that can be taken to solve these complications. However, this research is solely concerned with SP as a solution to these problems. Therefore the game is simplified, and the strategies are limited. Aforementioned there are two categories of players that participate in the game. These are the Shore Power firm and the shipping companies. Within each category, the strategies are the same, but the extent to which it is carried out may vary within a category. The same applies to the payoff players will receive for executing the same strategy within the same category. The first player is the Shore Power firm.

The Shore Power Firm has control over the installations that are built ashore. Ships come in and are escorted to a particular terminal, where ships will run their AE. This scenario repeats itself for years. The choice a firm has is to install SPI in specific terminals. Ports differ in size; this means that the amount of terminals that can be retrofitted differs per port. To install an SPI on a terminal takes an initial investment and time. After a certain amount of time, which is described in section 5.3.2, the SPI are ready to use, and ships come in once again. When a ship is applicable for the SP connection, the firm has once again a decision. Whether or not to connect that particular ship to the SPI. These choices are depicted in

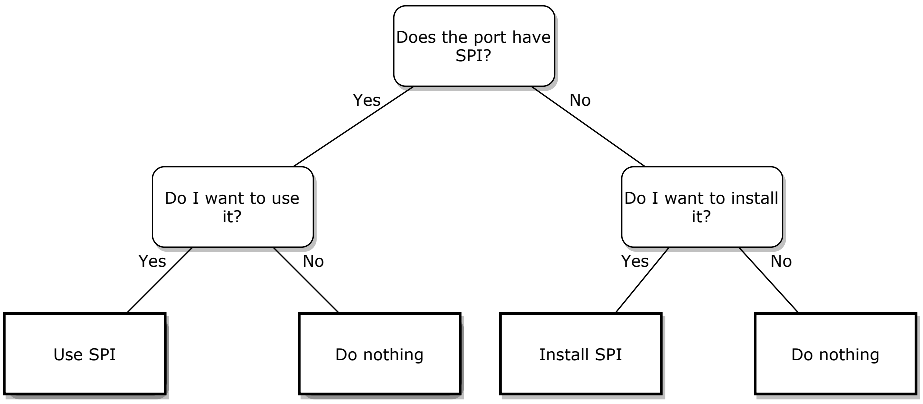

Figure 5.1: Strategies of the Shore Power firm

The second category of players is a shipping company. A shipping company owns many ships and transports goods in containers or bulk from one port to the other. The strategies of shipping companies have the same structure as that of the Shore Power Firm. After entering multiple ports and running the AE, it can decide to retrofit a ship in order to handle an SP connection. Shipping companies have many ships; in absolute numbers, this differs for each shipping company. The ships itself can differ as well. It can be depreciated within a year, or it is brand new with many years to come. The payoff of course differs, more on this in section 5.3.3. Once again, after ships have been retrofitted and enter a port, it can decide to use the SP connection on the premise that the port is equipped with SPI as well. The choices of shipping companies are structured and depicted in

5.3.2 Time and order of play

After the strategies of the players have been mentioned, the period of the game and the order in which they make decisions are described. These orders help process the rules so far and creating a sense of structure. Besides the start and the end, the game has two different stages. The first stage is continuous and embodies the commonplace activities around ports. Ships navigate between ports and after they are berthed have the choice to, if possible, to use SP or run the AE. Ports have a similar choice between offering the SP, if possible, or not. In-game terms this situation runs for the next year. At the end of a year, ports and ship owners have another choice.

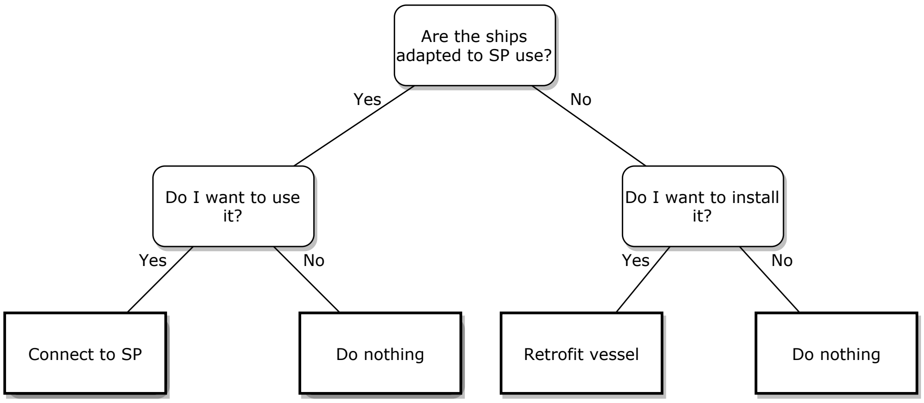

Figure 5.2: Strategies of shipping companies

This second stage happens once every year. It starts with assigning values to all the variables. After this is done, the ship owners and the Shore Power Firm will calculate whether or not to install SP. The decisive moment is based on the utility calculation. When a ship or quay is retrofitted, it will take a year before it is suitable for SP. After this decision moment, the game will run continuously for another year. The decision moment a year later will have updated information about which ports or ships have been retrofitted. This update should change the utility calculation. The total period of the game will be 20 years, which means that there will be 20 discrete decision moments throughout one game.

5.3.3 Utility

The utility has been explained in chapter 2, but in short, it used to capture the behaviour of the players in respect to their values, goals and ambition. A rational player will always try to maximise the utility. In order to maximise the utility it has to calculate all the known values and variables in the game, this implies that the player is intelligent. Throughout the game, there is a moment each year where the players will calculate everything and try to maximise their utility based on their strategies.

There are four different utility functions used in the game, two for the Shore Power Firms category and two for the shipping company category. The first one calculates the utility for the Shore Power Firm of installing SPI. The second calculates the utility of using SP when ships are berthed. Thirdly is the utility function which calculates the utility of retrofitting a ship with SP for shipping companies. Lastly, the decision of using SP when there is a possibility for shipping companies.

These functions are complex and capture the essence of the trade-offs both ports and shipping companies have to go through. Captured in these functions are all the costs and benefits of SP as well as the variables of different prices and the connections and influence of the players interpersonal. How these utility functions are solved and how the rest of the game is simulated can be read in section 5.4

5.3.4 Sequence of the game

When combining the players and the rules as mentioned above, the results are a specific game. A sequence of such a game can be seen in table 5.1. This sequence embodies one round in the game, in total twenty round will be played which covers twenty years. This number is derived from the depreciation of the installations of SP on ships and in ports. This number was put on twenty (anonymous shipping company A, 2020). In the game, this means that after twenty years shipping companies and the port firm have to decide to once again invest in SP. In the game, this means that they can not use SP for a short amount of time. The absence of SP usage could interfere with results and give the wrong impression.

On top of that, looking twenty years ahead makes the decisions and therefore, the results less reliable because many variables will change. Lastly, the game chooses a certain number of ships and does not change that number. That means that no new ships will be created. It is unlikely that after twenty years, when the ships are all nearly depreciated, these huge investments will be made again. So incorporating that function would be unlikely. The game is designed in such a way that it only looks at the initial years where ships have to decide to invest. New ships are less costly and will always install these installations. So the game uses twenty rounds representing twenty years.

Table 5.1: Sequence of the game

1	Calculate all the variables (prices etc.)
2	Determine the amount of users and suppliers of SP
3	Calculate the utility functions for all the players
4	A port without SPI can decide to invest in SP
5	Port with SPI can decide to use it
6	Shipping company without SP on vessels can decide to install it
7	Shipping company with SP installed can decide to use it
8	Determine matches between ports and ships for SP
9	The new installments take a year for ports and ships
10	Run the game for a year

5.4 Simulating the game

One could say that the prerequisites for the game are met. The final step in such a game is actually to play it, doing so would create insight and answer the research questions stated at the beginning of this research. How the game is played is set out here. A weighty aspect of this game is the many computations that have to be calculated each decision making the round. Those calculations, the changing formula's and the random variables have to be modelled in order to play a game. Building this from square one was one of the challenges in this research. The steps taken in designing such a model from the ground up are displayed in fig. 5.3.

The first step of analysing the real world SP problem has been done in the literature review, which can be read in section 1.3.1. This analysis yielded in the insight of the need for game theory to analyse the situation. The insight leads to step two, which is the design of the game environment. During this stage, the assumptions, players and rules of the game are introduced. Aforementioned, the game has to be built in a digital environment to cope with the substantial computational requirements. The input for this model is designed in step 3, which is discussed in chapter 6. The discussion means that all the formula's, players, characteristics and variables regarding SP have to be quantified.

The concepts of the problem are input for the model. Building this model is step 4. This model was designed to capture the ambitions of the stakeholders in the port environment and simulate the network effects of the implementation of SP. It has aspects of systems dynamics, agent-based models with the foundation of game theory. Combining these three into a quantitative programming model is done in MATLAB. The argument for choosing MATLAB is the natural import of data, and the accessible mathematical operation one can compute (Moore, 2017). The final step, after building the model, is running the simulations and confirm the Nash equilibrium and see what the effect of the strategies are on the equilibrium by changing the input of the model.

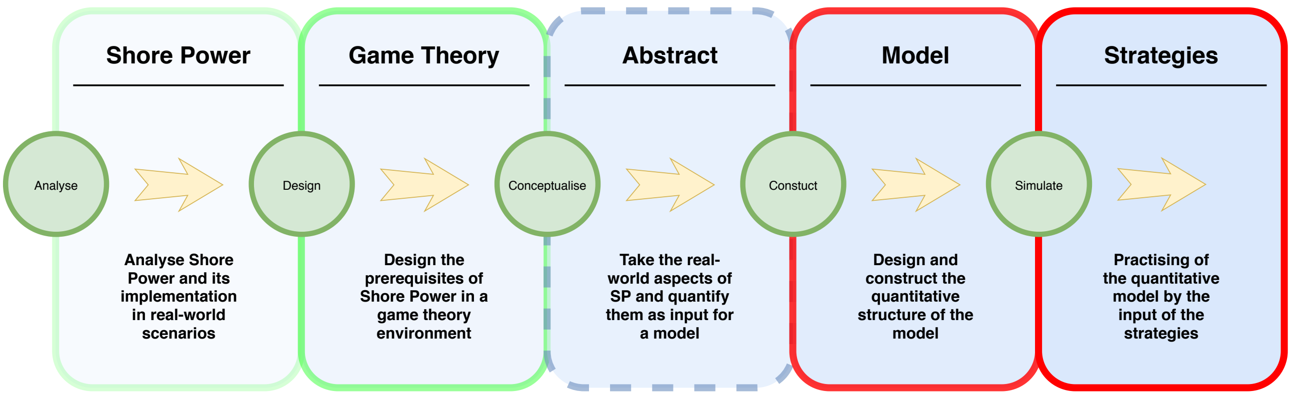

Figure 5.3: Modelling steps

5.5 Conclusions

In this section, the game was designed. In words is described how the game can be played. The general, game types, the network between players and SP Characteristics assumptions are limitations of the real-world scenario. However, for the SP game, it doesn't lead to inaccurate conclusions. Some SP related assumptions have to be mentioned in the discussion and can be incorporated in future research. The rules depict the outline. With the strategies, players and order of play, a sequence of the game can be made. With all this information, it is necessary to conceptualise the current situation. The conceptualisation should function as input for model build later on.

Chapter 6

Specification of the Game Design

In this chapter the SP environment is quantified in game theory terms. The utility functions and the variables on which these functions depend like the level of investments and depreciation, the amount of hours of SP in ports, the type of vessels and the fuel and electricity mix are all described below and will be the structure for the simulations. As described in the research approach this section will answer the first sub-question which is formulated below. The sub-sub-questions are answered in the different sections of this chapter.

Hoog, midden, laag scenario

How can the properties of Shore Power function as input for the designed game?

1. What are the utility functions for the stakeholders?
2. How can the properties of Shore Power be quantified?
3. What are the generalisations needed for this game to function?

6.1 Utility functions

The utility functions are crucial in understanding the behaviour of the players. In this section the four utility that describe the behaviour of the ports and the shipping companies in two aspects are given. These are the choice of investing in retrofitting a ship and the port and eventually using it if possible. All the elements are explained below the functions. Although these functions look simple, the elements itself can vary for each port and shipping company and even change from year to year. How all these elements are determined can be read in the following sections.

$$U_{i,t}^{SPE} = (F_{i,v,e} \times P_{f,j,t} + E_{i,v,e} \times P_{e,j,t} + M_i^e) \times (1 + S_i^{\%}) \times SP_{i,t}^{\%} - I_i - M_i^I \quad (6.1)$$

Where,
U_i^{SPE} Is the utility of the shipping company in retrofitting vessel i in €/year
$F_{i,v,e}$ Is the consumption of fuel specified for the vessel i, vessel type v and engine of the vessel e in kg
$P_{f,j}$ Is the price of the fuel f in port j in €/ton
$E_{i,v,e}$ Is the use of electricity specified for the vessel i, vessel type v and engine of the vessel e in kWh
$P_{e,j}$ Is the price of the electricity e in port j in €/kWh
M_i^e Is the maintenance costs of the engine saved vessel i in €/year
$S_i^{\%}$ Is the willingness of the shipping company i to pay more for sustainable options in percentage
$SP_i^{\%}$ Is the factor that indicates which percentage of hours the ship i can use SP when berthed in ports
I_i Is the investment of retrofitting the vessel i expressed in €/year
M_i^I Is the maintenance of the SP systems on board of vessel i expressed in €/year

Throughout a year, shipping companies decide how to provide their vessels with power. At the end of the year the shipping companies decide whether or not to install Shore Power Equipment on all of their vessels. With formula 6.1 the utility of such an investment is calculated for each vessel. When this turns out positive for a specific ship, the construction will start and the investment is made.

$$U_{i,t}^{Use} = (F_{i,v,e} \times P_{f,j,t} + E_{i,v,e} \times P_{e,j,t} + M_i^e) \times (1 + S_{i,t}^{\%}) \times C_{i,j} \quad (6.2)$$

Where,
U_i^{Use} Is the utility of the shipping company in retrofitting vessel i €/year
$F_{i,v,e}$ Is the consumption of fuel specified for the vessel i, vessel type v and engine of the vessel e in kg
$P_{f,j}$ Is the price of the fuel f in port j in €/ton
$E_{i,v,e}$ Is the use of electricity specified for the vessel i, vessel type v and engine of the vessel e in kWh
$P_{e,j}$ Is the price of the electricity e in port j in €/kWh
M_i^e Is the maintenance costs of the engine saved for vessel i in €/year
$S_i^{\%}$ Is the willingness of the shipping company i to pay more for sustainable options in percentage
$C_{i,j}$ Is a binary decision variable and is depended on the choice of the shipping company. It is one when shipping company i decides to use SP in port j and zero otherwise

As soon as a vessel is equipped with the right technology to receive power from the shore, it calculates if it's financially attractive to do so. With formula 6.2, each vessel determines the total amount of hours it can use SP by checking other ports. This formula can only be used when both the vessel and the ports it visits are capable of using SP. When this formula results in a positive utility for the specific vessel, the vessel will use SP in the designated ports.

$$U_{j,t}^{SPI} = \sum_{i}^{j} (N_j^{i,t} \times C_j^{i,t}) \times (1 + S_{j,t}^{\%}) \times SP_{j,t}^{\%} - I_j - M_j^I \quad (6.3)$$

Where,
U_j^{SPI} Is the utility of the Shore Power Firm to invest in SPI for port j in €/year
N_j^i Is the total numbers of ships that visit port j
C_j^i Is the contribution ship i has to pay yearly to port j to make use of the SPI
$\sum_i^j$ Indicates the sum of all the vessels that berth in port j
$S_j^{\%}$ Is the willingness of the Shore Power Firm j to pay more for sustainable options in percentage
$SP_j^{\%}$ Is the factor that indicates which percentage of hours the ships will use SP in port j
I_j Is the investment of retrofitting the berth in port j expressed in €/year
M_j^I Is the maintenance of the SPI in port j expressed in €/year

there are multiple ways in which ports can be responsible for the exhaust of ships. On the contrary, there are multiple ways in which this can be profitable as well. A subscription model is a safe and profitable option (Anonymous Shipping Company A, 2020). This research uses this model as a basis. Formula 6.3 counts for each port how many ships are willing to use SP in that specific port. Each vessel will pay a yearly fee. The fee is calculated in such a way that 80% of the ships have to use SP in order for the port to break even. When the formula results in a positive utility, the required infrastructure will be build inside the port.

$$U_j^{use} = (N_j^{i,t} \times C_j^{i,t}) \times (1 + S_{j,t}^{\%}) \times C_{i,j} \quad (6.4)$$

Where,
U_j^{Use} is the utility of the Shore Power Firm to use SP j in €/year
N_j^i Is the total numbers of ships that visit port j
C_j^i Is the contribution ship i has to pay yearly to port j to make use of the SPI
$S_j^{\%}$ Is the willingness of the Shore Power Firm j to pay more for sustainable options in percentage
$C_{i,j}$ Is a binary decision variable and is depended on the choice of the shipping company. It is one when shipping company i decides to use SP in port j and zero otherwise

Formula 6.4 works in a similar manner as formula 6.2. After the initial investment it checks for each port if it's financially attractive to make use of the Sp installations. This decision is based on the outcome of the formula. A positive utility is a green light.

When the the utility functions U_i^{SPE} and U_j^{SPI} are positive the binary decision variable $C_{i,j}$ equals to one. This makes sure that the utility functions U_i^{SPI} and U_j^{SPI} only generate a value when it is possible to calculate the utility. The other elements in the utility functions are going to be explained in the next sections of this chapter.

6.2 Type of Vessels

What the characteristics of the vessel are has impact on the amount of initial investment and how big the benefits of SP are. In this section is explained which type of vessels there are, the power of the engines and the influence of the age of the vessel. In ports around the world, many different types of vessel come in and berth. These different vessel types have different engine sizes and different costs of retrofitting. For the analysis, the vessels are grouped into 4 categories; Bulk Carriers, General Cargo, Container Ships, Product Carriers and Ro-Ro. Using data from the Port of Rotterdam showed that in the week from 4 to 10 may of 2020. 3604 vessels were cargo vessel, 2209 were tankers, 441 were passenger ships and 40 containerships. The size of the AE is related to, but not only dependent on the dead weight tonnage. A container ship without gear will not have the same AE capacity as a vessel designed to transport refrigerated containers. Per category the power of the AE is given (Musyoka, 2013).

