Financing Renewable Energy Innovations in Europe:

Investment Criteria of Early Stage Investors and Guidelines for the Business Plan Development in the Context of Wave Energy Conversion

by

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Abstract

This paper investigates the ability of current public and private early-stage funding of new RE technology in Europe to promote innovation to an extend in accordance with the ambitious COP21 targets. The necessary analysis of the specific environment of wholesale power markets in Europe reveals a need for a change of paradigm in its organization alongside with the necessity to elaborate a “post-subsidy era” methodology to evaluate RE power plants from fluctuating renewable energy. The study focuses on Ocean Energy, expected to count for 10% of total European power production by 2050. The PEST analysis, combined to a bottom-up approach performed using a promising example of a technology innovation in the Wave Energy Conversion area, reveals a number of potential improvements. While public support is mainly indirect, because driven towards project finance, innovators are suffering from increased uncertainty, and so likelihood of total loss, due to their dependence on future support policies. Compared to any other venture-capital proposal new RE technology is suffering from the pure price (LCOE) value proposition. In the case of Wave Energy Conversion alternative business models in combination with other areas of the blue economy, such as aquaculture, marina infrastructure and erosion management are conceivable.

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List of Acronyms

CAPM:	Capital Asset Pricing Model
CCS:	Carbon Capture and Storage
CfD:	Contract for Difference
EIB:	European Investment Bank
ETS:	Emissions Transaction System
FiT:	Feed-in Tariffs
GDP:	Gross Domestic Product
IEA:	International Energy Association
IPP:	Independent Power Producer
IRENA:	International Renewable Energy Association
LCOE:	Levelized Cost of Energy
MiFid2:	Market in Financial instrument directive 2
MSR:	Market Stability Reserve
NER :	New Entrants Reserve (EU ETS)
OWC:	Oscillating Water Column
PPA:	Power Purchase Agreement
PV:	Photovoltaic
REMIT:	Regulation on wholesale Energy Market Integrity and Transparency
RE:	Renewable Energy
SET:	Strategic Energy Technology plan (EU commission)
SEAI:	Sustainable Energy Authority of Ireland
SPV:	Special Purpose Vehicle
WEC:	Wave Energy Converter

Part 1 Introduction

"Renewables should be like the Manhattan Project and the Apollo Project - the Government should put tens of billions of dollars into R&D", Bill Gates urged in a pledge to "bend the curve", when speaking to the Financial Times on tackling climate change. Referring to CO_2 emissions, he said that current technologies could only reduce them at a cost which is "beyond astronomical". He furthermore added that "the only way you can get to the very positive scenario is by great innovation" and urged "high-risk" investment in new technology.[1] Thereby, according to the Future of Electricity report presented by the World Economic Forum, "an overall investment of $8 trillion on new renewable and conventional power plants, transmission and distribution infrastructure, and energy efficiency measures is necessary until 2040 to meet current policy objectives".[2] Consequently, if the proportion of renewable energy generation should increase to meet the 2°C Climate Change Scenario, there is indeed a tremendous amount of investments to be made in the renewable energy sector. According to Bill Gates´ statement, the targets for climate change cannot just be met with current technologies at the current pace of implementing renewable energy, a statement which appears to have been confirmed by the International Energy Agency (IEA). Its latest report reveals that the only renewable energy technology that is on track to meet the technology-specific interim 2025 targets is the solar PV.[3] The IEA identifies the reasons for the increasingly slow growth of additional annual capacity from renewable energy as sluggish economic growth, policy uncertainty in OECD member countries, and persistent economic and non-economic barriers in OECD non-member economies.[4] So the reasons identified by the agency represent a lack of reliable and predictable support for the currently available technologies rather than a lack of funding for new technologies. In fact, Bill Gates´ proposition implies several statements. The first is that there are not enough affordable renewable energy power plant projects. Second, there is enormous investment in the development of new renewable technology to be made. And the third is that the public sector should bear a large proportion of this financial effort.

At this stage of the discussion, we have to distinguish between investments in renewable energy projects and investments in the technology itself. The latter, in fact, means investing in technology providing companies. Indeed, since the economic

[1] http://www.ft.com/cms/s/2/4f66ff5c-1a47-11e5-a130-2e7db721f996.html#axzz3s8rrGjtp accessed 21st November 2015

[2] (World Economic Forum - Bain & Company, 2015), p. 7

[3] (Tracking Clean Energy Progress 2015, IEA, 2015), p. 25

[4] (Tracking Clean Energy Progress 2015, IEA, 2015), p. 24

success of a technology company is associated with the number of installations of its technology, the value of an investment in such a company is related to the expected number of future power plant implementations. An investment in a renewable energy power plant is nevertheless related to the achievable support scheme at the time of the investment. This situation persists as long as the grid parity has not reached a constancy, or a change of paradigm occurs, introducing another pricing model for the supply of electricity. In Germany, for example, the nonprofit foundation Agora Energiewende calls for introducing a capacity market.[5] Nevertheless, under current conditions, we might have a situation where the investment in a renewable energy project is profitable but the company providing the technology has looming prospects due to changes expected in the support policy. One can observe this phenomenon when examining the market value of the pure renewable energy technology provider. The value of such stocks has been highly volatile in the past, due to policy changes and uncertainties.[6] So far, one conclusion can be drawn from these considerations. The profitability of such an investment into new renewable technology will largely depend on the future design and support policy of the electricity market. The assumption that an investor would have to make in his return calculations with regards to support policy ought to be very conservative, which means considering that the feed-in tariffs disappear in the near future.

A detailed examination of the figures over the past ten years reveals that the total asset finance of utility-scale renewable energy projects grew 10% in 2014 to $170.7 billion.[7] This amount is still below the record level of $ 181.2 billion in 2011, but the decreases during the years 2012 and 2013 have been stopped. In particular, Europe accounted for $36.2 billion in 2014, which is significantly below the investments attained in the 2007-12 period, due to changes in the support policy.[8] The amount of investments in new technology during this period reveals the genuine lack of interest in the industry. New investments totaled $2.8 billion in 2014, as compared to $10 billion in 2008, at a time where venture capital investment was at its highest level for more than a decade.[9] Particularly, early stage investments are still shrinking.[10] So, coming back to Bill

5 (Öko-Institut: Erneuerbare-Energien-Gesetz 3.0, 2014)

6 See Appendix A, share Value of wind turbine producer Nordex

7 (Frankfurt School of Finance-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, 2015), figure 34 p. 51.

8 (Frankfurt School of Finance-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, 2015), p. 52

9 (Frankfurt School of Finance-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, 2015), p. 66

10 (Frankfurt School of Finance-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, 2015), p. 67

Gates´ statement, there is probably both a lack of investment in renewable energy projects and in new technologies. Though investments in new projects seem to have picked-up again due to increased competitiveness of proven technology and slowly improving support policy, there is an obvious lack of interest in the development of new technologies, especially at the early stage.

The following part of this work will attempt to determine the reasons for this by examining the determinants of the future renewable energy technologies´ profitability and by identifying the investment criteria of potential investors. It will thereby investigate the profitability of renewable power generation in the current and foreseeable electricity market design. The analysis will be limited to the European market since market design may differ considerably from one jurisdiction to another. The research will be done by means of internet research, academic literature and interpretative analysis.

In his interview with the Financial Times, Bill Gates mentioned new technologies at an early experimental stage, as, for example, capturing the energy of the jet stream in the form of high-altitude wind power. Though a certain amount of these concepts are very promising, the present work should focus on technologies that are closer to be marketable and, at the same time capable of meeting a significant amount of the world´s electricity demand, such as renewable energy from the oceans. According to the IEA, the current annual world electricity demand is 17,500 TWh. The aggregate potential of tidal, wave, thermal conversion and salinity gradient energy amounts to about 20,000 TWh to 80,000 TWh.[11] Despite this potential, the investments in the marine energy sector are of a figurative nature at the most, with a total of $ 400 million out of a total new investment amount of $ 270.2 billion for the year 2014.[12] This seems to be in contradiction with the targets of the industry and the European commission. As a matter of fact, Commissioner Karmenu Vella foresees a contribution of 10% to the European power demand by 2050.[13] Part 3 of the work presented will analyze the current stage of development of wave energy conversion, for identifying the reasons why, in particular, this technology did not yet experience a pick-up in investments. The analysis is retrained to wave energy as an example of the marine energy complex, as on one hand, the necessary explanatory introduction of the

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11 (Energy Technology Initiatives 2013 - IEA, 2013)

12 (Frankfurt School of Finance-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, 2015) p. 15

13 Statement made at the Ocean Energy 2015 conference in Dublin http://www.oceanenergy-europe.eu/index.php/communication/press-corner/412-press-release-ocean-energy-industry-presents-its-game-plan-to-political-leaders-in-dublin accessed 24th November 2015

renewable energy source should be kept as short as possible, and on the other hand, its potential use by various technologies is widely feasible geographically. On the opposite, for example, tidal energy is confined to a limited number of sites with high energy potential. The research will be limited to the European market, which is currently the most active market in this field, in order to confine the analysis to a relatively homogenous support policy. In addition to the methodologies used in the previous part, a number of insights acquired from the most important convention of the industry, the annual meeting of the members of the Ocean Energy Europe association[14] which took place in Dublin in October 2015, will be of great benefit to the present study.

The Parts 4 and 5 that follow will consider a concrete example of a company that has designed a wave energy conversion system and is seeking early stage funding. Here the process of conceiving a business plan and creating a value proposition can be considered as a bottom-up approach. Any contingencies accompanying the conception of a specific value proposition, should, on one hand, be guided by our previous findings. On the other hand, the process itself should help to issue some recommendations and guidelines for technology providers seeking early stage funding. At the same time, a number of issues related to the support policy may be addressed. Part 4 will introduce the HACE (Hydro Air Concept Experimental) concept and place the technology in the current landscape of wave energy conversion technologies and providers of such engines. Part 5 will be dedicated to the analysis of the business case. These parts largely rely on the information provided by the founder of the company, Jean-Luc Stanek, and the information about the competition, either publicly disclosed through their internet sites, or presented at the Ocean Energy Europe conference. The methodologies and representations employed are mainly taken from the toolboxes of the different marketing fields.

[14] http://www.oceanenergy-europe.eu/index.php

Part 2 Electricity Markets in Europe: Current Situation, Outlook and Profitability of Power Generation from Renewable Energy

The world electricity markets in particular in Europe, have only been liberalized for the short while, since the EU had adopted the first liberalization directives in 1996.[15] The rules and regulations governing the power generation from renewable energy (RE) sources, in particular, are still different from country to country, as well as subject to frequent changes. At the same time, the overwhelming majority of renewable power generation projects could only reach profitability with the help of public financial support. For the aforementioned reasons, this requires a closer look at the prevailing and forthcoming bodies of regulations and market organization.

2.1 Importance of public policies and market design in the EU. The interaction of the EU Emissions Trading System and the subsidy schemes.

Currently some surveys claim that photovoltaic (PV) power generation has reached grid parity in Germany, Italy and Spain[16]. In fact, the costs for generation are being compared to retail prices for electricity. This comparison only makes sense if the producer is able to sell his production at retail prices or consumes it himself. Real grid parity at the utility level will only be reached when production costs are below the market price for electricity. Actually, even if some analysts from renowned investment banks like Vishal Shah from Deutsche Bank predict grid parity for a future as early as 2017,[17] current RE projects still need public support. Indeed, according to the report "Global trends in renewable energy investment 2015" of the Frankfurt School of Finance–UNEP Collaborating Centre for Climate & Sustainable Energy Finance, the global average levelized cost of electricity is still above $ 100 per MWh,[18] which is well above the current market price in the EU. The number of RE projects of a specific technology is thus highly dependent on public support policies. Further, the value of a company providing a specific RE technology is or has hitherto been determined mainly by these prevailing and anticipated support policies. Unfortunately, for any new technology provider, the amount of subsidies, in particular the level of

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15 http://ec.europa.eu/competition/sectors/energy/overview_en.html accessed 11th October 2015 (Energy and Environment, n.d.)

16 http://www.pv-tech.org/news/report_commercial_solar_hits_grid_parity_in_spain_germany_and_italy accessed 20th June 2014

17 http://www.energypost.eu/deutsche-bank-solar-grid-parity-world-2017/ accessed 26th September 2015

18 See Frankfurt School of Finance-UNEP Collaboration Centre for Climate & Sustainable Energy Finance: Global Trends in Renewable Energy Investment 2015, Figure 10, p. 9: Global average levelised cost of electricity

Feed in Tariffs (FiT) in the EU, are decreasing in the aftermath of the European public debt crisis. For instance, in some cases, Italian and Spanish tariffs for PV power have been reduced retroactively by public authorities for existing RE power plants.[19´20] This obviously had a negative impact on the profitability of the concerned projects, and, further questioned the reliability of public policies with regard to their commitment to promote renewables. In Germany, feed-in tariffs are gradually lowered and replaced by auctions where project developers bid for a certain power purchase agreement (PPA) level. The award is then given to the bidder with the lowest price.[21] These circumstances call for investigating situations where subsidies are withdrawn or reduced to a minimum. This is particularly true when considering investing in a new technology, as indeed, by the time the technology is mature, the subsidies may no longer be available. To some extent these circumstances make private investments in power plants of proven RE technology more attractive than investments in development of new technologies where there is no specific public support for Research &Development. Indeed, total venture capital investment in new technology has decreased to $ 1 billion in 2014, compared to $ 5.1 billion for government R&D and $ 6.6 billion for corporate R&D. At the same time, investment in projects from asset finance grew from $ 30.4 billion in 2008 to $ 170.7 billion in 2014[22]. In Europe, the total venture capital and private equity investment only amounted to $ 300 million.[23]

Due to its crucial importance for the economy of a country on one hand, and its technical contingencies on the other hand, the power production industry is subject to very specific constraints. Indeed, the proceeds of any power plant depend on the regulatory design of the specific receiving power grid. At the same time, power generation dependents on public policy, in particular concerning the treatment of externalities like pollution.[24] At least, the signatory parties of the Kyoto protocol have

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19 http://www.solarserver.com/solar-magazine/solar-news/archive-2013/2013/kw29/spain-retroactively-cuts-feed-in-tariffs-yet-again.html accessed 10th June 2015

20 http://www.sunwindenergy.com/photovoltaics/spain-and-italy-reduce-feed-tariffs accessed 26th September 2015

21 http://www.erneuerbare-energien.de/EE/Navigation/DE/Recht-Politik/EEG-Ausschreibungen/eeg-ausschreibungen.html accessed 10th October 2015

22 See Frankfurt School of Finance-UNEP Collaboration Centre for Climate & Sustainable Energy Finance, 2015: Global Trends in Renewable Energy Investment 2015, Figure 3, p.15

23 See Frankfurt School of Finance-UNEP Collaboration Centre for Climate & Sustainable Energy Finance, 2015: Global Trends in Renewable Energy Investment 2015, Figure 18, p.24

24 For a description of the economic dimension of externalities see (Varian, 2010) “Example: pollution vouchers” Chapter 34, p.654ff

targets on carbon emission since it entered into force in February 2005[25]. The Kyoto protocol foresees the use of so-called market mechanisms (Emissions Trading, Clean development Mechanism and Joint implementation) in addition to the national measures to meet the CO_2 emissions targets. In general, the signatory countries try to achieve the reduction of their national carbon emissions by means of carbon taxes or compliant carbon emission trading systems, combined with support schemes for power production from renewable energy sources. The EU has implemented the EU emission trading system (ETS) with the obligation for larger companies to buy emission rights to the extent corresponding to their emissions.[26] The idea is to make conventional power plants more expensive to operate, coinciding with their respective emission levels. The EU ETS, while theoretically the best means to achieve the transition from conventional power production to renewables,[27] missed its target for a number of reasons that are external to the nature of the instrument itself. Although they have no incidence on the purpose of the current text, it is worthwhile to at least mention the followings:

- The EU administrations have granted too many emission rights free of charge, as they can hardly impose the duties or quotas in the same way that a central government body would be able to.
- In addition, the amount of power produced from RE had not been sufficiently taken into consideration when setting the overall limits.
- The system was designed to allow the use of emission rights (EU emission allowances) over a long period of time instead of making them "perishable" by limiting their validity period which would have most probably forced the prices for EUAs to increase over time.
- The original design of the instrument, as normal tradeable good subject to V.A.T., which could be traded outside of the rules and regulations for financial instruments, opened the door to an incredible amount of criminal activity[28].

One probably should have thought about creating a sort of independent central bank for emission rights, whose mission it would be to achieve the EU emission targets.

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25 http://unfccc.int/kyoto_protocol/items/2830.php accessed 10th October 2015

26 All information related to the EU ETS can be found on the official website of the EU http://ec.europa.eu/clima/policies/ets/index_en.htm

27 For a founded assessment of the EU ETS see (Endres, 2007) p.295

28 (Frunza, 2013)

There are a number of discussions about the design of a future ETS going on.[29] The current answer of the EU commission to the problems, which is integrating the EUA in the Market in Financial Instrument Directive (MiFid2) regulation body, and, introducing a Market Stability Reserve (MSR), is going in the right direction. It may still not be enough to avoid price discrepancies, especially during longer-lasting economic downturns. Indeed, it requires either a kind of discretionary option to limit the amount of EUA allocated during a certain period of time, or a short period of validity to adapt to the prevailing market conditions. Now the role of such a central body would be to make sure the participants of the scheme meet their emission targets. Since these are decreasing with time, the number of auctioned emission rights, and therefore the number of available emission rights in this ideal example, would also decrease over time. The foreseeable consequence would be a higher price the more the validity period of the emission right would be into the future. Such a situation would introduce increasing production cost for a specific power plant, since the cost of emission rights has to be added to the fuel costs. At constant technology level, the cost of power generation would then increase with time, provided that the expected fuel prices do not decrease with time. However, a quick glance at the current future price curves for oil convinces us of the opposite.[30] This in turn means that the difference between the levelized costs of energy (LCOE) of a conventional power plant, compared to one of RE power, decreases when a longer period is considered. Effectively, the running cost of the RE power plant are nearly constant, at repair and maintenance level, while the running costs of fossil fuel generation would then increase over time. At a certain point in time, depending on the initial costs, the LCOE of the RE power plant may even get cheaper than that of the conventional power plant. Since the eligibility period for feed-in tariffs in the EU ranges from 15 to 25 years,[31] the calculation period commonly used for RE project is from 15 to 25 years. Indeed, using this methodology for convenience reasons will at most underestimate the value of a project if wrong. However, the lifetime of most power plants exceed that period, therefore it seems legitimate to consider a longer period, particularly if an abstraction of supposed feed-in tariffs is made. Hence, a policy that favors an increasing price curve for emission rights, combined with lower, even decreasing feed-in tariffs over a longer time period, may achieve the switch from fossil to renewable power generation in a smoother way than the current policy does. The graph below shows a number of

29 Some interesting views are expressed on the site https://icapcarbonaction.com/about-emissions-trading/introduction

30 See brent forward curve Appendix A

31 http://www.res-legal.eu/compare-support-schemes/

calculations of the internal rate of return of an investment in a coal fired power plant with different prices for emission rights.[32]

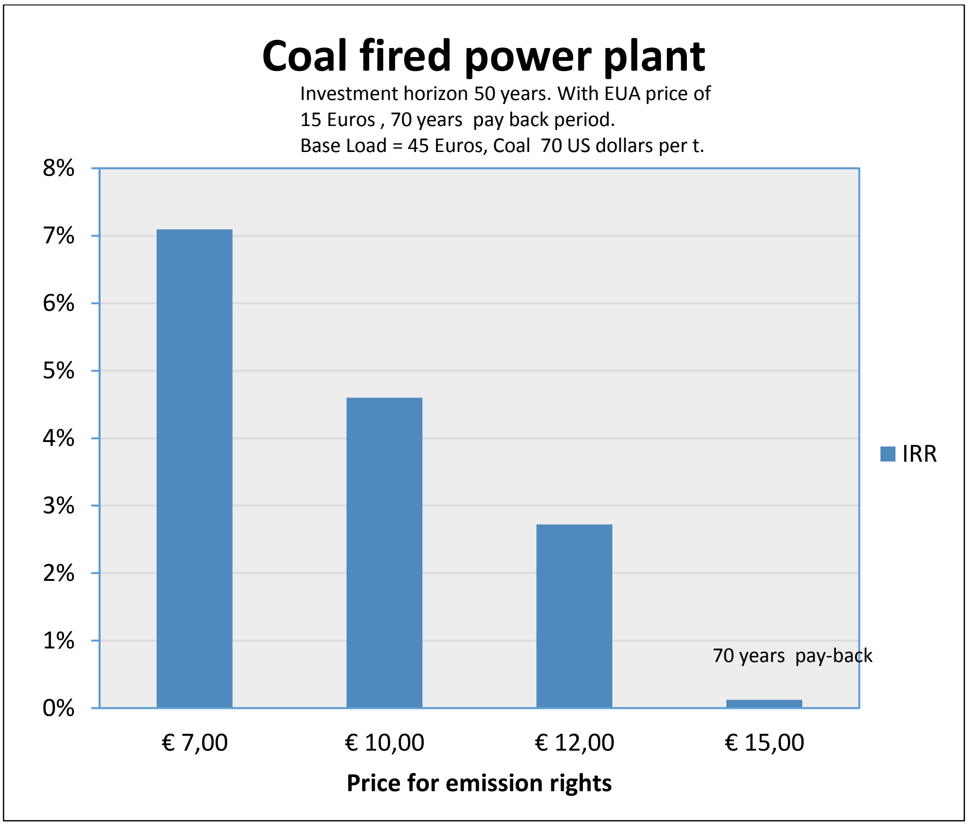

Figure 1: Internal Rate of Return - Coal fired power plant

These calculations show that the coal fired power plant, which is currently the cheapest mean of fossil fuel power generation, is likely to be unprofitable at emission rights prices above € 12.

Looking at the profitability of a wind power plant at a favorable site in Germany, we get the following results as shown in table 1 below.[33]

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32 Prices for the emission rights have been kept constant over the period, for simplicity reasons. The value for the "Dark Spread" has been calculated using the formula published by Bloomberg. Initial investment calculations use numbers from Wikipedia https://de.wikipedia.org/wiki/Kohlekraftwerk#Kosten_f.C3.BCr_Kohlekraftwerksneubauten

33 Numbers are taken from https://www.wind-energie.de/sites/default/files/download/publication/kostensituation-der-windenergie-land-deutschland/20140730_kostensituation_windenergie_land.pdf

Table 1: Internal Rate of Return - Wind Power Plant

Values per MW	**Initial Cash-Flows**	**Cash-Flows year 1 to 30**			
Total turbine cost	€ 1,150,000	Baseload price	€ 45.00	Investment horizon	30
additional charges	€ 374,000	running cost	€ 24.00	Annuity factor	21.80
CAPEX	€ 1,524,000	earnings	€ 149,796.00	IRR	2.2%
Capacity Factor	38%	Profit	€ 69,904.80	NPV	- 0.01
MWh per year	3328.8				

In the particular context of these calculations, the wind power plant would be more profitable than the coal fired power plant if the price for emission rights is above approximately € 13. Though these calculations only serve as an example, and do not take into consideration the uncertainty of wind power production due to the variability of the wind power resource, they show that high emission prices can make renewables more profitable than fossil fuel power generation. One should nonetheless bear in mind that the power plant thus considered should be profitable in the first place, which means it should yield a proper return related to the risk characteristics of its revenues. Unfortunately, this is not the case yet without subsidies. Nonetheless, this comparison shows the current dilemma that utility companies do face. Investments in conventional power plants are partly no longer profitable, due to the amount of renewable energy from fluctuating energy sources fed into the grid, namely wind and PV. This is the reason why numerous market participants call for a change of paradigm.