The age of the vessels has impact on the cost effectiveness of SP. When the ship-side investment of retrofitting to SP is depreciated over 20 years but the ship is already 25 years old, the investment can not be spread over 20 years. In the formulas the number of depreciation has to be compared with the life expectancy of the vessel. The smallest number has to be used. Research showed that in 2007, the world merchant fleet had an average year of 9.9 years old (Andreoni, Miola, & Perujo, 2008).

A preliminary calculation of the utility functions of different type of ships resulted in four ships being the most applicable for SP. These ships are discussed below. In the appendix a wider range of ships is elaborated on.

Container ship

In Liner Trades, the most common used vessel is the container ship. By their inter-modalism and the protective nature of the steel outside, containers have revolutionized international trade. The capacity of such a vessel is expressed in TEU, which stands for Twenty feet Equivalent Unit. With a capacity of 21,413 TUE, the OOCL Hong Kong is the largest container vessel in operation today, build in 2017. The International Standards Organization (ISO) standardized the dimension of the containers, which is 20ft by 8ft by 8 ft 6inches. Other variations are in use today are the forty feet equivalent (FEU) and the hi-cube or the super cube with a height of 9ft. . Container sizes and properties are governed by International Standards Organization (ISO) standards with a TEU measuring 20ft by 8ft by 8ft 6inches (Length by width by height). Containers with a length of 40ft are becoming more prevalent and hence the term FEU (Forty feet Equivalent Unit) was coined for their reference. Other container variations in trade today include hi-cube or super cube which have a height of 9ft 6inches.

Oil tanker

A special kind of bulk carrier is the product carrier. These tankers carry liquid bulk, which is crude oil products in the most cases. These vessels used lateral and longitudinal bulkheads to divide rooms in the vessel. This simple system separates multiple centre tanks and two wing tanks. The two wing tanks are used for ballast water in case the cargo hold is empty. The centre tanks are used for the liquid bulk. To protect sea water from oil pollution, new tankers are designed with a double hull which should prevent this in case of accidents. The product carriers are classified on the category of cargo like liquid natural gas and liquid petroleum gas and they are classified on the weight they can carry. Ranging from medium all the way to ultra large crude carriers.

Reefer

A reefer vessel transports cargo in cargo holds in which the temperature is kept artificially low. The temperature can even be kept well below zero to transport meat or fish deep-frozen, for example. Refrigeration vessels can be divided into refrigerated vessels and freezer vessels. Freezed goods are transported at -20 °C, refrigerated products between 0 °C and + 13.3 °C depending on the product. Usually both types of vessels can cool and freeze. The difference is in the dimensions and speed. Ships used for refrigerated transport are larger (> 100 metres) and faster (> 20 knots). This higher speed is necessary to limit the spoilage of the refrigerated cargo (usually fruit) as much as possible and these ships are therefore also called fruit hunters. Freezer ships are usually smaller and slower. Refrigerated vessels are usually white to reflect the heat of the sun.

Passenger

A passenger ship is a ship whose main function is to carry passengers. According to the International Maritime Organization, European and national laws, a passenger ship is a ship that carries more than 12 passengers. These are therefore people who do not work on a ship. A passenger ship has to meet special requirements. On a seagoing passenger ship, for example, a doctor must be on board and special safety requirements apply. There are three types of passenger ship: the mail boat, the ferry and the cruise ship. Especially the cruise ships demand a lot of energy because of the many functionalities on board. A cruise ship stops at various ports to give passengers the opportunity to make excursions.

Berthed hours in ports and Weight

Each of these vessels have a specific weight and an average amount of time they spend in ports. To eventually calculate the fuel consumption of each of these vessel type, the Gross Tonnage (GT) of these types has to be known. The GT is the best correlation with regard to the fuel consumption. It showed much better correlation than for instance the amount of auxiliary power available on a ship (Hulskotte & Denier van der Gon, 2010). The correlation with AE power has been done in other studies as well. The weight is given for each of the vessel types (Brake, Kauffman, & Hulskotte, 2019).

1. Oil Tanker: 73200 GT
2. Container Ship: 54200 GT
3. Reefer: 12100 GT
4. Passenger: 45400 GT

With the weight the consumption is calculated later on in this chapter. Next to the weight, the total hours each vessel is berthed is crucial information as well. The container and reefer ships are, relative to the other two ships, longer in the ports. On average the reefer and container ships are berthed for 3000 hours, were as the Oil Tankers and Passengers ships spend more hours at sea and are berthed for an average of 1000 hours (Samskip, 2020).

6.3 investment costs

The high investment costs are the largest barrier to large scale diffusion of the technology. It makes is less probable as a cost-effective alternative to the AE. The level of investment however can differ for the players as well as how the annual costs are calculated. The investment costs are included into the total cost of ownership, which can be divided into the CAPEX and the OPEX. The CAPEX are the capital expenditures and represent the investment costs. On the other hand are the OPEX, which are the the operating expenditures. These are the recurring costs which include maintenance. An explanation for both is give for each player, starting off with the Shore Powe Firm.

Ports

The Shore Power Firm needs to retrofit the berth in order to be able to supply SP. What should be includes in the shore-side infrastructure are; substations, transformers, frequency converter, control panel, plugs and underground cables. The extent to which this is already present differs for each port. The most expensive requirement are the frequency converter and the substations which supply the high-voltage power. The literature on the investment costs varies mostly from $300,000 to $5 million per berth (California Air Board, 2018). This depends on the power demand, frequecy, port location and vessel types. The cost of modifying a terminal was estimated by CARB to be around $5 million (California Air Resources board, 2007) and the Port of Rotterdam estimated around €4 million per berth (Doves, 2006). On the other hand there are examples of Gothenburg were two berths were estimated on €255,000. The lack of frequency converter, the already present high-voltage power and the low power requirements for the vessels squeezed the costs significantly. There is Amsterdam for which the costs were estimated on €5 million per berth (D. Vree, 2008). Finally with a breakdown of the different elements ENTEC the price was estimated on €1,5 million (Jonge, 2005). Running this game would require multiple simulations of different prices and a selection of ports on their price category. There are also operational costs like the yearly inspection and the preventive maintenance. Additionally, most researchers estimate the maintenance cost are approximately 5% of the initial investment costs (D. Vree, 2008).

Taking the above literature in consideration the costs for ports are determined in three different categories and are suited for small, medium and large vessels. The data is chosen from the Entec study (Jonge, 2005). In the table below the CAPEX costs can be seen (table 6.1).

Table 6.1: The cost of retrofitting a berth in different scenarios

Type of port	small vessel	Medium vessel	Large vessel
Low cost option	€ 322,995.00	€ 322,995.00	€ 322,995.00
Medium cost option	€ 569,157.00	€ 612,907.00	€ 656,657.00
High cost option	€ 1,112,586.00	€ 1,156,336.00	€ 1,200,086.00

Taking these scenario's into account forces a decision on how the investment costs in the game should be. Shore Power B.V. in the port of Rotterdam estimates the costs for the SPI in the port on seven to ten million (Anonymous Shipping Company A, 2020). This is a twenty MW installation with four connections. These connections are not that expensive, the total amount of MW determines largely the price. Further in this chapter the energy consumption of the vessels are determined but for now it is safe to assume that on average the vessels use approximately 2.5MW per hour. This means that on average four to eight ships could make use of the installations simultaneously. In the model, each port is visited by thirty ships. While all these thirty ships do not use the port simultaneously, one of these installations is not sufficient. Therefore the retrofit of each port will be €14 million.

Vessels

Retrofitting a vessel so that it can take advantage of SP while hotelling requires a couple of technologies onboard. An electrical distribution system, switchboard and control panel, transformer and a cable real system. Old ships need to be retrofitted with this equipment while new ships have it as part of their naval architecture already. Retrofitting old ships can cost up 150 to 200% of new-build projects. The need for an onboard transformer and the vessel type and size will influence the costs for the ship-side modification but it will range somewhere between $ 300,000 to $1-2 million (Wang et al., 2015). The California Air Resources board made an overview of the different type of vessels and the corresponding cost and it resulted in roughly the same level of investment between $ 300,000 to $2 million (California Air Resources board, 2007). An overview of the prices based on the internal volume of the vessel is given by ((IMO), 2018). Based on the different sizes and the engine requirements Environ investigated 12 vessels and the average prices of retrofitting was $500,000 (ENVIRON International Corporation, 2004). Although outdated, this is the most complete study on the costs of retrofitting. By abstracting the weight out of the equation t can be calculated, with the data from Environ, that per TUE capacity the average cost for investment is $ 172. Additionally, most researchers estimate the maintenance cost are approximately 5% of the initial investment costs (D. Vree, 2008)

Taking the above literature in consideration, the cost price of the investments for retrofitting a vessel are given below. The costs are based on ((IMO), 2018) and (Brake et al., 2019). The eventual price is determined through an iteration between the indication of the price for retrofitting and the weight class is belonged to.

1. Oil tanker: €508k
2. Container Ship: €337k
3. Reefer: €142k
4. Passenger: €666k

Annualized costs

The APEX costs for the investments on-shore and off-shore are hard to determine and the literature on the topic gives mixed results. Because the prices can not be stated with certainty, they will be determined on the type of vessel and port and will vary in the different simulation to determine the impact on the utility. The total investments costs will be reduced to an annual cost price based on the design life cycle and the interest rate in the following formula.

$$I_{i,j} = \frac{Inv_{ij} \times r}{1 - (1 + r)^{-n}} \tag{6.5}$$

Where,
$I_{i,j}$ is the annualized costs for vessel i or port j.
Inv_{ij} Is the sum of the investments done by port j or on vessel i.
The interest rate is r.
n Is the amount of years in which the investment is depreciated.

The annualized costs for the maintenance $M^I_{i,j}$ are calculated by taking a percentage (in the literature it is 5% (D. Vree, 2008)) from the CAPEX costs $I_{i,j}$ for either vessel i or port j.

6.4 Fuel and Electricity

Fuel and electricity have a big impact on the cost of using SP versus running the AE. Fuel is expensive and emits many pollutants which can be translated to societal health costs. In this section the fuel and electricity costs, sources and health consequences will be displayed.

6.4.1 Fuel

The International Maritime Organization (IMO) started to regulate the environmental impact of shipping with MARPOL 73/78 (the International Convention for the Prevention of Pollution from Ships, 1973 as amended by the Protocol of 1978 relating thereto). Subsequently, Annex VI of the Convention entered into force in 2005, limiting for the first time sulphur oxide (SOx) and nitrogen oxide (NOx) levels in ship emissions. In terms of SOx, the first global limit was set at 4.50% mass/mass (m/m) sulphur in fuel oil. In addition, Annex VI also established Emission Control Areas (ECA), a small number of restricted zones around several densely populated areas, where the sulphur limit was set much lower. In 2012, the global limit was lowered to 3.50% m / m. In 2015, the ECA (Emission Control Area) zone limit was lowered to 0.10%. In 2020 the ECA limit remains the same, but the global limit drops to 0.50%. Despite some concerns that both shipping and refineries will need more time to prepare for the change, the IMO has recently confirmed that the 0.50% limit will not be postponed and that all ships will be required to comply or face severe penalties, including being declared unseaworthy, from 1 January 2020 (Laval, 2018). Fuel after 2020 can be divided into five main categories:

1. Fuel oil with ultra-low sulphur content (ULSFO), up to 0,10 %.
2. Very low sulphur fuel oil (VLSFO), up to 0,50 %.
3. Heavy fuel oil, maximum 3,50 %
4. LNG (liquefied natural gas)
5. Other

The set of new fuels put on the market to meet the ECA limit of 0,10 % will continue to be used. These fuels are predominantly pure distillates. However, they can also be blended together as a hybrid - gas oil mixed with residual oil. In most cases these fuels work properly with standardised engine designs, although they may demand some operational modifications due to the comparatively low viscosity of the fuel. Because of the potentially high demand for these fuels, the maritime sector may face competition from other industries and these fuels will become increasingly expensive (Laval, 2018). The ULSFO is the fuel that is used in the SECA (Sulfur Emission Control Areas) zone. This area consists among other areas of all the European ports, The ports in the USA and the Ports in Canada. According to the Chinese Maritime Safety Administration, the sulfur limit on the coastline is still set at 0,5% but there are plans to change this in 2022 and set it to the SECA standard.

The ships of Samskip use Marine Gas Oil (MGO) when located in the ports. As a result this research will uses the prices of MGO. The prices of MGO will vary between major bukering locations and in time as well. In the figure below, the price of MGO over the past year can be seen. The price is extremely low at the moment due to the decline of demand for oil. Different price scenarios are used to determine the price of the fuel in a specific port. This is expressed in $P_{f,j}$. The game will use three different scenarios:

1. **Low** : €300/mt
2. **Medium** : €500/mt
3. **High** : €700/mt

What is important for the calculation of the the fuel consumption for each ship is the average consumption. This is given in table below. The consumption is expressed in kg fuel per GT.hour.

1. Oil Tanker: 19.3

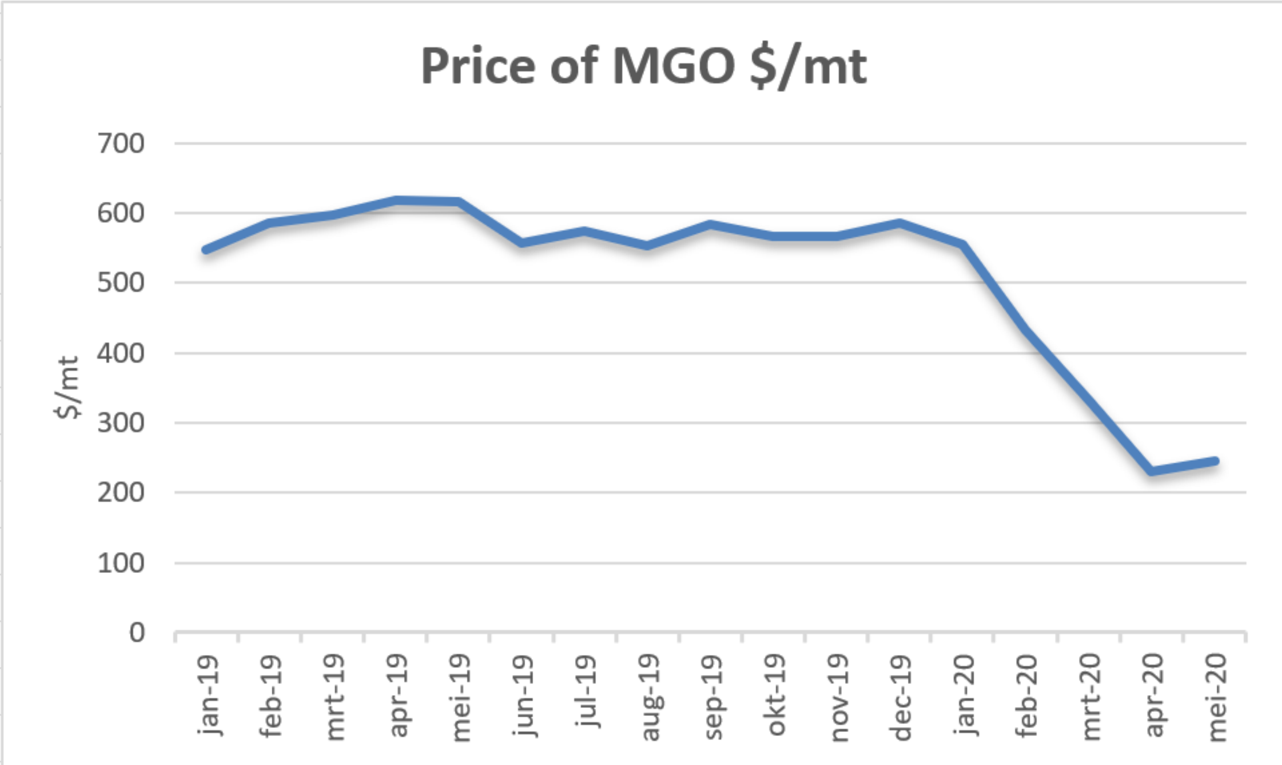

Figure 6.1: Price of MGO - one year

2. Container Ship: 6.0
3. Reefer: 24.6
4. Passenger: 32.4

With the knowledge about the fuel consumption, the type of vessels and the weight of the vessel the consumptio can be specified. The first step is calculating the fuel consumption for vessel i;

$$F_i = V_i \times h_i \times E_i \tag{6.6}$$

Where
F_i is the Fuel consumption for vessel i in kg
V_i Is the size of vessel i in GT. h_i Is the total hours of vessel i it can use SP in ports in one year.
E_v Is the rate of fuel consumption for vessel i in kg per GT.hour.

The Fuel consumption needs to be specified for the vessel and engine type with the following equation.

$$F_{i,v,e} = F_i \times f_v \times f_e \tag{6.7}$$

Where
$F_{i,v,e}$ Is the consumption of fuel specified for the vessel type and engine.
F_i is the Fuel consumption for vessel i in kg
f_v Is the fraction of fuel per vessel type (v).
f_e Is the fraction of the engine for the fuel consumption (e).

6.4.2 Electricity

The OPEX of the SP installations consist for the biggest part out of electricity costs. The price of electricity depends on the electricity supply contract, the energy mix and the country. The operating cost for the shore-side electricity increases if taxes for electricity are applied in a country. Because the electricity costs are a relatively significant factor in the cost effectiveness equation of SP, an increase in the price due to tax, has a major impact on the eventual feasibility. A preliminary conclusion, based on the above mentioned logic, is that SP is the most cost effective at the places where fuel costs are high and electricity cost are low. This section states the type of energy, the prices of energy in different locations and the average consumption of the different type of vessels at berth.

Types of energy

The social, economic and environmental benefits of SP come from the use of electricity instead of fuel. The level of these benefits greatly depend on the mix of the electricity. When the costs of harmful emissions are taken into acount in a business game, the energy mix has a great impact on the cost-effectivess of the investment especially for countries who are higly dependend on fossil fuels as their main power source (Winkel et al., 2016). The sources for the electricity are:

1. Coal
2. Natural Gas
3. Oil
4. Biomass
5. Renewables
6. Nuclear

Each port is located in different countries and continent, a big share of the energy mix in Europe is Nuclear Energy, something that the other continents are less developed in (Statistics, 2013). Depending on the location of port j, different energy mixes will be used.

Prices of energy

Besides the mix of the electricy, the prices of electricity also vary in ports around the world. Even within a country the prices may very, depending on the cost of generation, taxed and the source of generation. For exaple, a ship with an AE power requirement in berth of 600 kW, will pay an electricity bill each day of $432, $1584, $1872 and $2304 for Fujairah, Houston, Rotterdam and Singapore respectively (Fiadomor, 2009) The different prices per kWh in diffrent countries can be seen in table 6.2.

Table 6.2: Electricty prices in different countries (USD/kWh

Country	Year	Month	Business electricity rates
Australia	2019	9	0.17
Belgium	2019	9	0.13
Brazil	2019	9	0.12
Canada	2019	9	0.09
China	2019	9	0.09
Denmark	2019	9	0.27
Germany	2019	9	0.21
Hong Kong	2019	9	0.14
Hungary	2019	9	0.12
Italy	2019	9	0.21
Japan	2019	9	0.21
Netherlands	2019	9	0.13
Russia	2019	9	0.08
Singapore	2019	9	0.15
South Korea	2019	9	0.08
United Kingdom	2019	9	0.19
USA	2019	9	0.11

The model will use three different scenarios:

1. **Low** : €0,07/kWh
2. **Medium** : €0,10/kWh
3. **High** : €0,13/kWh

Average consumption

When in berthm each ship uses its AE to supply the system of the vessel with power. The fuel consumption has been calculated for each vessel type. It is measured in kg fuel / GT.hour. Each vessel has different engines with different characteristcs. This study averages the fuel consumption per kWh. This average is 220 g / kWh. With this number the following AE power requirements for each vessel type can be calculated and are seen below.

1. Oil Tanker: 6.42 MWh
2. Container Ship: 1.48 MWh
3. Reefer: 1.36 MWh
4. Passenger: 6.68 MWh

6.5 Emissions

Both the fuel and the electricity consumed in vessels comes at a price of GHG emissions. The quantity of the exhaust can be seen for the different scenarios in which they are burned and produced. The prices of the substances per kg emitted can be seen in table .1 and come from (De Bruyn et al., 2018). Although the emissions are not used in the utility functions they are a driving force behind the SP technology. For future strategies and impact measurements this data is required.

Emissions for fuel

The fuel described above emits pollution in the air when burned in AE. Per kg of fuel, one can check in table 6.3 how much gram of each pollutant gets emitted into the air (Brake et al., 2019). This data can be compared with traditional fuels to calculate the impact of the combustion. For each of the pollutants a price is given which should represent the associated health cost for one kilogram. Everything can be seen in the table below.

Table 6.3: Emission factors for the fuel while berthing and the associated health impact

Pollutants	Factor (g/kg fuel)	Coal	LNG	biomass	Costs (€/kg)
CO	11	N/A	N/A	N/A	0.052
CO2	3150	887.6	360.2	162.5	0.057
NOx	39	0.342	0.164	0.332	14.8
PM	0.8	0.01	0.0002	0.022	65.3
SO2	4	0.231	0.0004	0.046	11.5
VOC	1.6	1.5	0.24	4.1	1.15

6.6 The remainder elements

The final section of this chapter contains the final elements of the utility equation of the first section. These elements are M_i^e, $S_{i,j}^{\%}$ and $SP_{i,j}^{\%}$. These are described below.

6.6.1 Engine maintenance

Besides the electricity costs the OPEX for SPI include maintenace on the investment. However, maintenance cost also apply to the AE that would run otherwise. When SPI is installed, ships can not get rid of the AE. In many cased the vessels need these engines on open sea, porths without SP berths and in case of a failure in the electricity supply. There are two benefits to be gained bu using SP in respect to the AE. First of all, the AE has an expected live cycle of a certain amount of hours or years. When these engines can shut down, in case of a connection from shore to the ships system, the expected life cycle increases. This increase means that the investment of AE can be spread over more years and it lowers the annualized costs. Since it is hard to calculate the effects of the increased life cycle, this benefit is not included in the SP utility functions.

The second benefit of using SP and turning down the AE, is the reduced maintenance costs for these engines. Vessels using SP will still need to to regular check the AE on maintenance routines. However, this maintenance routine is much lower than the maintenance check-ups required by vessels without SP. The routine of maintenance is done in a quiter and cleaner environment and happens much more regularly because the engines are shutted down. In Gothenburg, engineers cite this significant advantages compared to an evironment were the engine is left running (Jonge, 2005). This advantage can be quantified. The costs for maintenance of an engine vary depending on the amount of strokes, the brand and the size. A general costs for maintenance of the AE is given per hour (Jivén, 2004):

$$M_i^e = 1,6e$$

6.6.2 Sustainability factor

The sustainability factor is the percentage of willingness consumers or companies have to more additionally for sustainable products or services. A study showed that more than halve of the consumers are willing to pay for a sustainable beer versus a regular beer (Carley & Yahng, 2018). In this case the consumers payed a premium, but they knew that this purchasing behaviour my positively effect the environment. For large companies, it might not be the case that they would pay an additional 20% for a sustainable option because they might lose their competitive advantage. It is however, not only charity to be willing to pay more for the greener option. In most tenders, where shipping companies and ports might apply for, a sustainable branch of or vision often positively affects your score and enhances the chances of winning it.

In order to simulate the port environment and mimicking the decision choices of the stakeholders, it is necessary to include the sustainability factor in the utility functions. Based on information provided by Samskip the sustainability factor is determined on;

$$S_{i,j}^{\%} = 5\%$$

However, throughout different combinations this number can change.

6.6.3 SP percentage

The network effects are an import deal in this research. Because of the network effect the implementation of SP in one port can have a positive ipact on other ports. In the utility functions of ships and ports, the SP percentage or factor is determined. The game describes a situation with fifteen ports, fifteen shipping companies and 150 ships. For each of those a SP factor is determined each year. The 150 ships should create a big enough network that, such that the network effects can be determined on different stages of the simulation. On top of that, the different vessel types can be randomly distributed over the fifteen different shipping companies. These numbers could vary in other simulations as well.

For a ship it is predetermined which ports it will visit. When it calculates its utility, it checks which ports, of the one it's going to visit this year, has already installed SPI. In the game each ship visits three different ports. This means that the SP factor can either be 0%, 33%, 67% or 100%. This factor is mulitplied by the total amount of hours it visits ports in a year. When this number is a 1000 hours, with a SP factor of 33%, the utility function would calculate the potential profit of using SP for 330 hours per year.

On the contrary, each port is visited by 30 different ships each year. The utility function is setup in such a way that it counts the amount of ships that visit it and multiply it with a specific amount of contribution. Only the ships that actually use SP will pay the contribution. The SP factor is calculated by the amount of ships that have SPE, divided by thirty. The contribution is calculated in such a way that with 25 out of 30 ships, the port will break even.

6.7 Conclusions

The most important aspects of the conceptualisation are the utility functions mentioned in section 6.1. For these functions, some elements had to be investigated. The investment cost for both the ports and the vessel are known. The maintenance cost are directly dependent on these investments and are known as well. With the different vessel types explained, one can make predictions about the AE size and the fuel consumption's. The costs, source and emission factors of the electricity and fuel are known as well. With all this variables known the utility functions can be calculated by multiplying with the total berth hours spend inside the ports. The first step is calculating the fuel consumption with the following equation:

Finally, one could determine the total emission exhausted and what would be potentially saved by the use of SP by multiplying the fuel with the emission factor per substance. With the aforementioned information the utility can be calculated by using the equations in section 6.1. One important note is that some of the variables can not be determined with certainty or can change in the future. To compensate this uncertainty, the variables will vary throughout the games and many simulations will have to determine the impact of these variables.

Chapter 7

Testing the game for a Nash Equilibrium

This chapter explains the current position of the port environment with regards to SP. The game, which has been described and designed in the previous chapter is used to depict the current situation. In order to prove with the model that the SP technology is in a Nash Equilibrium, the model has to be tested. With guidance of the three sub-questions stated below this chapter answers the question if and why ports and shipping companies are in an equilibrium.

Why are the Ports and Shipping companies in an equilibrium regarding shore power without an incentive to upset it?

1. Can the designed game be used to prove the equilibrium?
2. Is there an equilibrium, using the game to prove it?
3. What are critical elements in this equilibrium?

7.1 The model

This section will go through the model. Based on an explanation of the software and the code in the program, the model will be explained. Essential functions and their design give a complete impression of the performance. In the appendix, an overview of all functions can be found. The game described in the previous chapters is based on autonomous parties who make decisions based on the most favourable outcome, in their opinion. The players in this game are shipping companies located in ports and harbours themselves. Both parties can choose to install SP. This choice is based on the outcome of the aforementioned utility functions. Every year in the game, these choices will are calculated in order to re-evaluate the most favourable outcome. There are many different ways to model these choices. The basis of these modulations can be found in the Agent-Based modelling, which is based on agents who make decisions based on their environment. The environment in this case is the choices of the other players and the many variables that are present in the SP environment.

The combination of Agent-based modelling and game theory is unusual, and there are few examples in the literature describing how this combination can be worked out properly. One of the challenges of this research is to design an environment in which these two theories come together and can be controlled. This research uses the software of Netlogo. It is designed to mimic the natural and social environment and to include both space and time in the model. It was designed by Uri Wilensky in 1990 and is based on Java. NetLogo is open software and can be used by anyone. The open devices and the easily manageable Java language make it an excellent choice for this research.

NetLogo provides several tools to simulate the agents. Functions can be controlled utilizing self-designed buttons, and in a separate window, the actions of all players can be tracked. In addition to controlling their action, it is possible to create graphs of different properties in the environments to quickly create an overview of the status of the game during the simulation. The most important thing to grasp from this overview is the dashboard which can be seen in the picture... Here one can see a world map with ports indicated as crosses. These crosses represent the most well known and biggest ports worldwide from Shanghai and Singapore to Rotterdam and Hamburg. On the left side of fig. 7.1 are 15 boats representing the shipping companies. Behind each shipping company are ten symbols representing ships belonging to the shipping company they are behind. Each type of symbol represents a different ship. The triangle for a container ship, the square for the oil tanker, the pentagon for the passenger ship and the circle for the reefer. Each ship has its characteristics. The colour of the ships, shipping companies, as well as the ports, can have three different values. Red, yellow and green. These stand for whether shore-based power is not present, under construction or already in use.

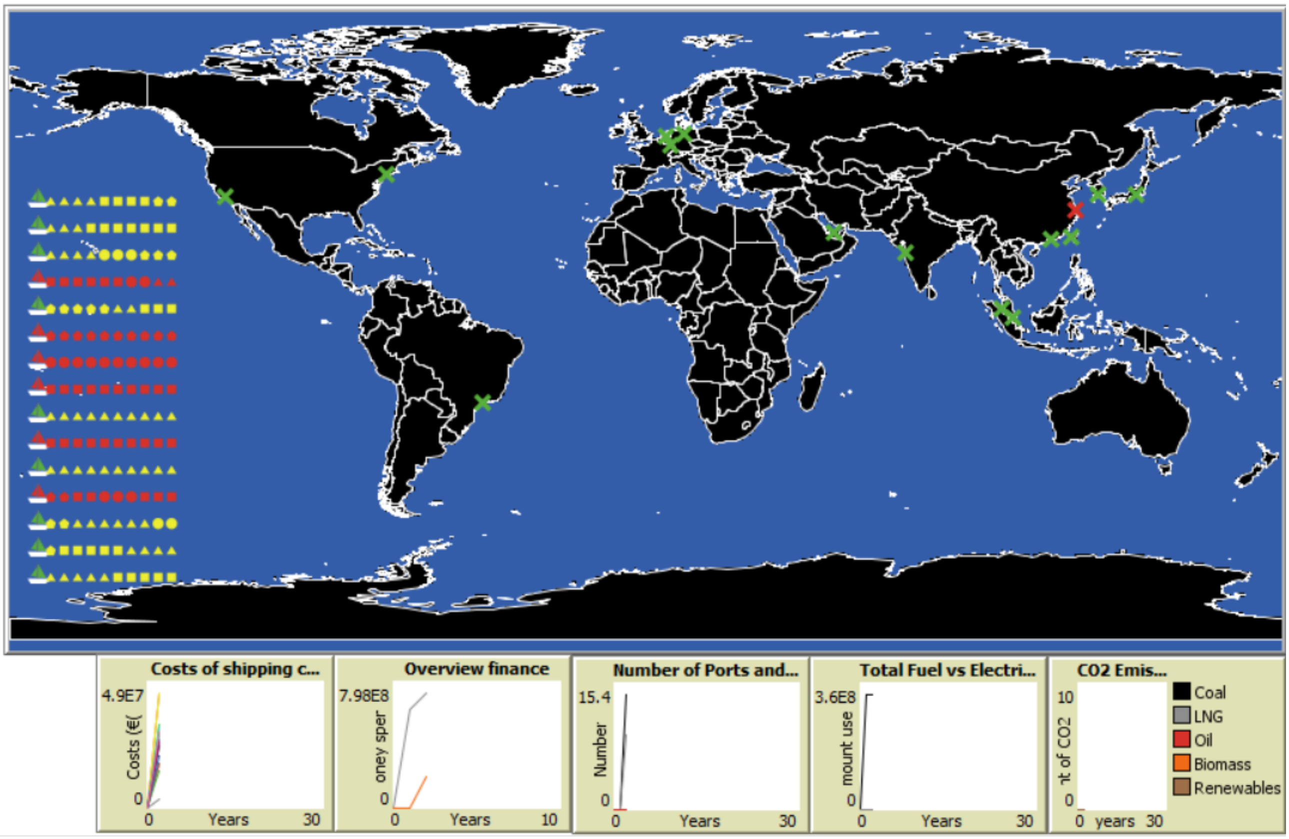

Figure 7.1: Map of Netlogo Game

In addition to the window of the world map and an overview of the agents' actions, there is another part of the dashboard that is used to control the game. In fig. 7.2 there are buttons, switches, sliders and input parameters that can be used to control the parameters in the game. In simulation control, buttons can be found that are used to set up and start the game. There is also a possibility to force shore power to be installed in specific ports or shipping companies. The general parameters provide the possibility to fix global variables such as electricity and fuel prices. There are several ways to run the simulation; one example is whether or not the prices of emissions caused by ships in ports can be used in the utility functions. These options will be discussed in the next chapter on strategies. The lower part of this dashboard regulates all input for the different types of ships. Chapter 6 shows the average values for container ships, oil tankers, passenger ships and reefers. Of course, the between the different ships, these values can differentiate immensely so in many cased, the average value will not always be accurate. Partly because of this, there is the possibility to adjust these kinds of values.

7.2 The tests

Before statements can be made or conclusions can be drawn about the actual situation of shore power, for example, whether it is in a Nash equilibrium, the model has to be tested. Through tests, this model has to prove if it is trustworthy and reliable by examining the outcome of several exceptional situations. These situations are not real and will not occur in the coming years; the only reason they are set up is to be able to say something about the reliability of the model itself. In this section, the model will be tested in four different scenarios;

Figure 7.2: Netlogo Controls

1. The price of electricity is close to zero
2. The price of fuel is maximum (1500 euro)
3. The cost of retrofitting ships is virtually zero
4. The cost of retrofitting ports is virtually zero

The outcome of this test provides insight into the model and can be used as reference material for further simulations. The outcome of the tests is measured in the number of ships that use shore-side electricity and the number of ports that use shore-side electricity. In addition to varying these parameters, the situation will be maintained as described in chapter 6. But before the tests are executed, a run-through of the model is demonstrated.

7.2.1 Run through

This section describes a full walkthrough of the game. The walkthrough demonstrates what the model is capable of and basically how it works. The game starts in year zero and reveals the choices and considerations of the players. The simulation runs until year twenty. This section does not elaborate on the code of the model. The most important functions are described in appendix A; the full code is available on request.

The start of the simulation starts with the installation of the environment. For this, the 'setup' button is used. This button gives the world form and places the ports, shipping companies and ships at a predefined location. In year zero, no party is equipped with SP, which can be seen by the red colour of the different players. At this moment, it is up to the administrator of the game to fill in the parameters. These parameters are described in picture 7.2. General inputs such as fuel price, power price, interest, engine maintenance and a sustainability factor are determined. The next step is to determine player specific properties such as the cost of a port and ship properties. The used values in this simulation are used as described in the previous chapter, but it is possible to deviate from this. Before the simulation starts, the 'Simulation Options' have to be determined.

These include the CO2 certificates, emission prices and an option for probability in the calculations. These options influence the course of the game and largely determine how the previously mentioned utility functions will look. Most of these simulation settings are discussed in the next two chapters. In this example, all these options will be turned off.

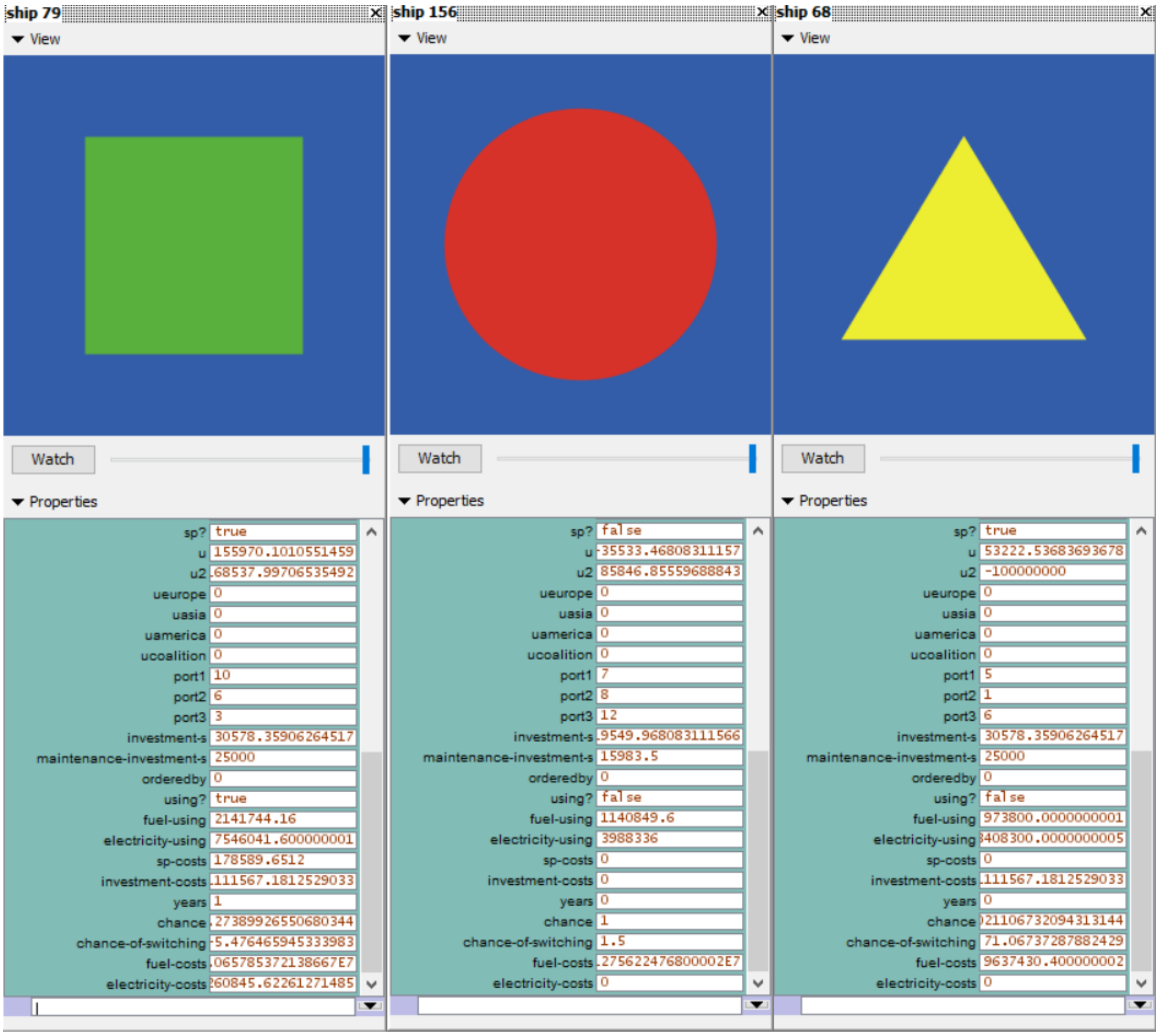

Figure 7.3: Three ships in different phases

To initiate the simulation, one has to press the 'GO' button. This button expires one year in the game. At the end of this year, each party calculates if they want to use SP. The calculation is done using a utility function. An example are the ships 68, 79 and 156 shown in picture . The properties show that one ship has a positive U and the other negative value. Ship xx, therefore, starts converting the ship. It changes from a red to a yellow colour. After one year it turns green, and SP can be used.