2.2 Change of paradigm: profitability of RE power production with decreasing public subsidies

In addition of a carbon emission cost, conventional power plants often have to face the priority given to electricity generated from renewable energy sources.[34] The consequences of the priority order are far reaching. Indeed, any conventional power producer, from fossil or nuclear fuel, is able to feed its current production into the power grid only when there is a surplus of power demand over the sum of the power production from renewable energy fed into the grid. This means that the production time of fossil fuel power generation decreases when the number of RE power plants

[34] http://www.res-legal.eu/compare-grid-issues/ accessed 10th October 2015

increases. In addition, wind and solar power plants do not face fuel costs, so they produce and feed-in their production whenever the resource is available for them. Consequently, the market price of electricity is lower when more electricity is produced from wind and sun power plants. In some cases, we are already facing temporarily negative power prices; and this indicates that the limit of useful RE generation has been reached.[35] In fact, this is a paradoxical situation. The larger the proportion of RE in electricity production, the cheaper the wholesale market price of electricity is. Indeed, this seems to be against common sense, as the power generation from renewables is still more expensive than from fossil fuel. Perhaps we can get closer to an explanation when we consider the following example. Let us imagine being a Spanish independent power producer owning a PV-plant subject to the retroactive cut of FiT in a way that the ex-post profitability of the project, as calculated before investment, is not given anymore. What can we do? Shut down the plant and stop producing electricity? Well, this would lead to the maximum possible loss, since the marginal cost of production of the power plant is very low, and equal to the repair and maintenance costs. Therefore, we would continue producing and sell the power to the market in order to minimize our loss. Even if we were to declare bankruptcy, our loan holders, who would then take ownership of the power plant, would then go on running the plant to reduce their loss. What do we learn from that consideration? In fact, once a RE power plant has been built and paid for, it will be running as long as the market price of electricity is above its marginal production cost. One can notice as well that the priority order is not relevant once the RE power plant is operating, because running costs of conventional power plants are anyway higher. In other words, the situation is irreversible. Conventional power production will get less attractive with the growing proportion of renewables. Even more, since the marginal cost of current production by means of RE is very cheap compared to fossil fuel, we can also expect tendencies to substitute fossil fuel energy consumption in other areas. Electrical cars, for example, are poised to replace gasoline-powered cars in the near future. At the same time, the demand for power storage should be increasing with the increasing amount of periodic excess in electricity production. We can, for instance, notice the appearance of the first power storage facilities for purpose of collecting cheap electricity from renewables.[36] Further, under these circumstances, it is probably not worth investing in the development of carbon capture and storage (CCS) solutions, since fossil fuel electricity production will get less attractive anyway. Now, if we recall the situation in the telecommunication markets 15 to 20 years ago,

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[35] (Negative Strompreise Ursachen und Wirkungen-Energy Brainpool GmbH&Co. KG, 2014)

[36] http://green.wiwo.de/schwerin-groesster-akku-deutschlands-ist-am-netz

there are some analogies to the state of the electricity markets. Indeed, at that time, a phone bill was mostly a result of variable fees proportional to the time one spent using the network. Today, most of us run on flat fees, with a monthly cap for the data volume. This makes sense for the telecommunication providers, as they as well face high initial investment costs to build the network, and, in comparison, low costs to maintain the service. Hence, the flat fees they earn cover the high initial costs, whereas the variable fees in excess of a certain amount will have to account for the variable costs. From the cost structure perspective, the only difference to renewables is the absence of the power storage problem. Thus, we can expect the electricity market to behave analogously to the telecommunication market as soon as the storage problem is solved at an acceptable cost. This explains in part why some lobby like the "Agora Energiewende" in Germany is advocating a change of paradigm in the structure of the public subvention to renewables[37]. They want the RE power plant to be paid a complex combination of fixed and variable subsidized fee. In the opinion of the author, the structural change of the market towards a "bandwidth" pricing model will be driven by market forces, to go along with the generalization of smart metering, the predominance of electricity generation from renewables, the introduction of electric vehicles and power storage. Indeed, utilities would be able to run their business in a profitable way only when they have the chance to charge the real costs to their customers. In the current German system, the retail consumer gets charged the cost of introducing RE via an external fee charged by the grid operator, who has to pay the FiT. A market design based on a functioning ETS, for example, would probably have at least the same incentive to switch to RE, and even force the utilities to accelerate the switch by finding new business models and pricing schemes.

Coming back to the purpose of the above analysis, which is to make reasonable assumptions about the future electricity market and the demand for renewable energy technologies, we retain following points:

- Investments in RE energy production will have to carry on in the first place, either through subsidies or through increasing constrains for fossil fuel power generation, until they have reached profitability.
- Feed-in tariffs will constantly decrease and being substituted by auctions or other price setting methodologies.
- The wholesale market price for electricity will be under constant pressure with the increasing proportion of renewables.

[37] (Öko-Institut: Erneuerbare-Energien-Gesetz 3.0, 2014)

- In the future, the profitability of new RE power plants will have to be achieved by capacity pricing, and to a decreasing part, through subsidies.

In this context, an investment in the development of a new RE technology is not attractive for an investor who is not inherently involved in electricity production. Indeed, as long as there is no outlook for the future profitability of RE power plants, they may be a lot of other investment opportunities with higher prospects on the surrounding conditions.

2.3 Appraisal of RE power plants in the absence of subsidies

The above mentioned assumptions have following implications on the valuation methodology for the future development of RE power plants, when considering introducing a new RE technology:

- Future Cash flows generated through the sales of electricity should be considered dependent of the market price for power, therefore subject to uncertainty, or to the market price of a Power Purchase Agreement (PPA) if available.
- The period taken into consideration should correspond to the lifetime of the power plant concerned.
- The shape (hourly distribution) of the electricity production is important as long as there are no short-term power storage facilities available, and a significant difference between base and peak load prices subsists.
- The correlation of the electricity production of the power plant concerned to the one of other RE power plants feeding the considered grid should be taken into consideration, as it determines whether the electricity will be produced at the same time as other RE power plants are producing or not.

The last point does not refer to the well-known fact that, in general, the correlation of the revenue generated by one asset to the revenue of all other assets is a price determinant. This latter refers to the portfolio theory in general and the Capital Asset Pricing Model (CAPM)[38], in particular. Though investments in RE projects are technically different from other investment types, the portfolio theory can be used to optimize investments in wind power plants[39] .We can find examples where this property probably had an influence on the investment decision. The Stadtwerke München, for example, though being a regional German utility, has invested in an

[38] For an exhaustive introduction to the concept, see (Copeland & Weston, 1988), p. 145-235

[39] (Fabien Roques, 2008)

offshore wind power plant in the UK (Gwynt y Môr)[40]. So in fact, we should add another item to our list, namely the correlation of the revenues generated by the specific power plant to the revenues generated by other power plants in general, regardless of the grids they are connected to.

Before we determine which appraisal methodology is the most accurate in our case, we shall investigate to which extend the correlation effects are significant a little more in detail. The table below represents the average monthly price difference between the German and the French power market from 2006 to 2015. One can observe that the price differences seem to be fairly widely distributed despite the markets being close to each other and even linked (with a limited bandwidth of course).

Table 2: Monthly price difference France to Germany (source Bloomberg)

Bloomberg — European Energy Prices Matrix

Market:	France	Display:	Power Country Spread	Currency:	EUR	Refresh
Start Date:	01/01/2006	Spread Market:	Germany	Last Update:	01/10/2015 14:36	

Country Spread - Base

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Q1	Q2	Q3	Q4	Cal
2006	2.3	9.2	5.0	-3.1	-2.3	0.0	-4.6	-11.0	-3.8	-6.8	-5.6	3.5	5.4	-1.8	-6.5	-3.0	-1.5
2007	2.5	-1.3	1.1	-1.5	-2.6	-7.5	0.5	-2.2	0.3	5.3	23.4	16.4	0.8	-3.9	-0.5	15.0	2.9
2008	9.2	2.7	9.7	2.9	0.2	-0.4	0.3	-3.1	0.1	6.4	5.6	7.1	7.3	0.9	-0.9	6.4	3.4
2009	6.1	1.5	0.1	1.5	-0.1	0.8	0.6	-0.2	0.6	25.5	4.5	8.5	2.6	0.7	0.3	12.9	4.2
2010	9.5	5.7	5.5	1.6	1.2	-0.8	-0.1	-2.7	-0.2	7.2	1.8	7.2	6.9	0.7	-1.0	5.5	3.0
2011	1.2	2.8	-0.3	-1.5	-3.3	-8.9	-9.0	-7.5	-2.7	0.6	0.1	2.2	1.1	-4.5	-6.4	1.0	-2.2
2012	2.0	27.5	3.5	1.4	0.1	1.5	0.7	0.4	1.6	5.3	2.7	6.5	10.6	1.0	0.9	4.9	4.3
2013	7.3	9.8	18.6	8.0	-0.9	-4.4	-2.1	-3.0	1.6	6.9	9.9	14.0	12.0	0.9	-1.2	10.2	5.5
2014	3.3	5.1	4.5	2.1	-0.5	-0.9	-6.4	-5.2	2.4	6.6	2.4	9.1	4.3	0.2	-3.1	6.1	1.9
2015	12.6	13.4	12.5	9.8	1.1	2.0	3.0	0.6	5.6				12.8	4.3	3.0		
2016																	
2017																	
2018																	
2019																	
2020																	
2021																	
Average	5.6	7.7	6.0	2.1	-0.7	-1.9	-1.7	-3.4	0.6	6.3	5.0	8.3	6.4	-0.2	-1.5	6.5	2.4

The correlation matrix of the daily power prices of the most important European power markets below confirms this presumption.

[40] https://www.swm.de/privatkunden/unternehmen/engagement/umwelt/ausbauoffensive-erneuerbare-energien/karte-interaktiv.html accessed 2nd October 2010

Table 3: Correlation matrix of daily power prices Germany, Nordpool, France, UK and Netherlands (source Bloomberg)

Start Date	01/01/2011
End Date	02/10/2015
Periodicity	Daily

		Epex Phelix	Nordpool power	Epex France	APX UK	APX NL
LPXBHRBS Index	Epex Phelix	1.000	0.238	0.179	-0.064	-0.073
ENWSSPAV Index	Nordpool power	0.238	1.000	0.565	0.395	0.384
PWNXFRAV Index	Epex France	0.179	0.565	1.000	0.439	0.704
PXPXBASE Index	APX UK	-0.064	0.395	0.439	1.000	0.459
AELCTDAY Index	APX NL	-0.073	0.384	0.704	0.459	1.000

Indeed, the markets are widely uncorrelated. Only the Netherlands and France seem to have a significant correlation. The conclusions we have to draw from those circumstances are as follows:

- An independent power producer (IPP) which sells its production directly to the grid operator has to take into consideration both the diversification due to the technology itself, as well as the diversification due to the different prices at different grids.
- An electric utility company which sells directly to the end customer initially needs to consider the diversification across other power plants feeding into the same grid first, because it has to secure delivery to its customer first.
- A given RE power plant will always have more value for an IPP than for a utility company if there is a diversification effect due to the grid´s price properties, unless the utility company is taking into consideration revenue metrics other than wholesale market prices.

The last comment may give us some indication as to what the driving forces for the development and generalization of the renewables in power generation could be. Indeed, the utility companies directly selling to the end users are able to integrate something additional to the wholesale market price of electricity. They are the only ones able to change the pricing paradigm towards a pricing fee for availability in combination with a bundle fee linked to consumption, since they will be able to integrate demand side management and new consumption profiles, such as those generated by the integration of electrical vehicle fleets.