These calculations are not only done for the ships but also the ports and shipping companies calculate their utility. In this phase of the game, the values will still be negative. These values can be seen in picture xxx. It also describes which other values are calculated for all parties—for example, the SP factor, maintenance costs and the amount of fuel used by that party.

The first time we stop the game is after three years. Three years means that there have been three different rounds in which the parties had the choice to switch or not. The situation started with an entire red field, which means that no player is able to use SP. With no player using SP, the SP factor of all parties is zero and therefore also the utility. For this purpose, the second utility function was created. This function gives shipping companies a choice. They can choose to bear the costs of both the SPE and the SPI. After three years, two shipping companies have made use of this. As a result, twenty ships and five ports use the construction for

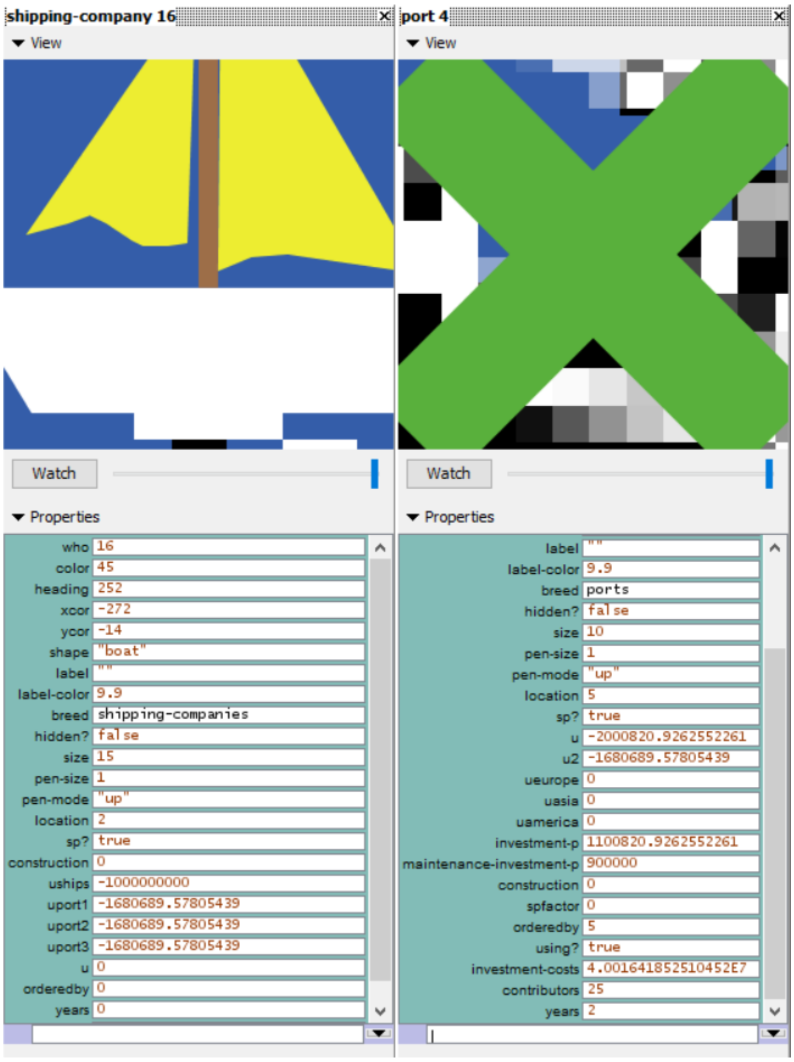

Figure 7.4: Port 4 and Shipping Company 16

SP. The five ports that are able to accept SP in year three make it more attractive for the other ships. The first movers influence others, and eighty ships start the construction. An overview is given in fig. 7.5.

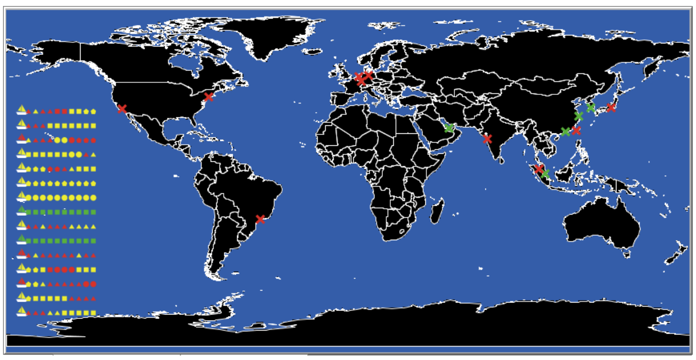

Figure 7.5: Year 3

The next moment the game is stopped is three years later, after a total of six years. Meanwhile, there have been six choice moments in which players could change strategy. Last time twenty ships were using SP, and it was under construction at eighty ships. Meanwhile, after six years, there are one hundred and twenty-nine ships that use SP, and there is one ship in which it will be installed. The impact on each other clearly shows the network effects. Initially, after three years, it was not profitable for these players to make high investments. The game has changed. Because several parties have already switched, technology has become intrinsically more valuable. As a result, some thirty additional ships have switched in three years, which amounts to twenty per cent of the total.

Figure 7.6: Year 6

The third time the simulation has been shut down is after nine years. Nine years means it is about halfway through. The network effects are still affecting the players. Many ships have been converted in the last rounds of the game; it is now also more enjoyable for ports to build the right infrastructure. While five ports already offered SP, two are now under construction. In total, there are only ten ships that do nothing with SP yet. These ten ships are container ships and reefers. Because of the low fuel consumption of this type of ship, the investments are less quickly recouped, and the utility is a lot lower compared to the other types of ships. At the end of the simulation, it will be shown how these ships react to an SP factor of 100%.

Figure 7.7: Year 9

The last time the simulation is shut down is after fourteen years. Year fourteen is the year in which SP construction started for the last time. The entire simulation will run for another six years, in which a number of things will be measured that will be discussed in a moment. The last four ships will be prepared for SP. As of year fifteen, all ships will be able to use SP. Because almost all ships are this far, there will also be much work in the harbours. Three ports are being converted. When, in year fifteen, all ships use SP, the last ports will also be converted. This means that in year sixteen all players will use SP. The SP factor is 100%. Figure XXX shows the course of the players' choices. The last step in this demonstration is to look at the final values. Different values are monitored during each game. When a ship does or does not use shore power, costs will or will not be spent on fuel, and among other things, CO_2 will be emitted. At each player's choice moment, all these values are also calculated. This ultimately gives the participants an idea of the impact they have on their choices. In picture XX, two graphs give an idea of the number of players that have switched. An overview of the financial impact is also given.

The first years of the simulation have the most significant impact on the network. Almost half of the ships are converted in the first few years. After several years this number is still gradually increasing. The graph next to

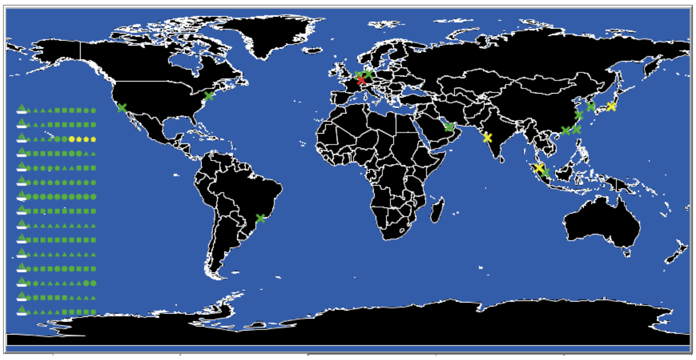

Figure 7.8: Year 14

it shows the financial picture. Due to the high investment costs more is spent in the first years, the substantial savings quickly overtake this on fuel costs. The graph compares the costs that the network would have had if nobody used SP. Figure XX shows the other values that are calculated for each round. The first value is the total fuel consumption of the network. The consumption does not increase as quickly as the number of converted vessels because there must be a match between the vessels and the ports before it is possible to switch to the use of SP. The last graph shows how much CO2 has been saved in total. The number depends on how power is generated. Logically, the most significant saving is the use of renewables.

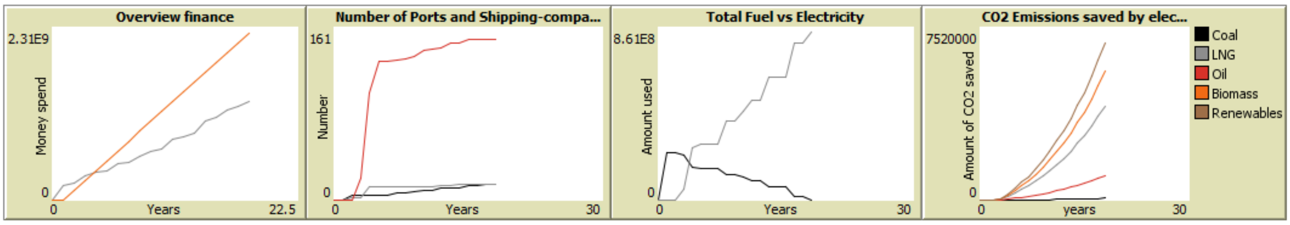

Figure 7.9: Different stats

7.2.2 Extreme scenario tests

After giving a walk through of the model, it is clear and explained how it works. To use the model for further research, test are executed to prove the reliability. The first test is varying the electricity price.

Electricity price

The first test varies the electricity price. Research has shown that this price plays a vital role in the financial feasibility of SP. When the price of electricity approaches zero, it should have a significant impact on the number of players switching. The results are as follows:

1. Number of Ships: 150 ships use SP.
2. Number of Ports: 15 Ports use SP.

Fuel price

The previous chapters have shown that the current fuel price is meagre compared to the multi-year average, which is due to the coronavirus outbreak as well as increasing tensions between different oil-producing countries. With the current rate, it is unlikely that SP can be seen as a financially viable solution. On the other hand, it can be assumed that prices will rise again in the coming years. In this test, we look at what happens when the fuel price is set at 1500 euro, which is about 2 to 3 times higher than the multi-year average.

1. Number of Ships: 150 ships use SP.
2. Number of Ports: 15 Ports use SP.

Ships costs

In addition to the OPEX, one should also think of the CAPEX. This is an essential input in the utility functions. The first situation that is considered is to reduce the investment costs for ships to zero euro. In practice, this would mean that there would be no costs or everything would be covered by subsidies. The only remaining costs are the costs of using shore-side electricity in ports. These contribution costs are deducted from the potential profit by saving fuel versus electricity. The results are as follows:

1. Number of Ships: 0 ships use SP
2. Number of Ports: 0 ships use SP

Port costs

The latter situation under review relates to the CAPEX of SP. In addition to investments by ships, investments by ports are now being examined. The costs of these investments can increase considerably and can reduce the utility considerably. When these costs go to zero, ships will also not have to sponsor a part of the investment in order to be able to make use of shore-side electricity. The profit in the utility functions of ports will come from these ships. With a cost of 0 euro, the profit will also be 0 euro. This makes it more attractive for shipping companies to place SPI themselves. The results are as follows:

1. Number of Ships: 0 ships use SP
2. Number of Ports: 0 ships use SP

In the situation were the fuel and electricity prices approach zero, the maximum number of ports and ships will retrofit and use SP. When the investment costs approach zero, none of the ships or ports will switch. While this might look counter intuitive, taken the rationality of the agents into account it is in line with the expectations. When the ships costs approach zero, the ports in the network do not offer SP and so the ships can not use it. Retrofitting the ships would not increase the utility. The same goes for the ports. In extreme conditions, the command utility2, calculates if it increases the utility to build a SP installation on the quay and retrofit all of its ships. When both the investment costs for ships and ports approach zero, this is sufficient for the shipping-companies to invest and utilize SP. The outcomes are in line with expectations and give green light for further testing of the model. The next step is to run the model in such a faithful imitation of reality to investigate whether the players are currently in a Nash equilibrium.

7.3 Nash Equilibrium

The model used to mimic the playing conditions is described and tested in the previous section. This section looks at whether the Nash equilibrium, which is suspected to be present in the SP game, can be proven. There are two ways to prove this. The model is used to determine how many players will switch to shore power from the zero situation. Besides, a more theoretical approach is used. Eventually, in this section, the two methods will be juxtaposed to prove together that this Nash equilibrium exists.

From the previous chapters, values have been determined that will serve as input for the model. Values include; fuel and electricity prices, interest, engine maintenance, depreciation years, number of hours per ship and more. When the simulation is run for 30 years, it shows that no party in the network will switch to SP. Ships, shipping companies and ports have no incentive to invest. This is since no party in the network is currently using SP. When a player switches out of the game, they will not be able to use it. Also, with the current rates, it is not profitable for a shipping company to take on both the costs of ships and the costs of shore infrastructure. This happens in more extreme situations described in the previous section and described in the function utility2. The simulations of the model show that it is not worthwhile for any party to switch, so it seems plausible that the players are in a Nash equilibrium. This can be explained using game theory.

To indicate in the game theory what a Nash equilibrium is, the situation is analyzed using a payoff table. The payoff table is simplified based on the situation as described above to show where the equilibrium is located clearly. The paramets for this example use a fuel price of €700 and an kWh price of €0.10. Suppose ship A uses its auxiliary engines in ports to produce power. Ship A is a Passenger Ship. The investment costs are €700,000. When Ship A has a SPfactor of %100, the utility is 400,000. When ship A makes the investment but cannot use it, it results in a utility of -100,000. In a similar situation port B can do nothing (utility equals 0), make an investment and use it (utility equals 400,000) or make an investment and not use it (utility equals -1,200,000).

The possibility to use or not depends on the choice of the other player. All the numbers are scaled down for better interpretation purposes. The payoff matrix can be found in table 7.1.

Table 7.1: Payoff matrix for two players

		Port B: Yes	Port B: No
Ship A	Yes	40,40	-10,0
	No	0,-120	0,0

The first step in solving the problem is to find a dominant strategy. When ship A does invest, it is convenient for port B to invest as well. When ship A does not invest, it is also the better choice for port B not to do so. So there is no dominant strategy here. The same can be said for port B. Step two is to look for a dominated strategy. This means that one strategy would be struck out, which is the case when it is always worse than another strategy. When going through the table, one can see that there is also no dominated strategy present. The last step is to check if there is a Nash equilibrium. This involves looking at every point in the table and checking if any of the players given that point have a better option. From this, it follows that at the point yes, yes and no, no the ship and the port are in a Nash equilibrium.

Table 7.2: Payoff matrix for three players

Port C chooses Yes		Ship B: Yes	Ship B: No
Ship A	Yes	40,40,40	40,0,-40
	No	0,40,-40	0,0,-120

Port C chooses No		Ship B: Yes	Ship B: No
Ship A	Yes	-10,-10,0	-10,0,0
	No	0,-10,0	0,0,0

The situation can also be played with three players instead of two. An example would be with two ships A and B and a port C. Ship B is a Container ship with investment costs of €500,000. When Ship A has a SPfactor of %100, the utility is 100,000. When ship B makes the investment but cannot use it, it results in a utility of -60,000 The payoff table is given in table 7.2. For Port B, there's an extra option, which is when one of the two Ships make use of its service. In this situation the Utility is -400,000. This situation has more possibilities, and the utility of the players depends on more than one party. Also, in this table, there are no dominant or dominated strategies. Again, there are two Nash equilibria on the points yes, yes, yes and no, no, no. This can be repeated with the situation with two ships and two ports of which the table is shown in table 7.3.

The situation repeats itself, and the Nash balances are still on the points yes, yes, yes, yes and no, no, no, no. Apart from the fact that it is becoming more and more complicated to show what this kind of payoff table looks like with more and more participants, it is not becoming more and more complicated to point out the Nash equilibriums. These equilibriums remain in the same places. The values taken in all tables are entirely abstract but illustrate the situation where the utility functions of the players are influenced by which opponents have or have not switched to SP. So the technology becomes worth more and more as more players join in. This is called the network effect.

Now that it is theoretically precise how the Nash balance can be assigned, it is necessary to see how this translates into the model. The model looks at each ship and port on its own. Suppose ship A visits ports 1, 2 and 3 and is moored in these ports for a total of 1000 hours. The model checks each round whether ports 1, 2 and 3 make use of shore power. If only port 2 uses SP, the SP factor will be equal to 1/3, or 33%. The program now calculates a utility that takes into account 333 hours of shore power and 667 hours of regular fuel. There has already been a simulation in which no party had switched; this is comparable in the previous examples with every player choosing no. The simulation showed that no party was stimulated. The other way around, as the simulation shows, also works. When all ports offer shore power, it pays off for the ships to switch. When all ships have switched, it is worthwhile for the ports to switch as well. This proves the two Nash equilibriums, everyone switches or no one switches.

Table 7.3: Payoff matrix for four players

Port D chooses Yes		Port C chooses Yes		Port C chooses No	
		Ship B: Yes	Ship B: No	Ship B: Yes	Ship B: No
Ship A	Yes	40,40,40,40	40,0,-40,0	15,15,15,40	15,0,0,-40
Ship A	No	0,40,-40,-40	0,0,-120,-120	0,15,0,-40	0,0,0,-120

Port D chooses No		Port C chooses Yes		Port C chooses No	
		Ship B: Yes	Ship B: No	Ship B: Yes	Ship B: No
Ship A	Yes	15,15,40,0	0,15,-40,0	-10,-10,0,0	-10,0,0,0
Ship A	No	0,15,-40,0	0,0,-120,0	0,-10,0,0	0,0,0,0

7.4 Conclusions

Through Netlogo's software, a model has been imitated that can simulate the SP problem. Both the theory and the model show that in the payoff tables, filled by the utility functions, two equilibria are created. These are always located at the top left or bottom right and represent the situations in which everyone is switching or when nobody is switching. In the next chapters, we will look at which strategies can be applied to convert the balance that each player is currently in (no one is switching) into the more favourable equilibrium.

Chapter 8

Strategies

This chapter, called strategies, explains what individual players or companies can undertake to implement the use of SP on a larger scale. The previous chapter shows that the players of the shore power game are in a Nash equilibrium. In this game, there are two equilibriums possible. Equilibrium 1 is located in the payoff table at the bottom right, and this covers each player's strategy to do nothing with SP. Equilibrium 2 is located in the payoff table at the top left and is the contradiction of equilibrium 1. Here everyone has chosen to switch. Equilibrium 2 would be a more favourable option for all players in the network, yet achieving this situation is not an easy task. This chapter formulates strategies that support the transition from the current position towards the more favourable position. The strategies are subdivided according to their origin. The origin can be from the shareholders in the network, from the game theory or insights from the simulations. In addition to the strategies being formulated, we also look at how they can be tested.

Which strategies can be formulated to disrupt the equilibrium and enhance the implementation of Shore Power?

1. Which strategies can be formulated on the base of game theory?
2. Which strategies can be formulated based on the stakeholders?
3. Which strategies can be formulated on the base of the simulations?

8.1 Strategies from stakeholders

The most important source of strategies comes from the network itself and has been formulated or verified by shareholders of parties or persons directly or indirectly involved with SP. Chapter 4 discusses which shareholders they are. These parties have been working on the implementation of shore-side electricity for some time and have possible solutions to speed up the implementation process. Not all possible solutions mentioned are explained and taken into account here, a pre-selection has already been made in the feasibility and applicability of the solutions. The first strategy mentioned concerns the inclusion of emissions.

Emissions

There are several ways to calculate whether a project or investment is a financially sound choice. These calculations can be done by looking at the Internal Rate of Return, Payback Time or Net Present Value. The choice herein can determine whether or not to invest. However, there are other possibilities within SP technology to arrive at different assessments. In the calculations, one can look at the purely financial consequences of the investment, but it is also an option to incur costs for the emissions that ships cause in ports. The impact on the environment and health of residents is an essential driver of the SP technology so it would be logical to include this in the calculations already.

There are two options to include the costs of emissions. The first of these is to have it solved by market forces, which can be done by emissions trading. Emission rights give countries or companies the right to emit certain greenhouse gases or other harmful gases. These include, for example, CO_2, CH_4, N_2O and NO_x. If the number of allowances is limited, it becomes expensive for companies to emit emissions, which should lead to the greening of the production process and investments in renewable energy. The price of a tonne of CO_2 is now 25 €.

The second option is to assess the impact of emissions caused by ships when burning their fuel. These health consequences due to air pollution, for example, are costly for the government. The impact of each tonne of emissions has been calculated by CE Delft and is presented in Chapter 6. These two options have been added to the model. Once they have been selected, the utility functions for ships change.

Coalitions

The second strategy that is dealt with and comes from the stakeholders is about forming alliances or coalitions. An often-heard argument is that ports want to oblige or encourage ships, but they are afraid of losing their competitive position. On the other hand, this also applies to ships; the costs will have to be recouped, which will increase the costs of transport, which may have an impact on the choice to use this party as a carrier. Making international agreements can help to make these kinds of investments but not lose a competitive position to each other. It is possible to prepare the ports in Europe with SP; these talks have already begun. Worldwide, it will be difficult to make agreements on this. In the model this is tested by preparing a group of ports, the network effects should ensure that the shore-side electricity technology spreads. How much this should cost and what it will yield for these ports will be investigated in the next chapter.

Policy

The third strategy is a standard solution but challenging to implement. Employing policy obligations on shore-side electricity technology could lead to the technology being pushed through, which leads to much commotion among shipping companies that do not want to declare themselves with costs, but also among ports that do not want to lose their competitive position. The commotion builds on the previous strategy because it must be tackled internationally. If this is not the case, ships may choose to take other routes. The model will test what happens when existing ships have the chance to retrofit until 2030. New ships should always be equipped with SPE.

Subsidy

The last point that is mentioned and comes from the shareholders of this network is to grant subsidies. In the previous chapter, it has been proven that there is a Nash equilibrium, which means that it is not worth switching at this moment. If several parties were to join, it would already become more attractive, but not yet attractive enough. There will remain a gap between the costs of the investment and the potential returns. One way of bridging this gap is to provide a subsidy. Governments could choose to make subsidies available to parties that want to work with SP.

Two characteristics need to be taken into account. The subsidy is used to raise the number of users of the technology over a certain threshold. Once this threshold is reached, there will be no need to provide a subsidy. In addition, it has been calculated that it is financially more attractive to use shore-side electricity when everyone has switched, and the players end up in the new equilibrium, in which the players are more profitable than they were compared to the original situation. So the subsidy could, if necessary, be a loan under very mild conditions because when a sufficient number of players will switch all the parties are more profitable. What is also important is that it currently costs governments money in indirect public health consequences. Because it is indirect, many people will not recognize this, but it should be possible to pay out the potential savings as a subsidy.

8.2 Strategies from Game Theory

The second direction from which strategies are formulated is from the game theory. This research uses game theory as a theoretical framework to describe and understand the situation. In chapter 1111 the different types of games are elaborated. The rules of the game are not chosen because it is easy to modulate but because it should be as close to reality as possible. It is assumed, both in the model and in reality, that players are rational and intelligent and do not cooperate. These assumptions have been questioned because they would not always fit well with what is happening in real life.

Discussions with shareholders revealed that in some cases, there is a need for cooperation with other parties and that not every shareholder will make a purely rational choice to make a sustainable investment, such as

SP. As a result, it was decided to adjust two aspects, or rules, of the game theory in order to measure the effects on the implementation. This is the non-cooperation versus the cooperation and the rational aspect of the agents.

Cooperation

What does the theory say about non-cooperative versus cooperative theory. Is it always non-cooperative? How do you go about it? What does it yield? This can't really be simulated. So we'll look at the data in purely theoretical terms. We need to form coalitions. In this theory, it's more about what a group can accomplish, or what each coalition can accomplish. It's not important how agents on an individual level make decisions within a coalition and it's not important how they communicate and coordinate. Assumption; the reward can be divided among themselves The questions to be asked are; What coalition is being formed? Everyone or just a part. How will the payoff be distributed?

Rationality

The last aspect that the game theory provides to analyze the situation differently is one of the basic principles of the theory; the rationality of the participants. Although the rationality has been questioned on several occasions in this research, it does not always seem to be the right approach to assess a situation as accurately as possible. This characteristic is criticized in the literature, but also shareholders in SP technology admitted that the decisions they made, are not all based on rationality alone. Chapter 6 initially wanted to take this into account by including a sustainability factor in the utility functions. Still, the players will only be guided by the outcome of the functions, something that does not always match reality.

In order to comply with the abovementioned conclusions, certain functions have been updated or added. It has been made possible for a player to counteract on the outcome of the utility function. The 'rebellion' of the player might be caused because many non-financial or socio-economic aspects are not included in the functions wich might be considered necessary by this player. A random choice is made to switch; the probability of switching is based on the ratio between the two choices, which means that if the utility of switching is 5% lower, the probability of switching is higher than if the utility were 20% lower. In addition to this probability, it is also possible to designate shipping companies, ships or ports as pioneers. In practice, it is more common for some companies in the network to pay less attention to the financial picture and risk switching as a pioneer while there is still much uncertainty in the market. The effect on the network needs to be figured out what happens when a player does make the switch. The results of the impact are stated in the next chapter.

8.3 Strategies from simulations

In the last couple chapters in which the game has been designed, much thought has been given to the properties that the players and the utility functions have. Similarly, during the development of the model, much thought was given into the influence of the various parameters as input on the outcome of the model. The gathered knowledge serves as the third and final source from which strategies are formulated. Two aspects are examined from this source. The first aspect is the influence of maintenance costs versus purchase costs (CAPEX vs OPEX). These are two values that can gradually rise or fall due to many external factors, but also due to time. This analysis will measure how effective changes are in triggering an increase in implementation. From this, policy or advice could be formulated in the future.

The second aspect to emerge from the simulations is several minimal values that are required in gaining information about the profitability for ships. The values could be specific prices that inform a ship or port when it is financially feasible to make the switch. For example, the fuel price in relation to the electricity price or the number of players that at least should make use of the investment in order for it to be profitable. This information can be used as guidance in investment decisions.

8.4 Conclusions

The strategies in this chapter are based on stakeholders, Game Theory and simulations. The aim of these strategies can be measured in two ways. They can either make sure that there is only one equilibrium left, which is the more favourable of the two, or they can make the players switch between the two equilibria. Whether this is even possible and what the effects are is displayed in the next chapter.

Chapter 9
Results

The past chapters have looked at shore power technology and the process of its implementation. Based on game theory, as a theoretical framework, a game has been designed. This game has been created based on in-depth research into the shareholders in the SP network, an extensive literature study and own calculations. After transforming the game into a model, the game theory and the model proved that the current starting point is a balance in which the participants are not stimulated to switch. Strategies have been drawn up to entice the players of this network to make the switch. Switching would improve the payoffs in the game, and the players would thus enhance the game together. The effects of these strategies are set out in this chapter to answer the following central question.

What is the impact of the strategic disruptions and what advise can be formulated out of the effects?

1. How can the strategies be formulated as input in the game?
2. What are the effects of the strategies on the outcome of the simulation?
3. What advice can be formulated from the strategic interference?

The sub-questions in this chapter will be explained for each strategy, and the general advice will emerge in conclusion. Before the strategies are presented, a baseline measurement is carried out. This baseline measurement is used as a reference material. In addition to the baseline measurement, research has also been carried out into critical elements in the SP calculations. An explanation and overview of these elements are given first.

In this first part, an overview of the critical elements in the shore power calculations is given. The designed game is based on utility functions that form the basis for the behaviour of the participants. The functions require much input. This input differs per participant but can also change over time. This variation results in many different possibilities and results of the utility functions. Based on a particular input, an overview of these variables is given in this section. The essential values, in this case, are the fuel price and the electricity price.

9.1 Critical elements

First comes the overview for ships. The utility function is used as described in chapter 6. All variables are filled in except the one that needs to be calculated. With all the required data, the utility can be set to zero; this can be used to calculate the minimum required input to make the investment financially feasible.

9.1.1 Prices

Here, the fuel price is asked and compared to the electricity price. The first calculations assume an investment of €250,000, an SP factor of 75%, a contribution to the port of €75000 per ship/year and some other less critical variables. In table 9.1 the required fuel prices can be viewed.

This table also assumes that each ship, in total, is moored in ports rougly 3000 hours. Each ship has different hourly consumption levels. For example, ship A is moored in several ports for 3000 hours in a year and

Table 9.1: Price combinations

3000 hours	100 l/h	3000 hours	300 l/h	3000 hours	600 l/h	3000 hours	1200 l/h
€/kWh	€/ton	€/kWh	€/liter	€/kWh	€/liter	€/kWh	€/liter
€ 0,01	€ 471,73	€ 0,01	€ 180,58	€ 0,01	€ 107,79	€ 0,01	€ 71,39
€ 0,02	€ 506,73	€ 0,02	€ 215,58	€ 0,02	€ 142,79	€ 0,02	€ 106,39
€ 0,03	€ 541,73	€ 0,03	€ 250,58	€ 0,03	€ 177,79	€ 0,03	€ 141,39
€ 0,04	€ 576,73	€ 0,04	€ 285,58	€ 0,04	€ 212,79	€ 0,04	€ 176,39
€ 0,05	€ 611,73	€ 0,05	€ 320,58	€ 0,05	€ 247,79	€ 0,05	€ 211,39
€ 0,06	€ 646,73	€ 0,06	€ 355,58	€ 0,06	€ 282,79	€ 0,06	€ 246,39
€ 0,07	€ 681,73	€ 0,07	€ 390,58	€ 0,07	€ 317,79	€ 0,07	€ 281,39
€ 0,08	€ 716,73	€ 0,08	€ 425,58	€ 0,08	€ 352,79	€ 0,08	€ 316,39
€ 0,09	€ 751,73	€ 0,09	€ 460,58	€ 0,09	€ 387,79	€ 0,09	€ 351,39
€ 0,10	€ 786,73	€ 0,10	€ 495,58	€ 0,10	€ 422,79	€ 0,10	€ 386,39
€ 0,11	€ 821,73	€ 0,11	€ 530,58	€ 0,11	€ 457,79	€ 0,11	€ 421,39
€ 0,12	€ 856,73	€ 0,12	€ 565,58	€ 0,12	€ 492,79	€ 0,12	€ 456,39
€ 0,13	€ 891,73	€ 0,13	€ 600,58	€ 0,13	€ 527,79	€ 0,13	€ 491,39
€ 0,14	€ 926,73	€ 0,14	€ 635,58	€ 0,14	€ 562,79	€ 0,14	€ 526,39
€ 0,15	€ 961,73	€ 0,15	€ 670,58	€ 0,15	€ 597,79	€ 0,15	€ 561,39
€ 0,16	€ 996,73	€ 0,16	€ 705,58	€ 0,16	€ 632,79	€ 0,16	€ 596,39
€ 0,17	€ 1.031,73	€ 0,17	€ 740,58	€ 0,17	€ 667,79	€ 0,17	€ 631,39
€ 0,18	€ 1.066,73	€ 0,18	€ 775,58	€ 0,18	€ 702,79	€ 0,18	€ 666,39
€ 0,19	€ 1.101,73	€ 0,19	€ 810,58	€ 0,19	€ 737,79	€ 0,19	€ 701,39
€ 0,20	€ 1.136,73	€ 0,20	€ 845,58	€ 0,20	€ 772,79	€ 0,20	€ 736,39

consumes an average of 300 litres of fuel per hour. The electricity that ship A could get has a kWh price of €0.10. This price means that the current fuel price should be at least €495 to make the investment financially feasible.

Another example is when the SP factor is 50%, and the conversion costs €1,000,000. For different consumptions, the ratio between the fuel price and the electricity price is given in fig. 9.1.

The current price of the fuel is about €300. This price is much lower than the average of recent years. It can already be seen from the tables that for many ships, it is in no way profitable to switch with such low fuel prices. The highest price of fuel per ton in the last two years has been about €650. This price makes it very attractive for many input combinations. In the appendix is a printout of the different possibilities that ships can encounter in ports. There is variation in the SP factor, contribution to ports and investment costs.

9.1.2 Hours

In addition to the relationship between fuel price and electricity price, there is another crucial factor in utility calculations. This factor is the SP factor. This factor stands for the percentage of hours moored in ports where this ship can use shore-side electricity. What is not essential in the calculations is the total number of hours in which shore-side electricity can be used. Because this varies for each ship, it was decided to calculate this total number of hours. After this, the SP factor can be calculated. In the table below the average electricity and fuel price of respectively €0.10/kWh and €500/ton is used. Subsequently, the table shows a variety of contributions to the ports, consumption per hour and various investment costs. The total number of hours per scenario is shown in table 9.2.

For example, ship A has a consumption of 300l/h and pays €50,000 to the port to be allowed to use shore-side electricity. The conversion costs amount to €500,000. This ship would have to use shore-side electricity for about 2330 hours each year before it could be profitable. The study shows that most ships are moored in ports for around 3,000 hours. This number means that these ships must have an SP factor of approximately 78%. That percentage is a lot higher than is currently available.

Assuming the 3000 hours. What kind of table will there be.... All these values give an idea of what it takes for ships to make profitable use of shore power. All these preconditions, such as the right prices and SP factor, are

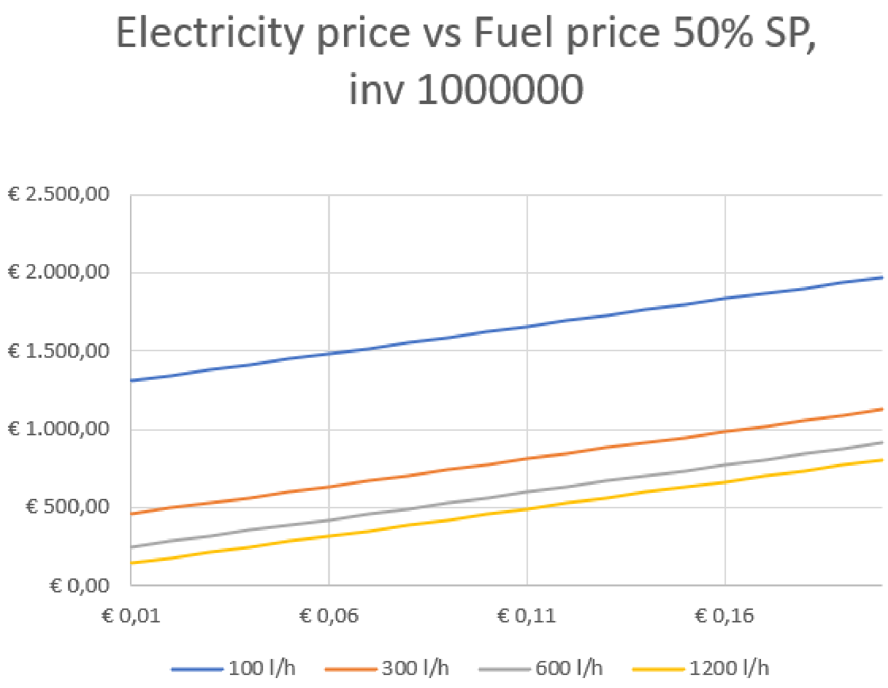

Figure 9.1: Different price ranges

not available as of right now. In the strategies mentioned below, possible solutions for these preconditions are mentioned, but first, the baseline measurement is explained.