Nevertheless, we still have to identify our appraisal methodology for the forthcoming power plant projects. Now we already know we have to take into consideration either the market price of electricity or another revenue metric if there is additional monetary advantage to the specific project for a given investor type. The time period retained is now the lifetime of the power plant, since we are no longer considering subsidy schemes. In addition, we have to introduce something that takes into consideration the different diversification effects mentioned above. A commonly used methodology in the financial literature to take account of this phenomenon is the use of a risk-adjusted discount rate in the net present value calculations. Using the same notation as in (Uwe Götze, 2015) p. 255, the discount factor is given by the following formula:

$$i = r_f + \beta \times \left(E(r_m) - r_f\right)$$

Where:

- r_f is the risk free rate of the period being considered
- $E(r_m)$ is the expected return of the global securities market
- $\beta = \frac{Cov(r_m, r_j)}{Var(r_m)}$, r_j is the return of the considered asset

It should be mentioned that there is no financial leverage considered here, because this would make the different projects incomparable. This makes sense because we want to compare the economic potential of the projects as such, independently of the financial structure in a first stage. Furthermore, since the methodology is used in case of uncertainty of the output, it is adequate for fluctuating renewable energy sources but not for bio-fuels since they can be used to produce electricity on demand. Though theoretically appealing, one should be sure to be able to choose and quantify sensible values for use in this formula. At first glance, this seems to be difficult because on one hand we should use figures, as the expected return of the global securities portfolio that we can observe on the capital markets. On the other hand, the expected return of our project is unfortunately not observable as such. In order to obtain a value or at least a methodology to evaluate the beta, we have to push our reasoning a bit further, and recall that RE projects are infrastructure investments and as such considered as being largely independent of the remaining industries and branches. Investments in infrastructure are part of a so-called alpha strategy, whose aim is to generated revenues that are not dependent on the overall capital market. If we believe that statement, the returns on investments in renewable energy projects are only correlated to investments of the same nature. This means we can limit our considerations to the returns generated by other renewable energy power plants, since the correlation to other assets is supposed to be zero. We are now close to being able to use the above formula as the total revenue generated by renewables is publicly available, at least within the EU, thanks to the transparency rules of the Regulation on wholesale Energy Market Integrity and Transparency (REMIT)[41]. There is still one technical hurdle. Since we do not know the individual costs of the power plants, we cannot estimate a global return for the renewable energy generation as a whole. We can suppose though the running costs to be independent of the amount of electricity produced, but proportional to the notional power of the power plant, since we are considering fluctuating renewable energy sources. Using these comments, we rewrite the expression for the beta factor above as a function of the initial investment, the running cost and the proceeds per unit (per MWp) installed and per time period considered:

$$\beta = \frac{Cov(y_m, y_j)}{Var(y_m)}$$

Where:

- $y_m = \frac{rev_m}{I_m + R_m}$
- $y_j = \frac{rev_j}{I_j + R_j}$
- rev_m = total revenues from RE power plants of the type considered for the period
- I_m = average initial investment for the RE power plants of the type considered and for the period
- R_m = average maintenance and repair cost of RE types considered for the period
- rev_j = total revenue from the specific power plant j for the period
- I_j = initial investment for the specific power plant j for the period

We should notice that only the revenues are random in the above formula. So in order to simplify calculations, one could express the beta in function of the covariance and variance of the revenues by taking out the constant factor. However, we still need to find a value for $E(r_m)$ which is the expected return of all renewable power plants. Recalling that this value represents the expected return of infrastructure investments one could use the past returns of a representative index of infrastructure investments, such as the S&P global infrastructure index. The annual return of the last five years of this index is 1.33%[42].

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[41] The information for the German market is available at http://www.netztransparenz.de/de/Marktprämie.htm

[42] http://us.spindices.com/indices/equity/sp-global-infrastructure-index accessed 4th December2015

The above methodology is certainly cumbersome in terms of the amount of data to be collected and processed, but once the dataset has been collected for the first time, the maintenance of the database should not require excessive work. Even if one does not use the above-mentioned methodology for calculations, the above analysis nonetheless leads to the following conclusions:

- The value of a specific power plant decreases the more its revenues are correlated to the revenues of other RE power plants, since the risk adjusted discount factor will increase.
- A negative correlation could even make an investment attractive though its expected return on investment is below the risk free rate.
- The methodology above can be used to implement a ranking of possible investments in a RE project.
- The return on investment in the infrastructure building area as measured by a large market index has generally been poor over the last five years, so the expected return on investment required by project investors should be at historically low level.

As an overall conclusion of this analysis, we should recall that the introduction of renewable energy production is irreversible. Especially the fluctuating RE sources do exercise pressure on the wholesale market price for electricity, due to their low marginal production costs. From an IPP or a utility company´s point of view, this means that renewables will account for an increasing amount of the power production, regardless of the future design of the power market. So in one way or another, they should become profitable. Furthermore, an independent investor is facing increasing risk, as the future design of the power market is uncertain. Hence, if not inherently interested in the power market, he will require a value proposition that is not dependent on the future market design. When we will consider the particular situation of wave energy conversion from an investor’s point of view, we shall define the resource type in particular in comparison to other RE in order to point out the relative value of WEC. In addition, we will look at possible by-products that may create extra value for some particular stakeholders. Keeping in mind the framework we have identified as appropriate for the valuation methodology of future RE power plants, we will turn our attention to the specificities of Wave Energy Conversion in the remaining parts of the present work.

Part 3 Wave Energy Conversion

In addition to the economic value of a single power plant or project, the overall potential of the resource is a key determinant of the expected number of engine that can be installed and sold. When assessing the potential of a renewable energy source, we are used to mentioning the overall availability of the resource and its potential share of global power generation. At that stage, we often consider the efficiency[43] of a given power generation technology as an indicator of the ability of the RE considered to contribute to a significant part to the overall energy or electricity production. However, one could question the accuracy of this indicator, especially when considering renewables which are assumed to be freely available like PV, wind power or energy from the ocean. In order to remind of the scale of numbers involved we recall following facts:

- The average sun irradiation is 1360.8 w/m² before entering the atmosphere.[44] The total solar energy arriving per year on 1 km² of the world´s hot desert is on average 2.2 TWh and 1% of the area of global deserts of 36 million km² would be sufficient to produce the entire annual primary energy consumption estimated at 17000 TWh/y in the year 2009.[45]
- According to a Stanford Report the world´s total power demand could be met by wind power solely.[46]

Now even if the number of 1% of the desert area seems something reachable, it is still 360.000 km² which have to be covered by solar panels. This is more than the total area of Poland (approximately 312.000 km²). One also has to think about how to transport the electricity to the place where it is consumed. Similarly, the 4 million 5 megawatt wind turbines needed to produce half the world’s power demand – as provided for by the Stanford study - have to be installed somewhere. The German offshore wind park Alpha Ventus[47], for example, has generated 248 GWh per year in average since start of operations, for an area of 3.8 km². If we compare this production to the power consumption of the city of Hamburg - about 12.4 million MWh[48] per year - then we would need an area of 190 km² to meet this consumption by means of offshore wind

43 In this context, efficiency usually means the proportion of the available energy the technology is able to harvest.

44 See (Quasching, 2011) p.53

45 (Desertec foundation - White book 4th edition, 2009)

46 (Stanford Report , 2012)

47 (Alpha Ventus, 2015)

48 (Stromnetz Hamburg, n.d.)

power. These considerations lead to the following comments concerning the assessment of fluctuating renewable energy sources, such as PV, wind and wave energy:

- We should consider the ratio power production to surface required instead of the pure efficiency of the technology considered.
- The technical and economical accessibility of the required surface is of great concern. Issues like grid connection, ownership and proximity to consumption area can have decisive influence on the economic viability on any project.
- The proportion of useful power generation has a great impact on the ability of the energy source considered to meet the power demand, at least as long as there is no sufficient affordable storage capacity available. In addition, it will have an impact on the financial appraisal of a given project, as shown in the previous part.

Before situating wave energy conversion using these criteria, one should briefly recall the basic fundamentals of wave energy and wave energy conversion.

3.1 Introduction to wave energy

3.1.1 Origin of waves

the following forces exert an influence on the generation of waves[49]:

- Wind produces friction on the water surface. Waves produced by the power of wind can collect that power over thousands of kilometers, provided there is no obstacle to their propagation.
- Through impetus given by boats, submarine earthquake or volcanic eruption. The last two forces would generate Tsunamis.
- Air pressure fluctuation in large areas which can generate non-propagating waves through resonance phenomena, usually in inland waters.
- Astronomical power, like the force of attraction of the moon and of other planets, generating tidal waves.
- The Coriolis force due to earth rotation.

Waves are characterized by their height H, their length L, their velocity (speed of propagation) and their period T. The latter represents the time needed for the wave to

[49] See (Zanke, 2002), p.248

completely pass-by one given point on the water´s surface. The different wave parameters are represented in figure 2 below.

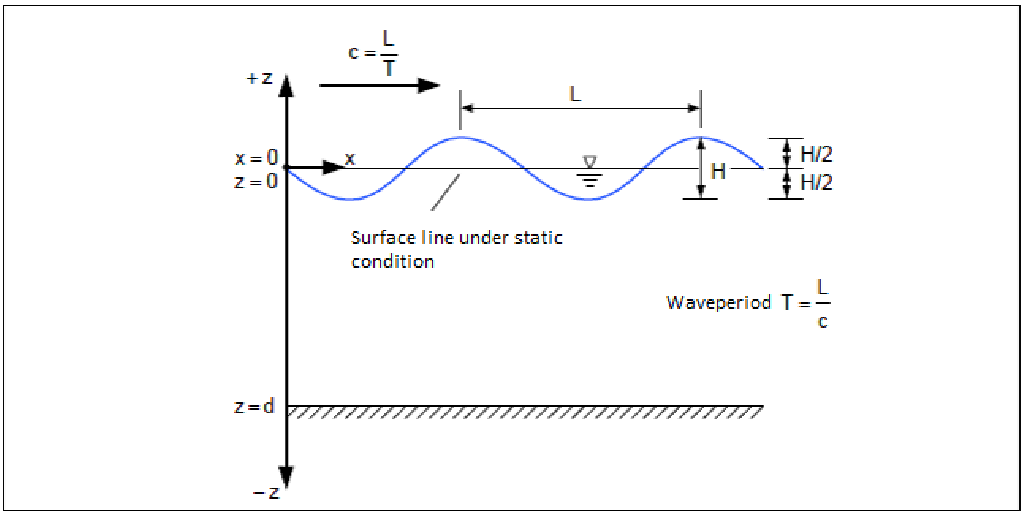

Figure 2: Definition of Wave Parameters, adaptation from (Zanke, 2002)

When there is no obstacle to the propagation of the wave, as is the case for deep water and offshore locations, the movement of the water particles close to the surface follow a trochoid[50]. As the wave approaches the shoreline, the water becomes shallow and the friction of the bottom works against the propagation of the wave towards the coast. The movement of the particles takes elliptical trajectory, whereby the ellipse becomes increasingly flat when the wave approaches the coast. Figure 3 below illustrates the wave movement offshore, intermediary near shore areas and shallow water areas.

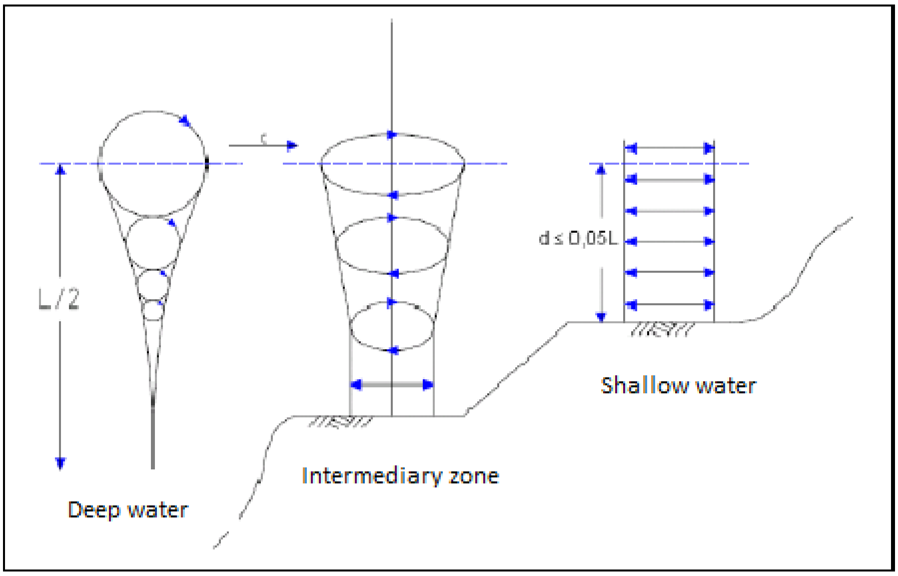

Figure 3: Orbital Trajectories, adaptation from (Wahl, 2006)

[50] A deep water wave simulation can be found at https://en.wikipedia.org/wiki/File:Deep_water_wave.gif, accessed 18th October 2015

In shallow waters the movement resumes to a seesaw trajectory we all can observe when we are looking at the sea from the beach during our holidays. As one can imagine, this will have implications on the energy available for conversion to electricity. It should be noted that, in summer, the waves tend to be higher during the night and in the morning, due to the temperature difference between the sea and the air during the night, which creates wind from the coast to the sea at these times. During daytime it is the other way round, meaning waves tend to be smaller.