9.2 Strategies

This part of the report presents the results of the strategies. For each strategy it is explained where it comes from, how it has been applied in the model, what the impact is and whether it is feasible in practice to look at it in this specific way. The strategy will be judged on a number of aspects;

1. The number of parties switched
2. Costs saved
3. Emission reduction
4. Impact number

In order to get a good picture of the impact of each strategy, it is compared with the current situation. Each simulation starts with different values and several values that will remain the same. Most values are as described

Table 9.2: Amount of hours, needed to break even

	Consumption (liter/hour)				
Contribution (€/year)	*100*	*300*	*600*	*1200*	**Investment costs (€)**
0	1833,41	653,10	332,26	167,59	*250000*
50000	4702,03	1674,97	852,11	429,81	*250000*
75000	6136,34	2185,91	1112,04	560,92	*250000*
0	3666,82	1306,21	664,51	335,18	*500000*
50000	6535,44	2328,08	1184,37	597,40	*500000*
75000	7969,75	2839,01	1444,30	728,51	*500000*
0	7333,65	2612,42	1329,02	670,37	*1000000*
50000	10202,26	3634,28	1848,88	932,59	*1000000*
75000	11636,57	4145,22	2108,81	1063,70	*1000000*

in chapter 6, but the prices of fuel and electricity and the SP factor are varied. If there are aspects of probability in the simulation, it is always repeated several times, and an average is drawn from it. The entire network consists of 15 ports, 15 shipping companies and 150 ships. The changes in values, or results, will be expressed as a percentage because absolute values are too arbitrary. Besides, as explained earlier, the simulation will run for a total of 20 years.

9.2.1 Control measurement

The standard test consists of 27 different combinations of different electricity prices, fuel prices and SP factor. In determining the SP factor, some ports are arbitrarily designated to install shore-side electricity. Because the impact on the grid can be different for each port, each combination is repeated several times to determine from the average. table 9.3 shows the percentage of ships switching under different conditions.

Table 9.3: Percentage of ships using SP - Standard

	Sp Factor			
Electricity Price (€/kWh)	*0,00%*	*33,00%*	*67,00%*	**Fuel Price (€/tonne)**
0,13	0%	0%	0%	*300*
0,1	0%	0%	0%	*300*
0,07	0%	0%	0%	*300*
0,13	0%	0%	0%	*500*
0,1	0%	9%	30%	*500*
0,07	0%	62%	85%	*500*
0,13	0%	61%	85%	*700*
0,1	100%	100%	100%	*700*
0,07	100%	100%	100%	*700*

The decision was made to express the difference and the impact on the network initially in terms of the number of ships making the switch. This is because it is also easy to determine environmental impact. Besides, ports are forced to make the switch in the simulation due to individual settings, which would give a distorted picture of reality. Looking at the table, it shows that with a fuel price of €300 no ship will switch to shore-side electricity regardless of other conditions. The outcome corresponds to the previously mentioned critical elements of SP. With the current fuel price, there will be no ship that dares to switch to SP in purely rational terms.

With a fuel price of €500, after 20 years an average of 20.6% of the ships will have switched. It does show, however, that in combination with a kWh price of €0.13 no ship will switch to SP. When the fuel price is €700, after 20 years, 83% of the ships will have switched. After four years this is only 70%. This number shows that due to the reinforcing network effects, it is becoming more and more economical to switch.

The impact of the electricity price is also considerable, although it fluctuates less than with the price of fuel. When the kWh price is €0.13, 16% of ships will be equipped with SP after 20 years. At €0.07, more than 49% of the vessels will have been converted. The starting number of ports where SPI is present also has a significant impact on the number of ships. When 67% of the ports have SPI, twice as many ships will have been converted compared to the situation where no port has SPI.

The situations with the highest fuel price and relatively low power costs will have the most significant impact. In 6 combinations 100% of the ships will switch to SP. The table above is used to compare the strategies below. The first strategy is to include the emission costs in the utility functions.

9.2.2 Emissions

There are several ways to include the costs of emissions caused by ships in the calculations of the ships themselves. As discussed in the previous chapter, it can be solved by the market or by setting prices on the different types of emissions. This study chooses to stay as close to reality as possible. In several studies, the consequences and costs of different emissions have been calculated. Although it is easy to implement, it is implausible that within the next 15 years all these costs will be recovered from those who emit it.

Something plausible is the use of CO2 certificates. The prices to be allowed to emit a ton of CO2 varies a lot over the last few years. In 2013 a ton only cost €3 while in 2019 the price was almost €30. When this option is ticked in the model, it checks for each ship how many hours it uses shore power per port. This data can be used to calculate how many litres of fuel have been saved in total. The fuel can be used to check how much CO2 emissions this had caused. The potentially saved emissions are multiplied by the price of CO2 certificates, and this is subtracted from the utility. Using this addition in the function will generate the results in table .1.

With a fuel price of €300, on average only about 4% of the ships pass over. The 4% is already more than the previous measurement, which had a 0% pass over rate. Increasing the price to 500 has a positive effect. In that scenario, 38% of the ships have SPE. In the highest fuel price scenario, 88% have SPE. Besides, the kWh price also has a significant impact. There is a 32% difference between the highest and the lowest scenario. table .2 shows the difference between the zero measurements. In fig. 9.2 the amount of ships that use SP is graphed. It shows that the equilibrium is settled after five years.

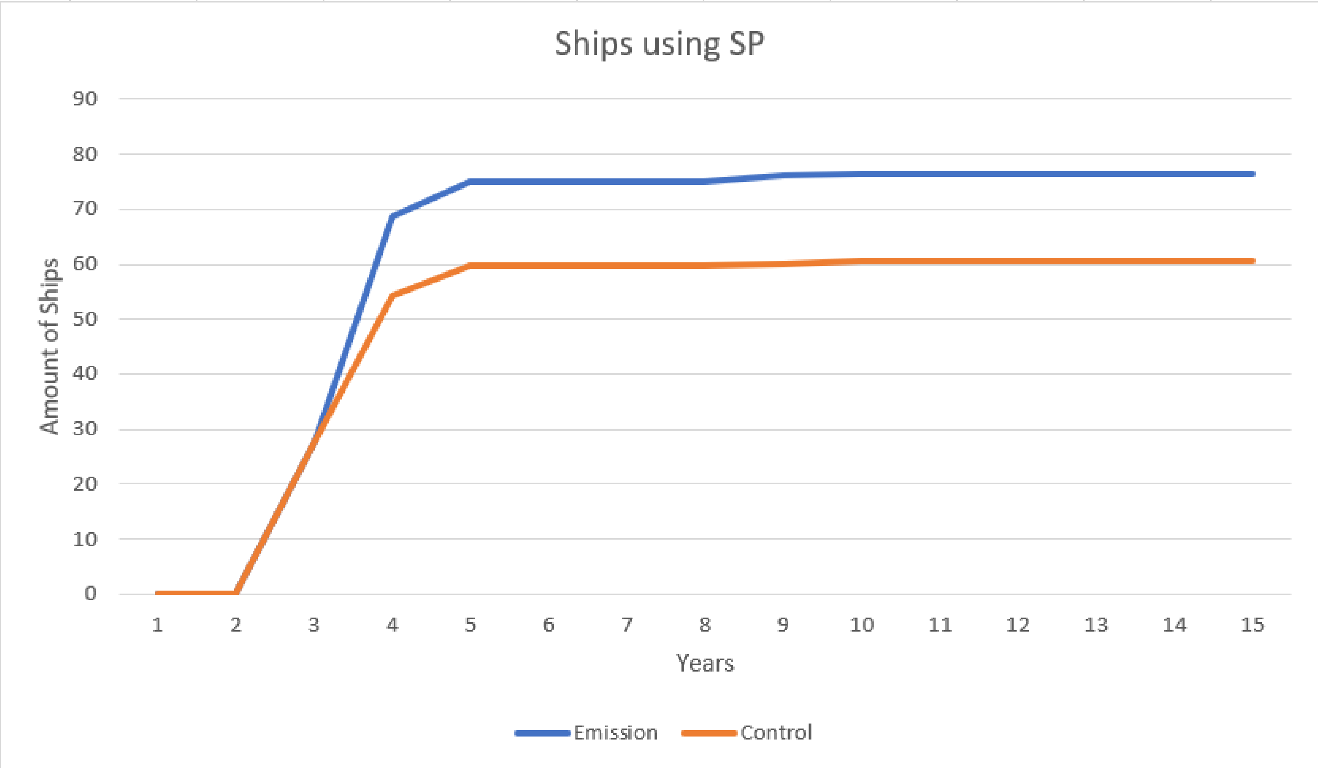

Figure 9.2: Impact of Emission prices on SP usage on ships

The achieved difference is found in the middle regions. It is in these regions since with a price of €700 per ton of fuel in almost every combination all ships had switched. It was to be expected that it would have a positive impact on the number of ships installing SPE. Also, it is not inconceivable that within some years, such prices will have to be paid for CO2 emissions. The impact of the strategy is summarized in fig. 9.3.

9.2.3 Coalitions

Within the chosen model, there are multiple possibilities to add coalitions. A coalition means that mutual agreements are made to add SP to ports or ships. A coalition could be formed between ports in a country, a continent or worldwide. Discussions with shareholders in the network have shown that there are exploratory talks about setting up such links within Europe. It is not yet known whether these kinds of negotiations are also taking place on other continents. The talks also revealed that global agreements are still too complicated at present.

The coalitions applied in this model are continental alliances. A separate connection has been chosen for America (North and South), Europe and Asia, respectively. It has been decided to make it compulsory to install shore-side electricity for all ports and ships that are in or visiting these ports. The ports of America, Europe and Asia represent respectively 20%, 20% and 33% of the network. Ships visiting one of these continents represent 47%,

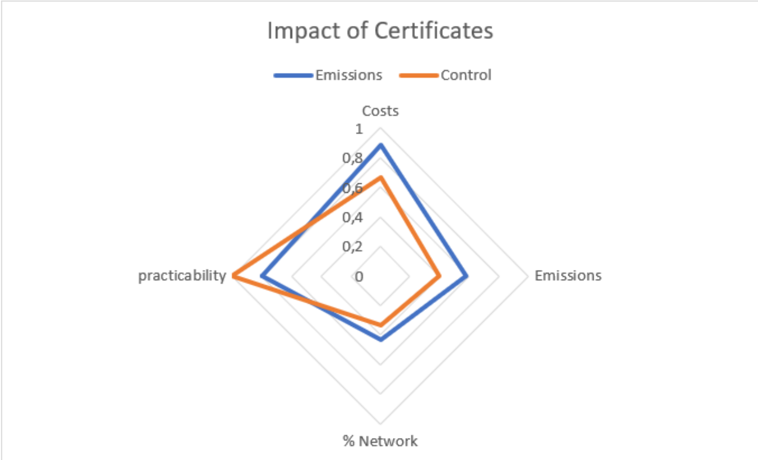

Figure 9.3: Impact of Emissions strategy

45% and 80% respectively. Together, this is more than 100% because ships come in more than one port. It would, therefore, be possible to compare the situation with the baseline measurement partially.

All ports in the model have been allocated a specific location. Each ship has been assigned three different ports to be visited. Different functions and buttons have been added to the model that can force ports and ships with these locations or destinations to install SP. An overview of the number of ships that have switched can be found in table .3. The way the usage of SP developed over the course of twenty years can be seen in fig. 9.4.

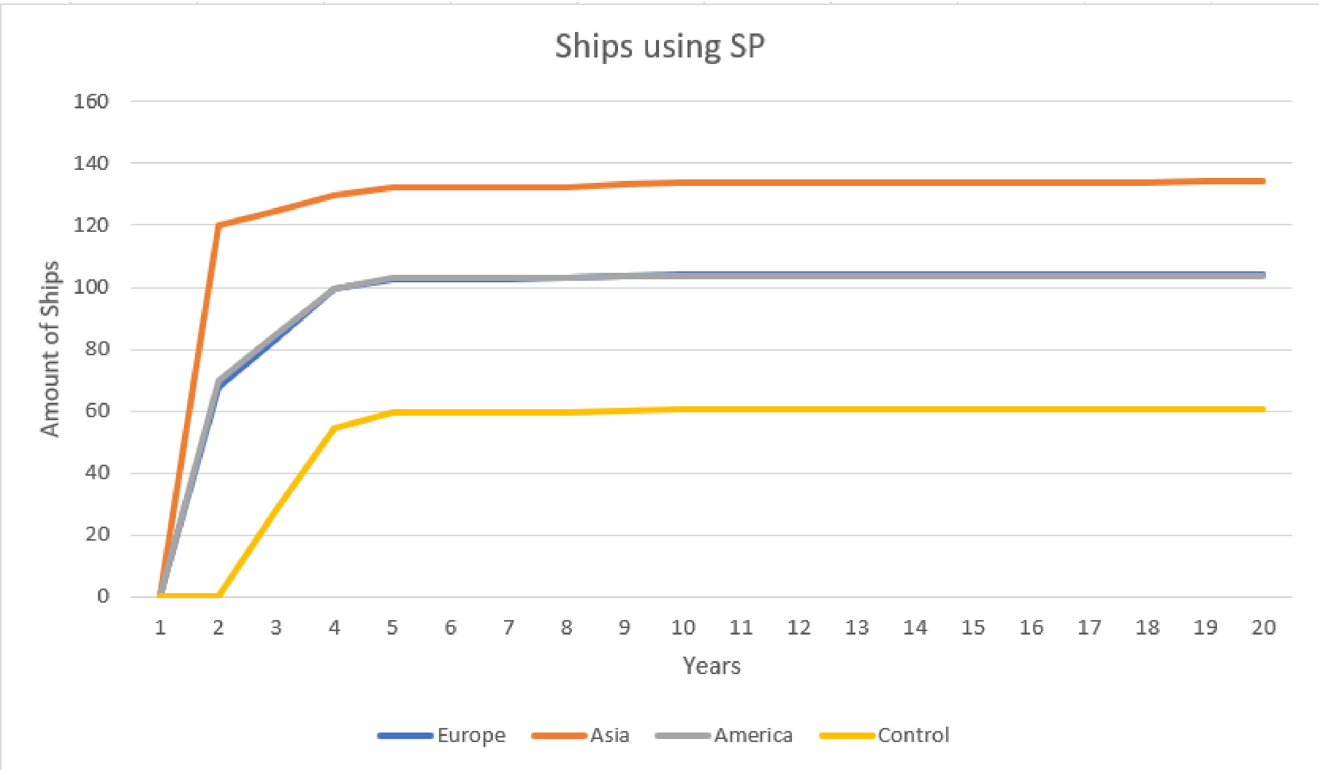

Figure 9.4: Impact of Coalition on SP usage on ships

Since individual ships have been designated to use SP from the start, it is logical that the percentages in the table are much higher. As a result, the table does not give a very accurate picture of the impact of this strategy. The values below should give a better impression. Also, it is to be expected that this can be implemented. Discussions are already going on in Europe, and other parties will not lag. With the imminent threat of mandatory emission reductions, many parties will have no choice but to engage in this kind of related action. The impact of the strategy is summarized in fig. 9.5.

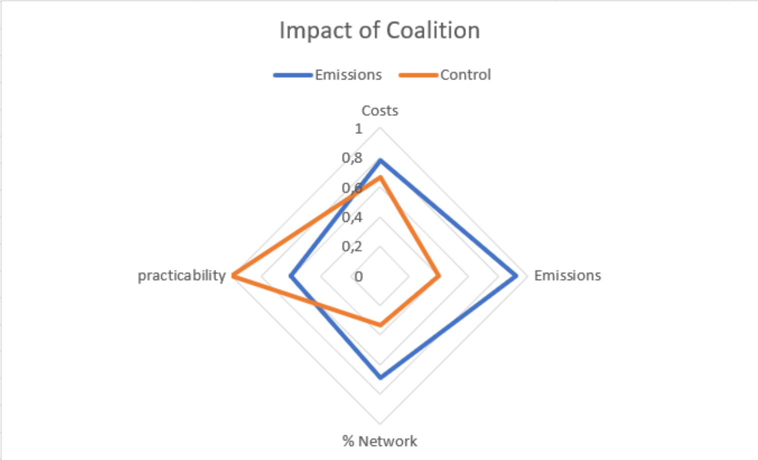

Figure 9.5: Impact of Coalition strategy

9.2.4 Policy

There are several types of policies that could be implemented and will result in more implementation of the SP technology. In addition to many air quality requirements, there could be a general obligation to use SP in ports, near residential areas. Here a distinction can be made between mandatory for ships, ports or both. If it becomes mandatory for both, there would be no need to investigate the impact of this. This section examines what the impact would be on the network if it became mandatory for ships or ports separately.

The utility functions of ports are designed to count which ships frequently enter the port and which of these ships is ready to use SP. Each ship contributes, and with 25 of the 30 ships, it is profitable for ports to build and run the facilities. When it becomes compulsory for all vessels to have SPE, it will automatically be profitable for all ports as well. This would have a 100% impact rate.

It will be more interesting to find out what happens when it becomes mandatory for ports to have these installations. In this case, the SP factor for ships is 100%. In table .4 the results can be seen to other variables. The way the usage of SP developed in ships is seen in fig. 9.6.

If it were compulsory for all ports to have SPI, the SP factor for ships would be 100%. In this case, an average of 45% of ships would change. The impact of the fuel price is still enormous. With a price of €300/tonne, it would not be profitable to switch under any circumstances. The most significant difference is in the most average case. At €500/tonne, 41% of the ships now switch from 0% when the SP factor is 0.

The above results were to be expected. However, it is disappointing that the impact is not higher. The network effects have a good result on the number of ships switching, but when the fuel price does not exceed €300, nothing will happen. In the table, at the beginning of the chapter, it is indicated that an average price of €0.04 is needed to make this profitable. So this will not work.

9.2.5 Subsidy

The use of subsidy as a strategy to break the balance comes from the shareholders in the network. After the contact with shipping companies and other parties, it became clear that under the current circumstances, it is not profitable for one party alone to make the switch. In other words, there is a gap between what it costs and what it delivers. The subsidy could bridge this gap. There are various ways to pay out subsidies for SP projects. The costs are in the CAPEX and OPEX.