3.1.2 Wave theory

In fact, as the motion of the sea is a complex interaction of the different forces mentioned above, it follows a stochastic distribution rather than a deterministic process. Nonetheless, a number of theories have been developed in the past centuries to explain parts of the sea condition. A common hypothesis of these deterministic theories is the assumption that we are in presence of one wave, or one group of waves, at the time. Thus, we are in presence of a single wave frequency. In this case, the waves are fully determined by their height, their length, their period and their direction.[51] There are two main branches of deterministic wave theories: the linear theory and the nonlinear theory. In general, the linear theory will be sufficient to describe waves in deep water condition, and be a sensible approximation in other areas.[52] Some results of the linear Airy-Laplace theory can be found in table 4 below:

Table 4: Established Results of the Linear Wave Theory, adaptation from (Zanke, 2002)

	Shallow water	Intermediary area	Deep water
Velocity c (function of deepness h)	c = L/T = $\sqrt{g.h}$	c = L/T $= \frac{g.T}{2\pi} \tanh\left(\frac{2\pi.h}{L}\right)$ $= \sqrt{\frac{g.L}{2\pi}.\tanh\frac{2\pi.h}{L}}$	c = L/T = $\frac{g.T}{2\pi}$ $\sqrt{\frac{g.L}{2\pi}}$ =1.56 T (m/s)
Wave length	L = T. $\sqrt{g.h}$	L = $\frac{g.T^2}{2\pi} \tanh\left(\frac{2\pi.h}{L}\right)$	L = $\frac{g.T^2}{2\pi}$ = 1.56 T^2 (m)
Energy (one wave per m crest)	$\frac{\rho.g.H^2}{8}$	$\frac{\rho.g.H^2}{8}$	$\frac{\rho.g.H^2}{8}$

According to the assumptions of the theory (low amplitude, constant deepness, regular waves…) the results should be applied only in the deep water area. In general, the

51 See (Wahl, 2006), p. 5

52 A more extensive view on wave theories can be found in (Stewart, 2012)

other areas require nonlinear models similar to those developed by Stokes in the 19th century.[53]

3.1.3 Predictability of waves and wave resource assessment

The prediction of ocean movement was even of great importance to maritime activity before mankind started to think about offshore renewable energy production. Indeed, navigation, exploration and installation of drilling platforms needed reliable predictions on the state of the sea. So historical data collections and prediction models are available at different levels. The academic framework is similar to the one used in the description of the wind resource. The bivariate Raleigh distribution, for example, is used for modelling wave height and period[54]. The data is collected by satellites and buoy sensors. Shallow water and near shore areas require more sophisticated modelling since the influence of the seabed increases with decreasing depth. There are a number of different models used in the industry. One can mention amongst others, for example, the SWAN model developed at Delf University of Technology[55] and the TOMAWAC model developed jointly by EDF recherche & development and laboratoire hydraulique Saint Venant supported by the French ministry for ecology, energy and sustainable development[56]. Various data sources are freely available, though not yet consolidated in a single entry point, such as the Global Atlas initiative which IRENA (International Renewable Energy Association) is attempting to establish. At the European level, WERATLAS was an initiative founded by the Cordis Joule program[57]. The software tool developed for wave data analysis is, however, no longer available. But the data can be consolidated in other applications, such as Globwave, an initiative funded by the European space agency ESA[58]. This is based on some wave and buoy data being freely available for specific ocean areas, but this information can solely be used for a first approximation of the resources, since the available data needs professional treatment on one hand, and might even be incomplete on the other hand. This is especially true if the data needed is in near shore areas, where wave motion has to be estimated via more complex modelling. Ifremer, the French public maritime research institute, is, for example, a well-known source of data, and publishes on a specific Website in cooperation with Météo France.[59] There

53 A mathematical description of Stokes can be found in (Lagrée, 2014)

54 (Wist, 2003)

55 http://www.fluidmechanics.tudelft.nl/

56 http://anemoc.cetmef.developpement-durable.gouv.fr/

57 http://www.macs.hw.ac.uk/~denis/wave/WERATLAS.pdf, accessed 1st November 2015

58 http://globwave.ifremer.fr/

59 http://www.previmer.org/

are also specialized commercial data providers like BMT Argoss[60] which offer various data based on SWAN type of models. Open Ocean, another data provider uses the TOMAWAC model[61].

The typical dataset a wave energy producer would look at should include following items:

3.1.3.1 Wave rose

Analogous to the wind rose chart, the wave rose shows the frequency of waves coming from a particular direction. In addition, the frequency of wave height is represented by different colors. In the example of figure 4 below, the waves are coming most frequently from the West-North West direction and second most frequently from the North-West direction. This information is particularly important if the device´s energy production is dependent on its position to the wave propagation.

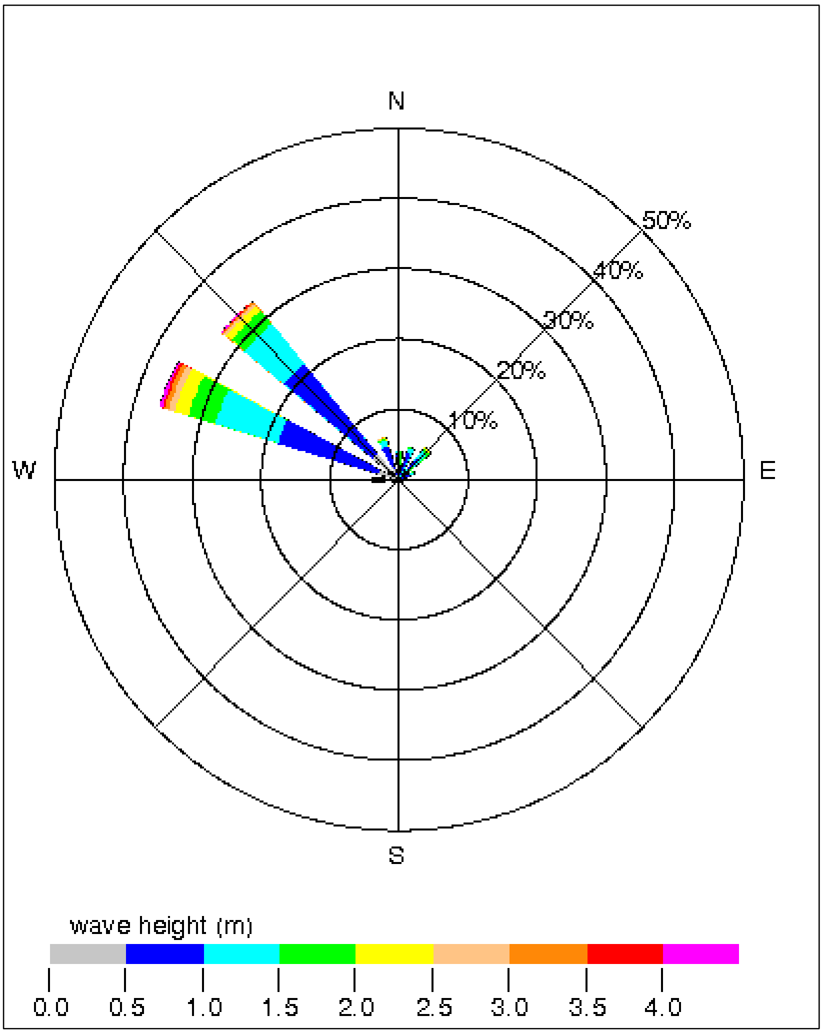

Figure 4: Wave Rose (BMT ARGOSS, 2015)

60 http://www.bmtargoss.com/

61 http://www.openocean.fr/en/

3.1.3.2 Periodic distribution of wave height (e.g. monthly)

The monthly distribution of the wave height will give an idea of the seasonal shape of the potential energy production. In the example below, we notice a relatively constant resource with slightly higher waves in the winter months. Obviously, once a site is seriously considered for an installation, a more granular view is necessary to evaluate the site. An hourly distribution through the day will give, for example, more information about how the electricity production would fit into the consumption pattern.

Table 5: Monthly Wave Height Distribution (BMT ARGOSS, 2015)

Monthly distribution table of wave height

Monthly distribution of wave height (m)

lower	upper	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.0	0.5	9.2	8.6	12.4	16.6	28.9	15.4	6.4	8.2	17.8	26.5	17.1	11.2
0.5	1.0	35.1	33.8	40.5	44.4	47.5	53.1	54.7	62.7	53.7	49.8	43.1	38.1
1.0	1.5	24.2	23.4	21.8	24.4	17.8	22.2	32.1	24.6	22.1	15.7	20.9	22.8
1.5	2.0	15.4	13.8	11.6	9.5	6.2	7.6	6.8	3.7	5.1	5.5	8.5	12.6
2.0	2.5	7.9	6.9	6.1	4.2	1.4	1.6	1.5	0.6	1.1	2.0	6.0	7.0
2.5	3.0	3.4	4.9	3.6	1.2	0.1	0.2	0.5	0.1	0.2	0.3	2.5	3.7
3.0	3.5	2.2	4.4	1.8	0.5	0.0	0.1	0	0	0.2	0.1	1.4	1.7
3.5	4.0	1.4	1.9	1.3	0.3	0	0	0	0	0	0	0.9	1.0
4.0	4.5	0.7	1.2	0.5	0.0	0	0	0	0	0	0	0.4	0.8
4.5	5.0	0.4	0.8	0.3	0	0	0	0	0	0	0	0.2	0.5
5.0	5.5	0.2	0.4	0.1	0	0	0	0	0	0	0	0.0	0.3
5.5	6.0	0.1	0.0	0.1	0	0	0	0	0	0	0	0.0	0.2
6.0	6.5	0	0	0	0	0	0	0	0	0	0	0	0.1
6.5	7.0	0	0	0	0	0	0	0	0	0	0	0	0
total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

3.1.3.3 Seasonal and interannual variation of wave height

The graph below shows seasonal mean heights values, 90% exceedance curves and maximum and minimum monthly mean values. This chart shows historical variance of the resource at the site considered. In the example below there is considerable variance in the winter months, where average wave heights have a minimum value of approximately half of the maximum value.

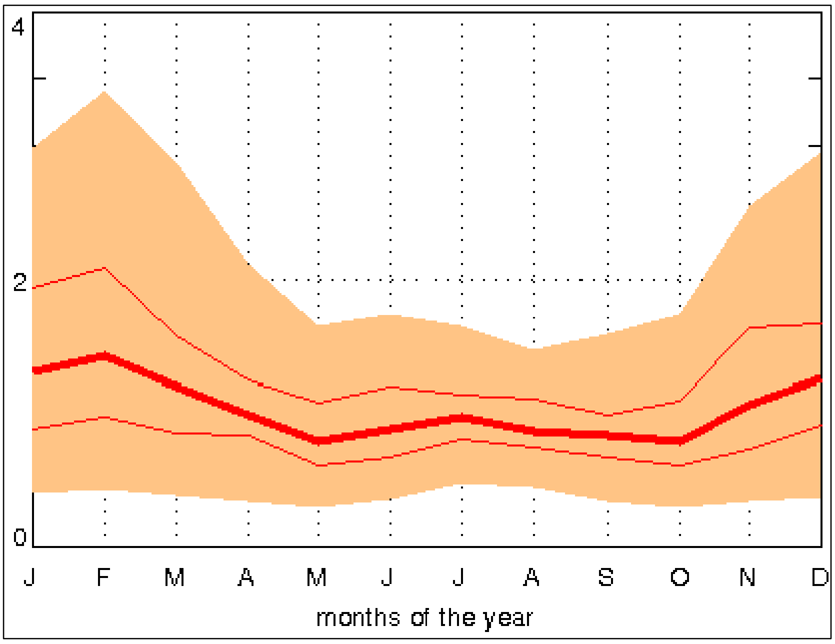

Figure 5: Seasonal Variation of Wave Height (BMT ARGOSS, 2015)

3.1.3.4 Joint frequency of wave height and wave period

The most important data in order to determine the power production of a device, however, is the joint distribution of wave height and period, since these two variables determine the energy included in the wave. The table below shows the annual frequency table of the different wave heights and periods for Iceland[62]. The total number of observations is scaled to a total of 1000. The frequency of wave height between 2.5 and 3 meters, with a period from 9 to 10 seconds, for example, is 36 out of 1000.

[62] http://www.macs.hw.ac.uk/~denis/wave/WERATLAS.pdf, accessed 1st November 2015

Table 6: Joint Height and Period Distribution SW Iceland

(Hs,Te) Table

Bivariate frequency table of Hs and Te

LOCATION: ICELAND / SW   SEASON: Annual

Hs(m) \ Te(sec)	0-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-18	18-20	TOTAL
0.0-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5-1.0	0	0	0	0	1	3	3	0	0	0	0	0	0	0	0	0	7
1.0-1.5	0	0	0	0	4	26	54	25	5	1	0	0	0	0	0	0	115
1.5-2.0	0	0	0	0	4	28	57	49	12	3	0	0	0	0	0	0	153
2.0-2.5	0	0	0	0	1	17	40	53	29	6	0	0	0	0	0	0	146
2.5-3.0	0	0	0	0	0	5	29	34	36	17	1	0	0	0	0	0	122
3.0-3.5	0	0	0	0	0	1	15	29	34	24	7	1	0	0	0	0	111
3.5-4.0	0	0	0	0	0	0	6	24	23	22	10	2	0	0	0	0	87
4.0-4.5	0	0	0	0	0	0	1	13	19	16	15	2	0	0	0	0	66
4.5-5.0	0	0	0	0	0	0	0	4	14	16	12	4	1	0	0	0	51
5.0-5.5	0	0	0	0	0	0	0	1	11	14	10	6	1	0	0	0	43
5.5-6.0	0	0	0	0	0	0	0	0	4	11	7	6	1	0	0	0	29
6.0-6.5	0	0	0	0	0	0	0	0	1	7	6	5	2	0	0	0	21
6.5-7.0	0	0	0	0	0	0	0	0	1	4	5	4	2	0	0	0	16
7.0-7.5	0	0	0	0	0	0	0	0	0	1	4	2	1	0	0	0	8
7.5-8.0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	0	0	6
8.0-8.5	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	3
8.5-9.0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	3
9.0-9.5	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2
9.5-10.0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
10-11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
11-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16-20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	10	80	205	232	189	142	81	38	13	1	0	0	1000

In this example, the frequency is concentrated around waves of about 2 m in height and a 9 s period. This data, combined with the power curve of the wave energy converter, provides the expected output at the considered site. The methodology is analogous to the one used to estimated electricity production of wind turbines: One has to combine the power curve of the turbine with the wind speed distribution to obtain the electricity production at a given site. There is a difference though, since the power of the wave depends on two variables, the wave height and the wave period, the power curve of the wave energy converter (WEC) depends on these two variables and one has to combine this power curve with the frequency table above or with the joint probability density function to obtain the expected power production. Indeed, the matrices should have the same multi-dimensional scaling, so one can multiply them. The figure below represents the power matrix of the Pelamis engine, a 750 kWe wave energy converter.

Table 7: Power Matrix of Pelamis (Murray, 2003)

Significant wave height (H_{sig}, m)	Power period (T_{pow}, s) 5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

To calculate the estimated power production for a shorter period of time, it is necessary to have frequency tables for shorter time periods, for example monthly or even shorter. Recalling the formula for the risk-adjusted discount factor, it is then possible to estimate the factor using the historical electricity prices of the relevant power grid corresponding to the time scale of the estimated average electricity production. The accuracy of the calculation will increase the shorter the time period considered. Ideally, one would use daily electricity production values.

In addition to the pure wave data, knowledge about the seabed is also necessary to optimize the location of the WEC because of the mooring conditions, the connection to the grid and the influence of the seabed on the wave resource, if the location is near shore. A substantial amount of European bathymetry data is freely available on the EMODnet (European Marine Observation and Data Network) website, initiated by the European commission[63]. Here as well, the data, if available for the location targeted, can be used as a first approximation of the reality. Once a detailed and reliable seabed topography is needed, it is recommended to use the services of specialized data providers. Ixblue[64], for example, is a bathymetry data provider. If detailed wave measurement has to be implemented at a specific site, specialized service providers are also available, such as DHI.[65]

63 http://www.emodnet-bathymetry.eu/

64 https://www.ixblue.com/

65 https://www.dhigroup.com/areas-of-expertise/coast-and-marine/survey-and-monitoring

From a project developer's point of view, there are a lot of similarities to the methodology used in the wind power generation industry. Indeed, the procedure to estimate the power production of a particular engine is the same. Even the underlying statistical techniques are the same. In addition, the wave resource assessment approach is quite similar to the methodology used in the wind sector. A project developer would make a first site assessment with the available historical data, followed by a detailed measurement campaign, depending on the complexity of the terrain and the size of the project. As a consequence, it is, however, worthwhile noticing that the power curve of WEC devices should be adapted to the shape of the resource.

3.1.4 Wave energy potential in Europe

In order to retain a similar yardstick as when illustrating PV and wind energy, one can mention the comparison introduced by waves4power on its website, stating that 576 km² of its power plant would meet all of Norway´s electricity demand.[66] This means that approximately 55 km² would be enough to meet the electricity consumption of the city of Hamburg.[67] This is less than a third of the surface needed by offshore wind parks. These results are, nonetheless, largely dependent on the reference site considered on one hand, as well as on the technology used. Indeed, waves4power´s buoy solution does not require a lot of surface to deploy its engine, whereas a solution like the Pelamis wave attenuator would require a larger surface area since its concept requires horizontal deployment of the engine. However, the magnitude of this comparison is testimony to the potential attributed to the wave energy resource.

A detailed investigation of the wave resource shows significant wave energy potential on the west coast regions, whereby the Mediterranean offers only limited potential. The map below in figure 11 shows the European distribution of wave power. The total European wave energy resource is estimated at 1000 TWh/yr[68] for a total electricity consumption of around 3100 TWh/yr for the EU28. We should keep in mind though, that the amount of electricity produced, at the end, is very much dependent on the device itself. Some may be well suited for high density offshore sites, while other engines may be more efficient in near to shore areas, where the energy density is lower.

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66 http://www.waves4power.com/wave-power-potential/ accessed 3rd November 2015

67 The electricity consumption of the city of Hamburg is around 12.400 GWh per year, compared to approximately 130.000 GWh per year for Norway in 2012, http://www.nve.no/Global/Energi/Analyser/Energi%20i%20Norge%20folder/FOLDE2013.pdf accessed 4th November 2015

68 (IRENA Ocean Energy Technology Brief, 2014)

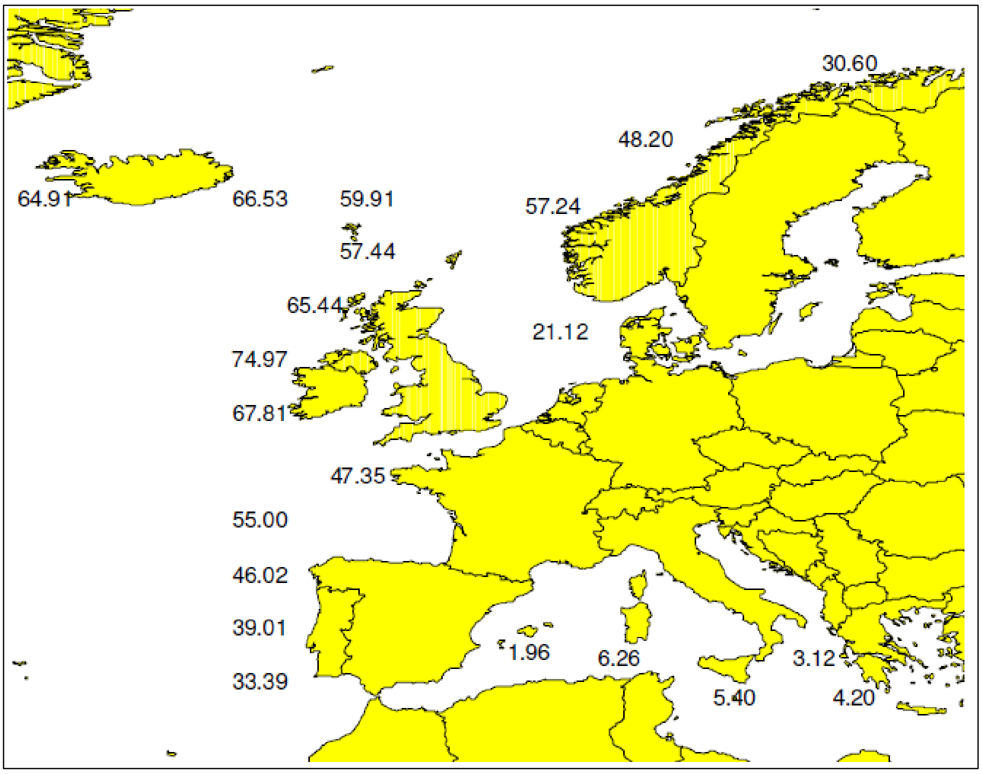

Figure 6: European Distribution of Wave Power (kW/m) (Murray, 2003)

However important the pure potential of the considered site is, the level of wholesale electricity price is of equally high importance for the economic viability of the site. Special interest should, therefore, be given to islands since the energy prices are usually high due to fuel transportation costs. The average energy costs in Hawaii are, for example, about $350/MWh, which is well above any European feed-in tariff.[69]

Nonetheless, since the range of available wave power is very large, from below 5 kW/m in the Mediterranean Sea, to above 70 kW/m on the Irish western coast, the adaptability of the engine to different resource levels will be a key determinant of the potential of the technology to reach commercial scale sales. In the following section, we examine the different types of WEC technologies, the current status of public aid and the most important market actors.

3.2 Wave energy conversion technologies

Using wave energy to produce electricity is not a new idea. Since the 1970s, different concepts have been elaborated. In contrast to the technology used to convert tidal energy into electricity, which basically uses a certain kind of turbine installed under water, there is a wide range of different WEC technologies. The different solutions differentiate themselves from how the motion of the sea is transformed into electricity,

[69] (Ocean Energy Europe - Damian Kunko, SMI vice-president, 2015)

on one hand, and from the location of the device (offshore, shallow waters or on the coastline). There are several ways the technologies can be classified. According to their mode of operation, there are three main types of WEC.

3.2.1 The oscillating water columns (OWC)

These devices essentially convert the vertical motion of the waves in the water column into air motion, which is then converted to electricity through an air turbine. These devices have also been designed for offshore solutions like the Oceanlinx[70] or as onshore concrete structure as the Limpet (Land Installed Marine Powered Energy Transformer).[71]

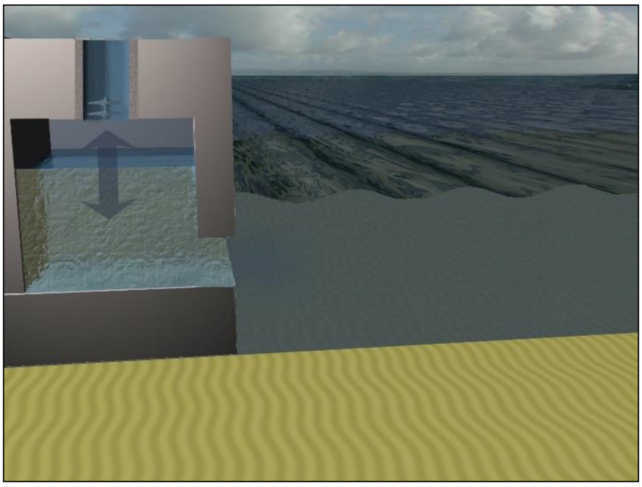

Figure 7: Oscillating Water Column

3.2.2 The overtopping devices

They are similar to the Wave Dragon[72], located on or nearshore. They capture incoming waves into reservoirs and release the water through pipes where power producing turbines are located.