The influence of different energy prices has already been calculated in the previous simulations. With the data, it is possible to determine when investment would be profitable. Depending on the local energy prices, a subsidy has to be paid to reduce these prices. The amount of subsidy depends on the country in which the SP

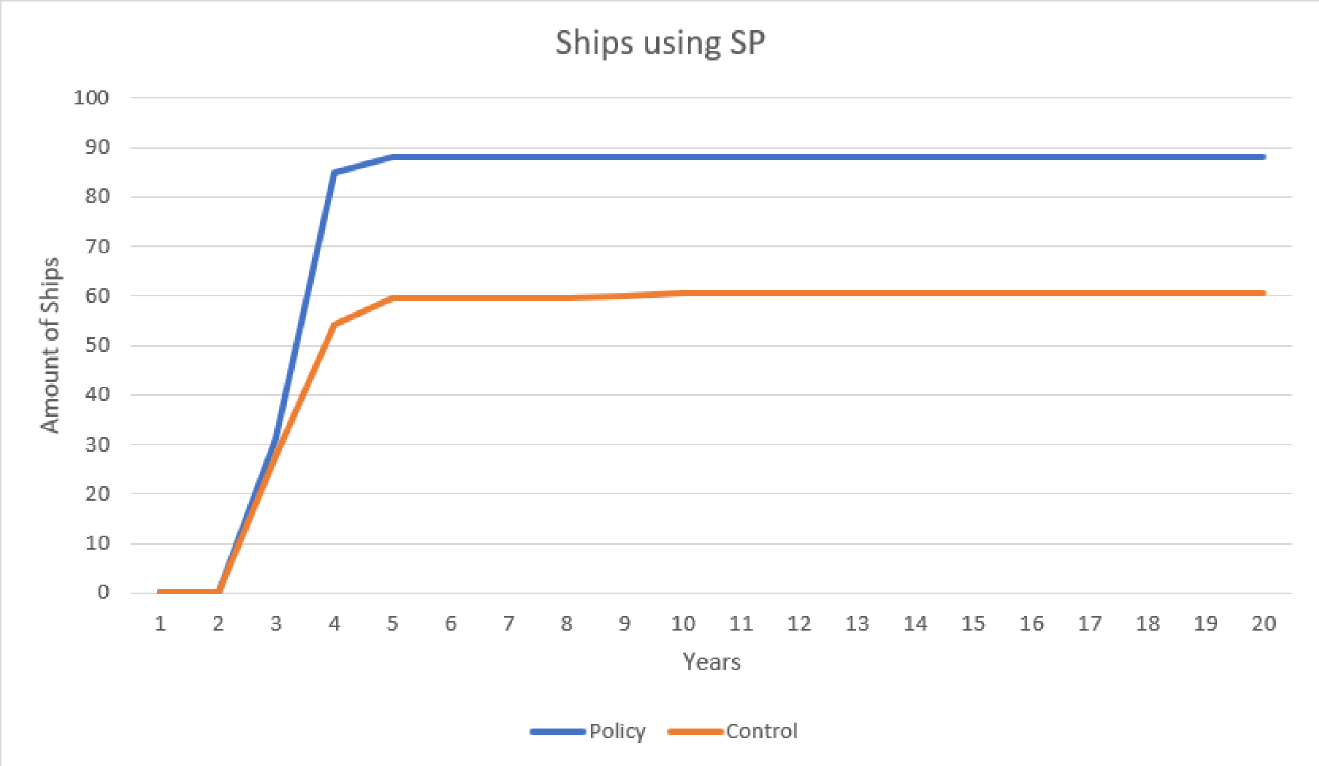

Figure 9.6: Impact of Policy on SP usage on ships

installations are used. The OPEX is not relevant for this part. That is why this section looks at the influence of SP's installation costs. In the following simulations, the investment costs of ships have first been halved. The cut in costs saves about €250,000 per ship. The number of ships switching can be seen in table .5.

When the table is compared to the standard table, there are almost no differences. When the fuel price is €300 or €700, there is no difference. In total, by reducing investment costs, 3% of ships are switching more to shore-side electricity than in previous years. In total it costs 150 x €250,000 = €37,500,000. The yield herein is nihil.

Another possibility is to reduce the costs of building SPI in the ports. The results look at the difference between the ships. According to the previously established utility functions, the reduction in ports means a reduction in the contribution, which should mean an increase in the utility. table .6 shows the results.

When this table is compared with earlier results, it shows a much larger change. When the fuel price is around €500/tonne, an average of 24% more ships change. In total, taking all combinations into account, 14% more ships change over. The total subsidy costs are also a lot higher. For 15 ports a total of 15 x €8,000,000 = €120,000,000. This amount is a lot more, but also produces proportionally more than subsidising the ships. It was to be expected that a higher subsidy would yield more in total than a lower subsidy. However, it turned out that subsidising the ports is also more efficient than paying out subsidies to ships. What has not yet been taken into account is that in real life, if ports received more subsidies for SPI, ports would sooner make this choice, which would increase the SP factor. Proportionally, this yields even more. This is not reflected in the model because of the choice to set up the utility functions in this way. The last overview shows the impact of this strategy in fig. 9.8.

9.2.6 Rationality

Strategies presented so far have either been taken from literature or obtained and verified from discussions with shareholders. The strategies have been formulated to provide a solution against the Nash balance that the players currently find themselves in. Using game theory, the Nash equilibrium has been proven. This section takes a critical look at several characteristics of the designed game. These properties have been formulated

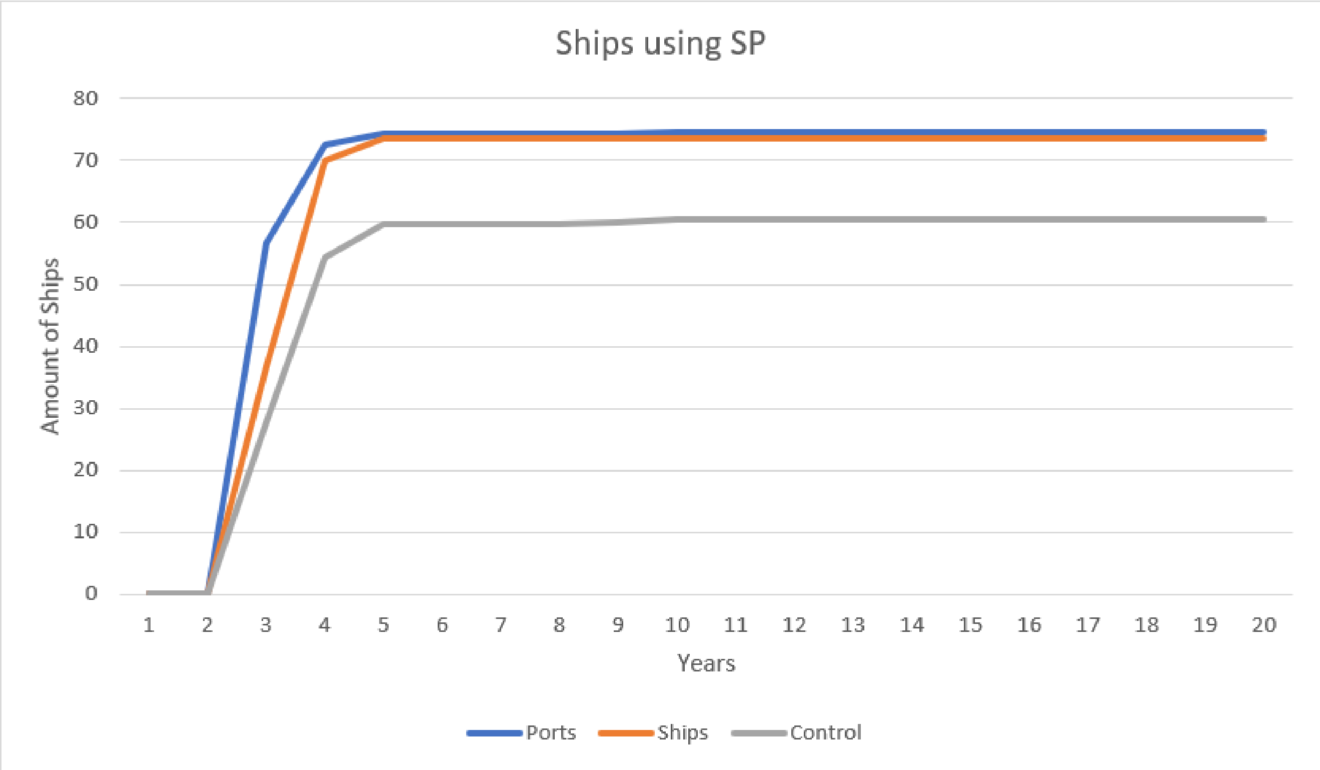

Figure 9.7: Impact of Subsidy on SP usage on ships

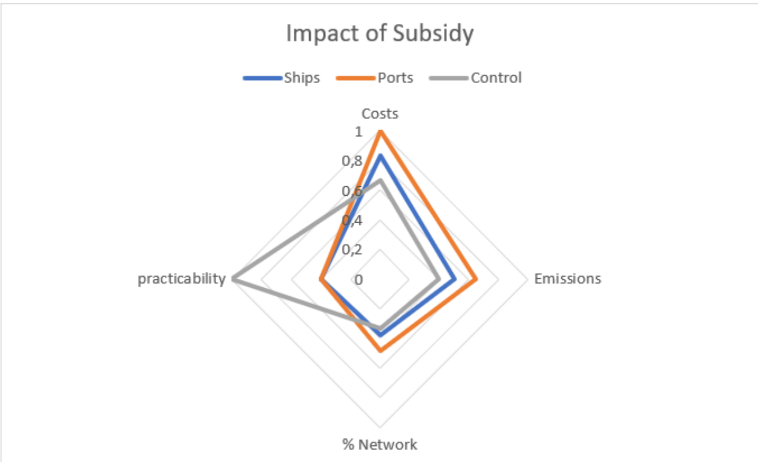

Figure 9.8: Impact of Subsidy strategy

as strategies that can help increase implementation. The first point to look at is the rational properties of the players.

As mentioned above, this section looks at the rationality of the players. In chapter 5, the characteristics of the players are critically examined. It is assumed that they are rational and intelligent, but the question is whether this is always the case in practice. In some cases, regardless of the outcome of their utility, participants in the game will still make the switch. The switch might be caused because they find it extremely important that it is a sustainable option, or because they are confident that it will pay off in the future.

They have chosen to add randomness to the model. When the rationality of the players is turned off, the utility is still calculated. However, when the revenues are close to the costs, but not yet over them, an opportunity to switch anyway is added—the closer to the revenues, the greater the chance that players will switch regardless.

For example; when the benefits are 85% of the costs, this player has a 10% chance of making the switch, which is calculated by 1 / (1-0.85) * 1.5. A slider can set different factors, like 1.5, in the main menu. When instead of 85%, it is 95%, there is a 30% chance of switching. In table 9.4, one can see the effects of this rationality change.

Table 9.4: Percentage of ships using SP - Rationality

	Sp Factor			
Electricity Price (€/kWh)	*0,00%*	*33,00%*	*67,00%*	**Fuel Price (€/tonne)**
0,13	0,00%	0,00%	0,00%	*300*
0,1	0,00%	0,00%	0,00%	*300*
0,07	0,00%	6,50%	23,30%	*300*
0,13	0,00%	23,90%	36,70%	*500*
0,1	0,00%	50,00%	81,80%	*500*
0,07	0,00%	86,30%	98,70%	*500*
0,13	0,00%	83,00%	100,00%	*700*
0,1	100,00%	100,00%	100,00%	*700*
0,07	100,00%	100,00%	100,00%	*700*

This change adds a total of 10% of the number of converted ships in the network. The choice has been made to put a limit on the not rational side of the players. According to the utility calculations, at least 75% of the revenues must be close to the costs. This adjustment can be changed in the main menu. Below are the impact numbers:

1. The number of ships switched: 66
2. Costs saved: 23,4% after 20 years
3. Emission reduction: 44% less CO_2

9.2.7 Cooperation

The last strategy being investigated also stems from a property of game theory. In the model and the game on which it is based, there is no cooperation between the parties. In Game Theory, this is called non-cooperative. The property means, as mentioned before that each player only looks at what adds value for the player. The fact that they can improve together does not influence the outcome. The best-known example of this is the prison dilemma.

In chapter 7, it has been proven, using the payoff tables, that there is a Nash equilibrium. To add a cooperative aspect, the payoffs of the different parties will be averaged. The best choice for each party individually will then become the best choice for the whole. How many parties cooperate depends on the coalitions that are formed. The coalition can consist of 2 players, half of the players or all players. In the model, it was decided to organise these coalitions again on a continental level.

In the model, in addition to the standard utility functions, a third function is added. This function checks per continent which ports are located there and which ships visit these ports. Because these are quite a few ports, the SP factor is automatically increased to 35 to 40% in the calculations. When the average of the utility is greater than 0, all these parties will work together to build SP installations. The coalitions consist of 3, 3 and 5 ports in America, Europe and Asia. The impact of activating this mode can be seen in table 9.5.

For comparison, the standard measurement has been put next to it. This part can be compared with the situation where the SP factor is 0. The results clearly show that at average prices, the impact of collaboration can be huge. In two combinations, the total number of ships goes from 0 to 100%. It looks like an absolute necessity for players to start working together and to jointly benefit. Something that still needs to be researched is how the profits should be distributed in these kinds of relationships.

9.3 Conclusions

From the strategies selected and elaborated on in this chapter some perform better, some cost more and some take longer to pay off. How well a strategy works is dependent on which criteria they are assessed. The research

Table 9.5: Percentage of ships using SP - Cooperation

	Coalitie aan uit		
Electricity Price (€/kWh)	On	Off	**Fuel Price (€/tonne)**
0,13	0,00%	0,00%	*300*
0,1	0,00%	0,00%	*300*
0,07	0,00%	0,00%	*300*
0,13	0,00%	0,00%	*500*
0,1	0,00%	0,00%	*500*
0,07	100,00%	0,00%	*500*
0,13	100,00%	0,00%	*700*
0,1	100,00%	100,00%	*700*
0,07	100,00%	100,00%	*700*

measures the effect on the amount of ships using SP and how much emission and costs are saved compared to none of the ships using SP.

All strategies have a certain benefit to them. If enhancing the total usage of SP is the goal, each strategy will help. It is up to governments and port authorities what will work best in their own country. Shipping companies can use the information provided in first section to judge if it is profitable to invest in SP. All the results will be interpreted in the discussion.

Chapter 10
Discussion

This concluding chapter discusses the various aspects of the research carried out. It deals with specific choices and shortcomings that were taken and experienced during the investigation. Also, it sets out what it has added in practical and scientific terms. Finally, a personal reflection on the research is given.

10.1 Interpretation of Research

This section interpreters the results from the tests, the limitation of the research and criticises the methods used.

Stakeholders as a source

During the literature review, it appeared that there were many problems with shore-based power, which were potential starting points for research. After the literature review, the stakeholders in the SP environment were mapped. These persons, parties and companies could give a better picture of the current situation and indicate which objectives they had and which values they considered essential. The conversations organised with the stakeholders generated a general impression and gave clarity on many topics. Because much different information is available in the literature, such as prices, depreciation time, willingness to pay for sustainability and more, it is not accurate to use a specific value in the models. The conversations have helped to give indications of the range of these values. Strategies have also been formulated and verified with various parties based on these interviews.

This research is conducted on behalf of the Technical University of Delft but was initiated by Samskip B.V. The other parties that were consulted were often competitors of Samskip or were cautious about sharing sensitive information. The values used were proved and or verified by other parties. Unfortunately, these parties were not willing to sign the delivered data. Therefore, the values used are more general and less specific, which does not contribute to the accuracy of the utility functions.

Literature research and discussions with shareholders showed that ports and shipping companies are stuck in a chicken and egg situation. The outcome of their investments depended on the choices of other parties. This breakthrough generated the foundation of the usage of Game Theory. One can wonder if it is logical to use and if there are any disadvantages in using it.

The use of Game Theory

In chapter 5, the rational and intelligent characteristics of the players have been criticised. Rationality is the basis of the game theory; not using this would be a significant violation of its use. It is criticised that people only act in a purely selfish way during the beginning of primary school, but from a certain age on they would prefer to make group decisions. This criticism is more applicable when individuals make decisions. Besides the rationality, selfish groups will not always perform better cite... When groups also have moral and altruistic characteristics, they will on average perform better. So the question is whether, in a situation where moral issue arises like SP, these kinds of feelings do not play a role.

The last point to look at is the Nash Equilibrium. Economists and psychologists have shown, after extensive testing, that in many cases, the participants of a game will not always conform to the predicted equilibrium.

So the question is whether the players of the SP game will find themselves forever in the predicted two equilibriums. Of course, in the long run, there will be changes in the rules of the game that will upset the balance. Even without these changes, it is not out of the ordinary that players eventually will change strategy. So with the current assumptions made by the game theory, it will not always be the right prediction of the participants' choices. When there are two Nash equilibriums, it should be possible, through collaboration, to move from the first to the second equilibrium.

Characteristics of Game Theory

Above, the use of Game Theory has already been questioned but in the chase where the use of it is already assumed, certain aspects can still be questioned. Research shows that players do not always conform to the Nash Equilibrium. In this research, too, it does not seem to be the most logical outcome, although it has been proven from the classic game theory.

Assuming that all aspects of the game are present, such as symmetric information provision, it is unthinkable that parties in this environment will not enter into dialogue with each other to increase their profits jointly. This willingness is something that is not included in the game or the model itself. Nevertheless, practice shows that discussions are already underway internationally to address this. In the long run, the non-cooperative aspect of this game will not be right even though players are indeed rational and intelligent.

Assumptions in the game

Ports are complex networks with many shareholders. In order to model this situation, many assumptions have to be made. These simplifications make it easier to calculate with the model. The more simplifications, the easier it becomes to calculate, but at the same time, it also becomes a less reliable model to conclude something about the actual situation. An important aspect here are the SP installations on the side of the harbour.

As it looks now, no one is responsible yet for setting up an SPI. A shipping company, which rents specific plots of land in ports from the port authority itself, could bear the costs. However, it could also be the port authority itself, or a network operator. The game has chosen to use a model as described in chapter 5. In it, there is an anonymous company that would pay for everything and recoup the investments through rent. There are countless other possibilities to get this profitable, but this research does not take that into account. The model is designed in such a way that the utility functions, based on the above-mentioned organisation, can easily be adapted.

Ships in the network are based on practical information and literature. Adjusting these values has a significant impact on the profitability of the SP investments. The original measurements and subsequent strategies will not always give a true picture of the impact on the network. It is more about the differences between these two measurements.