70 http://oceanlinx.com/ accessed 7th November 2015

71 https://en.wikipedia.org/wiki/Islay_LIMPET accessed 7th November 2015

72 http://www.wavedragon.net/ accessed 7th November 2015

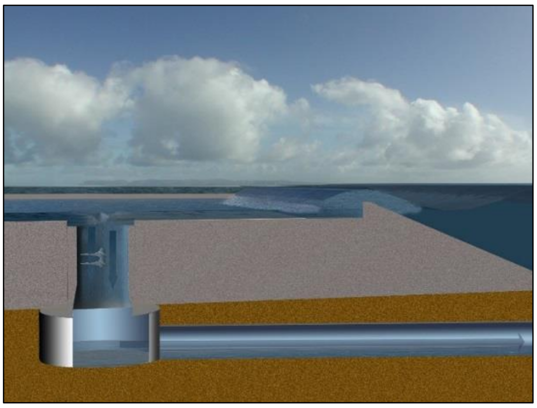

Figure 8: Overtopping Device

3.2.3 The engines converting the motion of their own body into electricity.

There are several different approaches in this category of devices. Without being exhaustive in our enumeration, the following solutions are representative of the different conceptual approaches.

The Archimedes Waveswing submerged wave power buoy converts sub-sea water pressure differentials into electricity via a direct drive generator.[73]

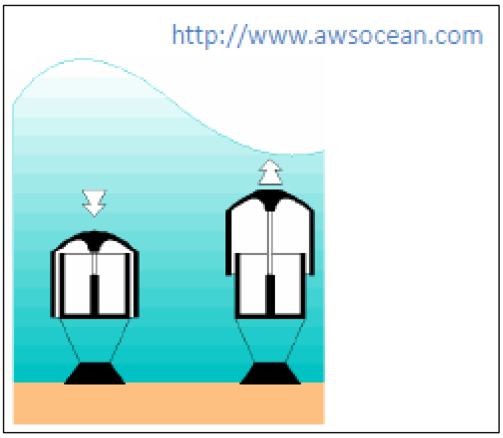

Figure 9: AWS Submerged Wave Power Buoy

The Pelamis engine is a wave attenuator with its body lying in the direction of the wave propagation. Its articulated body is "riding" the wave, each part of the body acting as a pump driving fluid through a hydraulic motor.[74]

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[73] http://awsocean.com/technology/archimedes-waveswing-submerged-wave-power-buoy/ accessed 7th November 2015

[74] https://en.wikipedia.org/wiki/Pelamis_Wave_Power accessed 7th November 2015

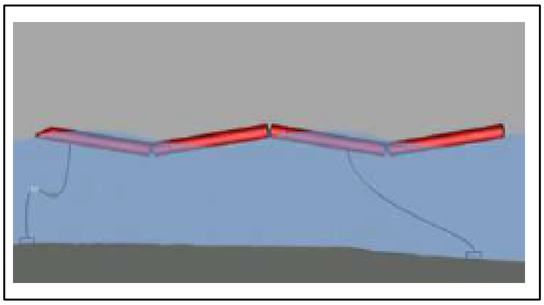

Figure 10: Pelamis

The CETO (Cylindrical Energy Transfer Oscillator) developed by Carnegie, is an engine operating under water, analogously to the AWS buoy though it uses hydraulic pumps instead of a direct drive generator. The buoy drives pumps and generators that are contained offshore within the buoy itself. The hydraulic energy from the pumps is converted to electricity within the device.[75]

The Penguin Wave Energy converter developed by Wello converts wave movement into gyration. The asymmetric shape of the floating device is used to capture the movement to a spinning rotator inside the device. The rotator is then directly connected to the generator, meaning conversion losses are avoided.

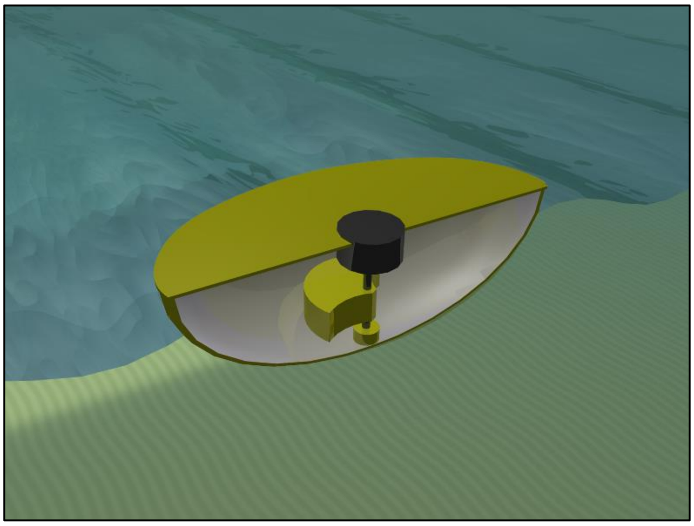

Figure 11: Rotating Mass Wave Energy Conversion

Albatern a Scottish wave energy technology company has developed WaveNet an offshore array-based WEC. The device is comprised of interconnected floating buoys that are flexible to move in any direction. The power of the wave is first converted to

[75] http://carnegiewave.com/what-is-ceto/ accessed 7th November 2015

hydraulic power, then aggregated through a hydrostatic transmission system common to the array of buoys and then converted into electricity.[76]

Waves4power, a Swedish technology developer, promotes a conceptually simpler device. Its solution consists of a floating buoy with a water piston inside. The piston is attached to a hydraulic pump which generates electricity.[77]

Before taking a closer look at the current status of the WEC technology provider, we will examine the different support and funding modalities available. Indeed, though we know we should suppose decreasing subsidies through time, currently available public support schemes may substantially change the economic viability of projects and thus of technology providing companies.

3.3 Public support schemes from the EU, national or regional public authorities

As member of the EU, there is a quite large but opaque amount of proposals from the various public authorities. The public support ranges from grants to feed-in tariffs or preferred access to facilities. One can notice the national support schemes in marine energy are not yet consolidated on RES LEGAL Europe[78], the online support schemes database of the European Commission. This is also a sign that the industry has not yet reached commercial maturity.

3.3.1 Public support at EU level

We have to distinguish between financial support provided directly to the company in order to help its development and aid that is directed towards projects implementing new technology. For the latter, there are essentially three suitable support schemes for ocean energies:

- The horizon 2020 Energy Research and Innovation program, with a total budget of 80 billion EUR from 2014 to 2020.[79] The program works by making public calls for research topic. Many calls require a team of at least three partners. The CEFOW (Clean Energy from Ocean Waves) project for example has been allocated € 17 million.[80] The project partners are Fortum Corporation a Finish

76 http://albatern.co.uk/wavenet/works/ accessed 7th November 2015

77 http://www.waves4power.com/method/ accessed 7th November 2015

78 http://www.res-legal.eu/

79 The projects financed under previous European framework Program FP6 and FP7 before 2015 can be found at http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=projects#results accessed 14th November 2015

80 http://www.wavehub.co.uk/wave-hub-site/cefow accessed 14th November 2015

utility company as project coordinator, Wello Direct Conversion responsible for the technology development, WaveHub, which is taking care of the infrastructure, and Greenmarine and Mojomaritime, which are accountable for engineering and marine operations. Finally, there are three environmental research partners, the universities of Exeter, Uppsala and Plymouth. At present, one call related to ocean energy could be identified on the commission's website. The topic of the call is "Second generation of design tools to ocean energy devices and arrays development and deployment".[81] The horizon 2020 program is more appropriate for generating flagship projects than developing specific innovative technology, since it requires the collaboration of partners that share the results of the project. Therefore, the field of excellence of the collaborating partners should be complementary rather than similar. In addition, at least some of the partners need solid reputation and financial soundness to be awarded projects of that dimension.

- The NER 300 program for innovative low-carbon first of-the-kind projects. This program was founded by the proceeds of the sale of 300 million allowances from the new entrants´ reserve (NER) set up for the ETS. The € 2.1 billion sales proceeds were allocated in two calls for proposals in 2012 and 2014. Five ocean energy projects were approved, amongst them two wave energy projects. The Westwave 5 MW demonstration project, located in Ireland, was granted € 23 million funding.[82] The SWELL WaveRoller project in Portugal was allocated another € 9 million.[83] The two tidal turbine projects and the thermal energy conversion platform project accounted for another total of about € 100 million. As the program is closed now, the commission has suggested replacing the program by an Innovation Fund endowed with 450 million allowances.[84]

- The 2014-2020 EU Structural funds, which are implemented at national level, are not dedicated specifically to renewable energies but can be used to support the transformation process of the local economy into a sustainable and competitive economy. The Welsh European Funding Office has granted £2 million of its £2 billion structural funds made available to Wales for the 2014 –

[81] http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/2176-lce-16-2017.html 14th November 2015

[82] http://www.esb.ie/main/innovation/westwave.jsp accessed 14th November 2015

[83] https://www.youtube.com/watch?v=0cejxB4MdpQ&feature=youtu.be accessed 14th November 2015

[84] (Ocean Energy Europe - Kerstin Lichtenvort, 2015)

2020 period to Marine Power Systems for testing a 1:4 scale WaveSub prototype.[85] In May 2015 they had already invested € 13 million in the commercial rollout of Deep Green, a 10 MW tidal and current power plant developed by Minesto.[86]

- The European Investment Bank (EIB) is offering various instruments to companies seeking direct support for their development. These instruments, a joint initiative launched by the EIB and the European Commission under Horizon 2020, are summarized under the brand name InnovFin, EU Finance for Innovators. These instruments range from energy demonstration projects financing - which is an indirect support instrument - to guarantees and venture capital for small and medium enterprises (SME) - which are direct support instruments. The projects can be financed up to 50% by loan. Eligible projects have to be at pre-commercial status between € 7.5 and € 75 million with a maximum maturity of 15 years. InnovFin SME venture capital, managed by the European Investment Fund (EIF) provides capital through selected financial intermediaries.

The amount of EU funding is thus very substantial. Nevertheless, one can observe that project financing is predominantly directed at relatively large projects at pre-commercial stage. Indeed, the authorities have drained the funds for companies and technologies able to reach utility scale production in an expected short period of time. In addition to pure financial support, the EC funded the Marine Renewables Infrastructure Network (MARINET), a network of research centers and organizations. The organization aims to streamline and facilitate testing by offering periods of free-of-charge access to test facilities.[87]

3.3.2 Public support at country level

As mentioned above, the national support schemes for ocean energy are not yet available on a consolidated basis for the EU member countries. The current support mechanisms can be categorized into push and pull mechanism. The push activities are direct investments or support of projects which is aimed at technology about to leave prototype status; pull mechanisms are technology neutral and in most cases feed-in tariffs. The table below lists the feed-in tariffs for a selection of countries.

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85 http://wefo.gov.wales/news/latest/151022-wave-sub/?lang=en accessed 14th November 2015

86 http://minesto.com/holyhead-deep-10mw/ accessed 14th November 2015

87 An exhaustive list of current projects can be found in Table 15, p.40 (2014 JRC Ocean Energy Status Report, 2015)

Table 8: Feed-In Tariffs adapted from (2014 JRC Ocean Energy Status Report, 2015)

United Kingdom	Renewable Obligation (RO) Scheme. Renewable Obligation Certificates (ROCs) buyout price set to £30 in 2002/3 rising to 43 GBP in 2014/15. RO scheme will be replaced by a Contract for Difference (CfD) scheme in 2016/2017. There will be three different technology “pots”. Off-shore wind and Ocean Energies in the same second pot will be allocated £150 million for the period. CfD allocated via auction per technology pot.
France	Feed-in Tariff for renewable electricity. Currently 15 c EUR/kWh for ocean energy
Ireland	Feed-in Tariff for ocean energy of 26 c EUR/kWh (up to 30 MW) starting 2016
Spain	Feed-in Tariff suspended for all renewables, replaced in 2014 by a scheme of a fixed annual investment bonus for existing installations.
Denmark	Maximum tariff of 8 c EUR/kWh (sum of market price and bonus) for ocean energy
Germany	Feed-in Tariff, 3.5–12.5 c EUR/kWh for ocean energy, depending on installed capacity
Norway	Feed-in Tariff of about 7–8 c EUR/kWh (total compensation)

There has been an additional number of specific activities in several countries. A detailed list can be found in (2014 JRC Ocean Energy Status Report, 2015) , table 25.