Advice to ports, shipping companies and government

The most important thing to consider for ports is the earning model. The questions of who invests and who pays must be answered from the outset. The game and model show that there is a business model in the current strategy. Establish a party that is responsible for the infrastructure in ports and have shipping companies contribute to making use of it. It should be profitable for both parties, but one can safely assume that the use of shore-side electricity will only increase. Building a shore-side electricity installation for purely private use is not financially attractive at the current exchange rates. There are many actions that can be taken to make the SPI more financially attractive. Hydrogen expansions are being researched in order to increase capacity utilisation. These possibilities will have to be investigated in further research.

The focus of this research is the transition points of the utility of ships. The transition points answer the question of when it is profitable for ships. Ships are the big polluters in this story but will not quickly feel called upon to make significant investments. In chapter 9 and the appendix, much information can be found that should answer the above questions. An important aspect here is first to check whether the right infrastructure has already been constructed in the ports. This outcome has a significant impact on utility over the years. If this is already the case, it is the right decision for new ships to purchase SPE. The advice to convert existing ships is somewhat less fixed. This advice largely depends on the fuel prices of the coming years. However, you can see that when the fuel price for a year on the... a large part of the investment has already been recouped. This is a piece of cautious advice.

The advice for both ports and shipping companies is to talk to each other and try to form coalitions. It turns out that this type of coalition significantly increases the profitability of the investments. When all ports are equipped with SPI, it is much quicker for ships to make this type of investment. Conversely, the same applies to ports which means that they can help each other. Global connections will be complicated, but different countries in a continent can have a significant positive impact on each other.

The idea of adding emissions prices to utility functions comes from the ideology of reducing emissions as much as possible. Governments will ultimately benefit the most because they will have to pay for health care costs in many countries. The best thing that government, regarding SP, can do to limit this is to build the right infrastructure in the ports. The strategy results showed that this had higher efficiency compared to subsidising investment costs for ships. If they paid this in full, they would be able to recoup their investments in the long term through contributions from shipping companies. What can also be done is to review taxes on electricity compared to fuel. If the burden of taxation were to shift more to fuel, it would in many cases, be much more advantageous for parties to switch.

10.2 Methods

In hindsight, there have been several decisive moments that have given direction to the research. One of these moments resulted in the use of Game Theory as a framework. Earlier in this report, many reasons have been given to justify its use. In particular, it has been beneficial to justify the choices made by all parties in the network. The outcome of the utility functions drawn up predicted the behaviour of the participants in the game very accurately.

Nevertheless, the use of the Game Theory also created some obstacles. As indicated above, the assumptions you make for the players of the game are limiting in achieving the desired results in the end. The limitations mean that the mentioned solutions are not in line with the Game Theory. Purely rational and selfish, there should be no parties that need cooperation. Nevertheless, this is visible as a result. When new parties want to work with the designed model to calculate how they can get SP profitable, they will also have to forget the previously mentioned assumptions. In conclusion, using the theory helped to set up the environment, but in the end, there are a few essential properties that had to be adjusted in order to draw the right conclusions. The next chapter mentions these properties.

10.3 Contribution

The current situation is untenable in the long run. So far the concentration of gas and particle levels are higher than allowed in Rotterdam because of the exhaust emitted out of the berthed ships in the Port. The solution proposed is Shore Power. Unfortunately, the shore power options are, depending on the location, only partly beneficial for the human health located in the vicinity of the port. At the same time, the annual and installation costs are too high to be economically feasible without funding.

Once the shore-side installations are built, ships are until now not forced to make use of these power sources. Although ships have the incentives to switch to shore power, their generators are expensive to run and most companies want to decrease their environmental impact, it is very expensive to adapt their ships to shore power. Both sides need to commit to this solution. Lastly, ships across the world can have different standards in their electricity supply. To make it more effective, international standards should be introduced.

To evaluate whether shore power is the right solution to the problems in the port, one should investigate the characteristics of the port and the ships that berth in the port. To meet the Paris Climate Agreement more ports in the world should limit their emissions. The question of “Cold Ironing” is a relevant one in this environment. So far there is no format to evaluate these complex issues. "These complex issues" would be the evaluation of a sustainable investment in a network of actors. This research should create insight in the current situation of the Port of Rotterdam and should act as a handhold towards other ports and local management across the world. It would be a contribution to the literature to standardise an evaluation method for these kind of innovations.

To deeply understand the shore power matter one has to recreate the process. The current situation is a combination of autonomous agents in a network and a multi criteria decision. The literature does not show results for the combination of MCDM and ABM. Combining these models is something new and the insights gained should have a scientific contribution. So far it can not be said what the benefits of the combination would be but a preliminary analysis indicates that it would generate a more accurate picture of this issue.

Chapter 11

Conclusion

Increasingly larger ports, increasing international transport and, above all, increased emissions in residential areas have led to the demand for SP. In the literature, research has been carried out in various areas into the obstacles to large-scale implementation. There are aspects in several dimensions that hold it back. Literature research has shown that many parties in the port environment are dependent on each other and are unintentionally stuck in a chicken-egg situation. This situation has been explained and described based on game theory. The research has led to the following research question:

Why is the implementation of Shore Power technology lacking in ports worldwide and how can how can this situation be analysed using game theory, such that the effects of strategic disruptions can be measured in simulations?

The purpose of this research is to find an answer to this question. Desk research, interviews, modelling and simulations have contributed to providing information or have served as a tool to make calculations and draw the right conclusions. These methods have been applied to answer the main question. In order to make the process more transparent and systematic, it has been divided into several chapters and sub-questions. Here, the sub-questions are answered individually.

How can the situation of Shore Power implementation be described, using game theory as a theoretical framework?

Once it is assumed that game theory is the right theory to describe the situation, it is necessary to consider how the game should be designed. Chapter 5 explains how this was done using desk research and information from interviews. Designing a game in game theory requires describing the assumptions, the participants in the game and the rules that determine the dynamics.

This game makes, to achieve an amount of playability, assumptions on different levels. These assumptions are made to get a simplified version of reality. Mostly it describes the game type, which is asymmetrical and discrete. There are general assumptions, assumptions specific to SP technology and finally, assumptions describing the network effects. Together they sketch an environment that makes it possible to precisely zoom in on specific aspects of SP in the game itself.

After the assumptions, the participants of the SP game are described. These are the shipping companies and port authorities who are responsible for the purchase of the SPI. In the game itself, shipping companies can also build this infrastructure, depending on the circumstances.

Finally, some rules determine how the game is played. There are twenty choice moments within each game because the game is played for twenty years. During these choice moments, players can determine their strategy based on utility functions. Each player has several functions that determine whether or not they use SP and therefore whether or not they want to build or buy it. Together, the assumptions, the players and the rules give an overview of how SP can be described as a game in game theory.

How can the properties of Shore Power function as input for the designed game?

In the previous sub-question, SP is described according to game theory. However, before the game can be played, real data is needed to fill in the blanks. Based on desk research and information from the interviews, this conceptualization has been realized. The first step is to set up the utility functions. The chosen parameters were assigned value accordingly. The most important aspect of the game is the utility function. This function explains the behaviour of the players. When this function is incorrect, no meaningful things can be said about the behaviour of the players. This function has been created through literature research and verification with shareholders in the port. For ships it looks like this;

$$U_i^{SPE} = (F_{i,v,e} \times P_{f,j} + E_{i,v,e} \times P_{e,j} + M_i^e) \times (1 + S_i^{\%}) \times SP_i^{\%} - I_i - M_i^I$$

"U" is the ship's utility here. All the other variables are discussed in chapter 6. For example, there are different prices for fuel, electricity, maintenance and conversion costs. Each ship calculates once a year whether it is worth it to use SP or not. A positive or negative utility indicates this decision. All these variables are derived from the properties of shore-side electricity itself. The properties that cannot be quantified have been estimated by shareholders or based or similar research. The functions and input together act as essential information to play the game.

Why are the Ports and Shipping companies in an equilibrium regarding shore power without an incentive to upset it?

Based on the answers of the previous sub-questions, the game was designed. In chapter 7, the designed game is made in Netlogo. This created a model which is used for simulation. These simulations support the existence of the Nash Equilibrium. The first step in proving this equilibrium is testing the model.

The main functions and applications of the model are explained in chapter 7. To prove that this model can be used, several tests have been developed that mimic extreme versions of the SP problem. Examples are electricity prices approaching zero. The model reacted as expected in these situations, so it is suitable to answer further questions.

The Nash Equilibrium indicates that it is not worth it for players to change strategy given the current strategy of the other players. Based on fictitious payoff tables, it appears that this situation continues in two situations. When all players do switch and when they do not. Assuming that there are no parties using SP, all players are now in the Nash Equilibrium. The next step in the research is disrupting this equilibrium.

Which strategies can be formulated to disrupt the equilibrium and enhance the implementation of Shore Power?

Now that it is proven that the players are in a Nash Equilibrium, it is necessary to improve the situation. There are two equilibriums, one of which is more favourable for the players and the environment. Strategies have been formulated that will cause the players to shift balance or ensure that only the favourable balance remains. These strategies are the result of discussions with shareholders and have been verified in these discussions as well. Strategies have also been formulated that question certain aspects of game theory. The strategies from the first category are: using emissions prices in the model, forming coalitions in the model, policy strategies and paying out subsidies. All these categories are potential solutions to the problem described above. Finally, there are also aspects of the game theory that can be adjusted so that in theory, the players will no longer end up in that equilibrium.

All these strategies originate from different sources and have been verified with different parties. In the last part of the research, the impact of the strategies will be examined.

What is the impact of the strategic disruptions and what advise can be formulated out of the effects?

In addition to formulating the strategies, they have to be integrated into the model as well. For each strategy, functions have been added or altered, or input was varied. Every possible combination of the model is simulated as a control measurement. The comparison between the control results and the strategy results determines the impact.

The first step is to create standard values for players of the game. An overview has been created of the preconditions needed to make the investments profitable. These are average prices but also the number of hours that need to be made and the average consumption. An overview can be found in the appendix.

Strategies that are feasible and also have an impact are adding prices for emissions and subsidizing the right infrastructure in ports. Emission prices are already used in many sectors, but the port environment is lagging behind in this respect. Besides, setting up the right structure in ports shows that it becomes much more profitable for ships to make the switch very quickly. This investment can be regained if the right business model is chosen.

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Appendix A

Important functions of the game explained

There are several essential functions in the code that describe how players behave, interact with each other, and make and justify choices. In the beginning, ships, shipping companies and ports are put on the map with specific characteristics. Within Netlogo, a race can be defined after which they are created with a create command. Each race has properties that can be defined at any time. Here is an example of a ship which is assigned a type of ship and the ports which this ship visits regularly. These locations correspond to the ports themselves. The ports and ships are created as follows;

```
create-ships 3 [
    set vessel 3 ;Passenger
    set company 1
    set port1 6
    set port2 8
    set port3 4
  ]
```

```
create-ports 1 [
  set location 4 ;Hong Kong
  setxy 181 41
  ]
```

These features can be used to keep track of which ships visit which ports and when both parties have installed shore power. This part determines the utility functions and is represented by the SP factor. For each repetition, the SP factor is calculated. It checks the status of the ports and ships and adds them up. For ships, the SP factor can be 0, 1/3, 2/3 or 1. For ports it is different. The business model that has been chosen makes use of contributions from ships. Every ship that wants to make use of shore power in a port contributes. The SP factor for ports sums all these ships using SP and can vary between 0 to 30. The functions are listed below.

```
to SPfactor-ports
  ask ports with [ location = 1 ] [
    set SPfactor (count ships with [ port1 = 1 and color = green or port2 = 1 and color =
    green or port3 = 1 and color = green ])
  ]
  ask ships with [ port1 = 9 and port2 = 7 and port3 = 2 ] [
    set SPfactor (count ports with [location = 9 and color = green or location = 7 and color =
     green or location = 2 and color = green])
  ]
End
```

The function described below is the core of the model, and it is the utility function of the ships. It is based on the conceptualization of chapter 6. First, the annual costs of investment and maintenance are determined. When the utility is positive, the use of SP will be initiated for this particular ship which is done with the code; set SP? True. There are several options for these functions when individual buttons in the home screen are pushed or switched the functions can change a bit. The function looks like this.

```
to utility-ships
  SPfactor-ships
  ships [
    set investment-s (investment-ship * interest ) / (1 - (1 + interest) ^ (-1 * depreciation-
    ships))
    set maintenance-investment-s 0.05 * investment-ship
    set chance -1 * (((fuel-consumption-weight * weight * (fuel-price / 1000 ) - electricity-
    consumption-weight * weight * electricity-price + engine-maintenance) * h * (1 + (
    sustainability-factor / 100 )) * (SPfactor / 3)) - investment-s - maintenance-investment-s
     - (contribution * (SPfactor))) / (((electricity-consumption-weight * weight * electricity
    -price) * h * (1 + (sustainability-factor / 100 )) * (SPfactor / 3)) + investment-s +
    maintenance-investment-s + (contribution * (SPfactor)))
     set U (((fuel-consumption-weight * weight * (fuel-price / 1000 ) - electricity-
    consumption-weight * weight * electricity-price + engine-maintenance) * h * (1 + (
    sustainability-factor / 100 )) * (SPfactor / 3)) - investment-s - maintenance-investment-s
     - (contribution * (SPfactor)))
        ifelse (U > 0 and not SP?)
        [
          set SP? true
          set U2 -100000000
        ]
        [
          set U2 (((fuel-consumption-weight * weight * (fuel-price / 1000 ) - electricity-
    consumption-weight * weight * electricity-price + engine-maintenance) * h * (1 + (
    sustainability-factor / 100 ) ) * (1 / 3)) - investment-s - maintenance-investment-s)
    ]
  ]
end
```

When the utility is negative, a second utility is calculated which can result in a shipping company converting its ships as well as installing an installation in a port. This is very expensive, and the installation will only be utilized a small percentage of the time. Exceptional circumstances have to arise before a positive value can be derived from this. Below is the function for port 1.

```
to utility2
  ask shipping-companies with [ location = 1 ] [
    set Uships (sum [U2] of ships with [company = 1 ])


    set Uport1 (sum [U2] of ports with [location = 1])
    set Uport2 (sum [U2] of ports with [location = 10])
    set Uport3 (sum [U2] of ports with [location = 9])
    if ( Uships + Uport1 > 0) [
      ask ports with [ location = 1 and not SP?] [
        set SP? true
        set orderedby 1
      ]
    ]
    if ( Uships + Uport2 > 0) [
      ask ports with [ location = 10 and not SP?] [
        set SP? true
        set orderedby 1
      ]
    ]
    if ( Uships + Uport3 > 0) [
          ask ports with [ location = 9 and not SP?] [
        set SP? true
        set orderedby 1
      ]
    ]
    if ((Uships + Uport1 > 0 or Uships + Uport2 > 0 or Uships + Uport3 > 0) and not SP?) [
```

```
      set SP? true
    ]
  ]
end
```

In addition to the utility functions and the other commands mentioned above, some essential functions are; keeping track of fuel and electricity, keeping track of costs incurred, keeping track of the number of ships using SP and initiating the construction of shore power. These functions can be read back in the appendix.

Appendix B
Results of strategies

Table .1: Percentage of ships using SP - Emissions

	Sp Factor			
Electricity Price (€/kWh)	*0,00%*	*33,00%*	*67,00%*	**Fuel Price (€/tonne)**
0,13	0%	0%	0%	*300*
0,1	0%	0%	0%	*300*
0,07	0%	9%	29%	*300*
0,13	0%	1%	10%	*500*
0,1	0%	55%	81%	*500*
0,07	0%	96%	100%	*500*
0,13	0%	90%	100%	*700*
0,1	100%	100%	100%	*700*
0,07	100%	100%	100%	*700*

Table .2: Percentage of ships using SP - Emission changes

	Sp Factor			
Electricity Price (€/kWh)	*0,00%*	*33,00%*	*67,00%*	**Fuel Price (€/tonne)**
0,13	0%	0%	0%	*300*
0,1	0%	0%	0%	*300*
0,07	0%	9%	29%	*300*
0,13	0%	1%	10%	*500*
0,1	0%	47%	51%	*500*
0,07	0%	34%	15%	*500*
0,13	0%	29%	15%	*700*
0,1	0%	0%	0%	*700*
0,07	0%	0%	0%	*700*

Table .3: Percentage of ships using SP - Coalitions

	Location			
Electricity Price (€/kWh)	America	Europe	Asia	**Fuel Price (€/tonne)**
0,13	46,70%	45,30%	80,00%	*300*
0,1	46,70%	45,30%	80,00%	*300*
0,07	46,70%	45,30%	80,00%	*300*
0,13	46,70%	45,30%	80,00%	*500*
0,1	46,70%	45,30%	80,00%	*500*
0,07	56,00%	51,30%	96,00%	*500*
0,13	56,00%	51,30%	87,30%	*700*
0,1	100,00%	100,00%	100,00%	*700*
0,07	100,00%	100,00%	100,00%	*700*

Table .4: Percentage of ships using SP - Policy

	Spfactor		
Electricity Price (€/kWh)	*0,00%*	*100,00%*	**Fuel Price (€/tonne)**
0,13	0%	0%	*300*
0,1	0%	0%	*300*
0,07	0%	0%	*300*
0,13	0%	0%	*500*
0,1	0%	37%	*500*
0,07	0%	87%	*500*
0,13	0%	87%	*700*
0,1	100%	100%	*700*
0,07	100%	100%	*700*

Table .5: Percentage of ships using SP - Ship Subsidy

	Sp Factor			
Electricity Price (€/kWh)	*0,00%*	*33,00%*	*67,00%*	**Fuel Price (€/tonne)**
0,13	0,00%	0,00%	0,00%	*300*
0,1	0,00%	0,00%	0,00%	*300*
0,07	0,00%	0,00%	0,00%	*300*
0,13	0,00%	0,00%	0,00%	*500*
0,1	0,00%	34,00%	54,90%	*500*
0,07	0,00%	79,00%	85,90%	*500*
0,13	0,00%	78,50%	85,90%	*700*
0,1	100,00%	100,00%	100,00%	*700*
0,07	100,00%	100,00%	100,00%	*700*

Table .6: Percentage of ships using SP - Port Subsidy

	Sp Factor			
Electricity Price (€/kWh)	*0,00%*	*33,00%*	*67,00%*	Fuel Price
0,13	0,00%	0,00%	0,00%	*300*
0,1	0,00%	0,00%	0,00%	*300*
0,07	0,00%	0,00%	0,00%	*300*
0,13	0,00%	0,00%	0,00%	*500*
0,1	0,00%	40,00%	73,30%	*500*
0,07	100,00%	100,00%	100,00%	*500*
0,13	100,00%	100,00%	100,00%	*700*
0,1	100,00%	100,00%	100,00%	*700*
0,07	100,00%	100,00%	100,00%	*700*