3.3.3 Public initiatives at regional level

There are a number of regional initiatives aimed, in particular, at promoting the concerned regions as an industrial site for the supply chain of the industry. A number of regions were represented at the Ocean Energy Europe 2015 venue in Dublin, the most important networking event of the industry in Europe. The French region of Brittany was represented by its development and innovation agency.[88] The pays de la Loire region was present via Weamec (West Atlantic Marine Energy Center).[89] The West Normandy Marine Energy is trying to attract companies to settle in the Basse-Normandie region. The Marine Energy Pembrokeshire is a private public partnership with the goal of establishing South West Wales as a “center of excellence” for marine energy generation[90]. The Maritime Cluster of West Sweden[91] is hosted by SP Technical Research Institute of Sweden. The cluster brings together the industry, research organization and public authorities in the marine energy segment. SP is fully owned by the Swedish government. Finally, Morlais Anglesey Marine Energy aims to establish Anglesey as a marine energy hub[92].

In summary, considering the number of public support scheme and the amounts involved, one might conclude that the public authorities are already well focused on the industry. The current European Commission is even reiterating its commitment to renewable energies in general through its new Strategic Energy Technology (SET) Plan. One of the top five priorities of the new plan, as presented during the Ocean Energy Europe 2015 conference in Dublin by Paul Verhoef, head of Unit, DG Research & Innovation, European Commission, is to be number one in renewable energies. Karmenu Vella, the commissioner for Environment, Maritime Affairs & Fisheries even pointed out on that occasion that 10% of the EU´s power demand of estimated 3.844 TWh could be met by 2050.[93] According to this political environment, one should expect the industry to soon take-off. But when listening to the floor-conversations at the event and the topics addressed at the panel question and answer

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88 http://www.bdi.fr/serving-the-regional-economy

89 http://www.mre-paysdelaloire.com/

90 http://www.marineenergypembrokeshire.co.uk/

91 http://maritimaklustret.se/english/

92 http://morlaisenergy.com/en/

93 Press release 20th October 2015 http://oceanenergy-europe.eu/index.php/communication/press-corner/412-press-release-ocean-energy-industry-presents-its-game-plan-to-political-leaders-in-dublin accessed 15 th November 15.

sessions, one could notice that a considerable amount of problems subsists. These have been mirrored in the Ocean Energy Forum´s Draft of Ocean Energy Strategic Roadmap.[94] The following recommendations amongst others are of great relevance:

- EU-wide standardized testing and result format in order to help technology developers to have access to finance by enabling investors to compare technologies based on measurable criteria.

- Ocean industry to cooperate with insurers and finance institutions to develop appropriate financial products.

- Governments to establish long-term revenue support schemes ensuring predictability of income for ocean energy projects.

However, the two last points mentioned may be contradictory to some extent. Indeed, one of the financial risk induced by any offshore project is the availability of the connection to the grid. If there is a problem with the connection, the power plant is not able to sell its production. This problem is not new since it is the same for offshore wind power plants. The problem is, however, that the risk on a single connection is higher, the higher the volume of electricity produced on one hand, and the higher the price at which the electricity could have been sold on the other hand. As a consequence, the higher the feed-in tariff, the higher the amount at risk for any insurer. At that point two possible improvements can be made. One solution would be to implement the same feed-in tariff for any offshore technology. This solution would make it easier to bundle the risks - independent of the technology - into one financial vehicle, and sell it back to institutional investors, either via a bond issue or through reinsurance companies underwriting the risk. In order to keep the incentive high for investments in ocean energy, more subsidies could be directed at the initial capital expenditure. A second line of thinking would be to introduce a financial instrument reducing the risk for a potential underwriter. This could, for example, be achieved with an issue of two bonds: one as a first tranche loss, and the second would then be under fire only when the nominal of the first had already been “consumed”. In this case, the first tranche loss probably has to be underwritten by public authorities, since it would be too expensive to finance otherwise. Public authorities would mitigate part of the risk through the numbers of tranches underwritten.

Coming back to the panoply of public aid offered, the only scheme taking into consideration to help companies in their infancy are the InnovFin SME schemes of the

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[94] (Ocean Energy Forum Strategic Roadmap, 2015)

EIB. Even those are only available through a list of recognized venture capitalist, so there is no direct access to public seed money, through the EU at least. In addition to public funding, there are public private partnership initiatives focusing on technology at early stage. For example, the KIC InnoEnergy initiative, where utilities, technology firms and public universities and research centres are founding members. The DeepGreen500 project, where Minesto is one of the partner, has benefited from that help.[95] The overall available public help is still, for the most part, directed at projects where several partners are engaged. In that situation, public funding for start-ups in this field is limited to incubation initiatives in relation with universities or public research entities. The reason for this is most probably that public authorities or institutions do not want to be involved in the choice of the technology or the company to support. Nevertheless, if the authorities would like to implement a policy that significantly improves the conditions to obtain seed money, they should think about instruments that limit the amount of loss for the private investor, in the case of a total loss event. Indeed, the problem of such investment is the high technology risk. The probability that the technology, after prototype development, does not proof viable from an economic point of view is relatively high. That makes an investment relatively unattractive, even if the expected return of the investment is high at the start. Indeed, as we know from the utility theory, if we suppose that any potential investor has a certain level of risk aversion, then the expected return on the investment, at the time the investment decision has to be made, must be very high to compensate for the possible total loss. The risk mitigation possibilities at the individual investor's level are, in addition, quite limited as the number of possible investment in this specific industry is limited on one hand, and the industry risk itself is quite difficult to mitigate, on the other hand. Indeed, it is not the same story as funding a new dotcom story in an existing portfolio of dotcom start-ups, where there is real risk mitigation due to portfolio diversification within the sector. In this context one could think about, for example, a support instrument that allows to bundle investments in several start-ups with a global first loss tranche for the whole portfolio. This could work as follows: The total loss events of the companies in the portfolio are carried by the first loss tranche up to a predefined amount. Every loss amount in excess would then be at the expense of the private investors. This would significantly improve the return profile for a private investor since the probability of total loss would be significantly lower. The cost of this tranche should be kept low by the authorities. In return for this subvention, the companies benefiting from the scheme could be obliged to share their

[95] http://www.kic-innoenergy.com/innovationproject/our-innovation-projects/deepgreen500/ accessed 15th November 2015

test results in order to speed-up the development process of the technology. At least in case the technology is abandoned, the test results could be made public to the other companies. The portfolio could be run by a fund manager designated after a beauty contest.

3.4 Private funding of ocean energy

The most remarkable matter of fact at the Ocean Energy Europe 2015 conference was the total absence of institutional investors, who usually have great appetite for renewable energy projects. Indeed, the combination of long term projects with state guarantee on the electricity price is very attractive for many market participants. Life insurance companies and pension funds, in particular, need to invest in long term assets to match the duration of their long term liabilities. This absence is apparently even more surprising since the overall market for RE projects is a “seller´s market”, as Jacqueline Huyhn, investment manager at 100% RE IPP, states when asked if she is satisfied by the investment opportunities currently available. The main reason for the absence of institutional investors is that only one ocean energy project has so far been financed with private money.[96].Black Rock Tidal Power managed to generate the first commercial tidal project with CAD 10.5 million in the Canadian region of Nova Scotia, thanks to very good feed in tariffs and PPA conditions[97]. Miss Huyhn added, when asked about investment criteria, that “… for the IPPs, they invest in the long term, with the objective to increase the production capacity, in order to supply the demand with the highest stability. The diversification (geographically and technology wise) of the portfolio is essential…” According to that statement IPPs should have interest in any new technology reaching commercial maturity, or in other words, comparable risk adjusted rate of return to other technologies. This is even truer for utilities that have to match the demand of their customers. Indeed, since the geographical diversification is limited by the geographical area of the grids their customers are connected to, the technological diversification is even more important. It is consequently not surprising that utilities are, along with project developers who have obviously an inherent interest in new projects, the main promotors for new technologies. In addition, utilities may have interest in gaining a stake into new technology, either by their own research and development, or by venture capital, since they may acquire significant competitive advantage if the technology gets groundbreaking results. Large entities like Edf, Engie and Alsthom are more inclined

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[96] In the meantime Carnegie announced a first Australian deal http://carnegiewave.com/wp-content/uploads/2015/11/151119_ASX-CBA-Deal_Final.pdf accessed 21th November 2015

[97] http://www.blackrocktidalpower.com/ru/news/ accessed 15th November 2015

to develop their own technology or to team up with a technology provider with reliable track record. Smaller utilities, such as Fortum and ESB (Westwave project), are open to smaller technology innovators.

In such an environment, it appears relatively challenging for small innovative and independent companies to get started. However, we have to differentiate wave energy from tidal energy in this context. Since a broad part of the tidal energy technology development consist of the development of a specific turbine, the technology providers in general already have a background in similar technologies, and, do not need specific financing since they are commercially successful in other areas. A typical example of that kind of company is Schottel,[98] the German group specialized in propulsion technologies, which provides the turbine of the Black Rock Tidal Power Project. Considering the wave energy technology providers present at the Ocean Energy 2015 conference, we notice that only the Australian company, Carnegie, is so far listed on a stock exchange. The majority of the others are mainly funded by grants from local authorities and usually work in partnership with public research institutions. Sea Power ltd, for example, relies, for the most part, on funds granted by the Sustainable Energy Authority of Ireland (SEAI). The Swansea based Marine Power Systems was funded by local private business angels and the Welsh government. Conversations amongst delegates at the Ocean Energy conference confirmed the impression of the difficulties to get seed money in this industry. Christoph Harwood, Commercial Director at Sustainable Marine Energy ltd, for example, mentioned the existence of so-called family offices of high net worth individuals, who are sometimes ready to invest in such risky enterprises. In contrast, early stage professional investors would not take that technology risk. Indeed, the latter prefer to invest in areas with less predictable technology risks.[99]A different and interesting approach to the early stage funding issue is given by Wavepower ltd, a technology developer who secured 50 million pounds funding to develop a state of the art wave energy technology. The apparent bet of the company is to constitute a multidisciplinary team able to analyze the problems and mistakes encountered so far by the previous technology development. The timing of that initiative seems to be good since a couple of technology providers had to close shop or are not far from

[98] http://www.schottel.de/de/home/

[99] (Bridginng the Funding Gap, Taylor Wessing, 2012) p.7

giving up for financial reasons. For example, Pelamis[100] and Aquamarine Power called in administrators.[101]

The findings of this part will be consolidated with additional considerations related to the social, economic and technological environment later, when considering the business model in the specific case of HACE. Before doing so in the last part of this thesis, we will now introduce the technology developed by HACE.

100 http://renewables.seenews.com/news/uk-s-pelamis-wave-power-to-go-into-administration-450095 accessed 15th November 2015

101 http://www.aquamarinepower.com/ accessed 15th November 2015

Part 4 Hydro Air Concept Experimental (HACE) an innovative multi-chamber oscillating water column concept

The remainder of this thesis will focus on a specific patented technology. In this part, we will first introduce the concept and situate the technology in the current landscape of wave conversion engines. At the same time, we will examine the possible applications of the concept. The next part will then deal with the possible business cases and value propositions to be offered to potential investors at this early stage of the technology.

4.1 HACE: a new patented application of an old concept[102].

The basic idea of the concept is to convert the vertical motion of the sea first into airflow in a closed container, which is then converted into electricity by a turbine integrated in the closed area. There are several conceivable designs of the engine. The first design is an anchored floating device with 3 arms maintained at constant distance to the seabed, as long as the wave height does not reach a certain level. Once the wave height is greater than the threshold or cut-off level, an intelligent mooring system allows the engine to move up and down with the wave, in order to avoid excessive forces acting on the engine. The figure below represents the three arms of the engine. The arms contain a system of water columns and air compartments.

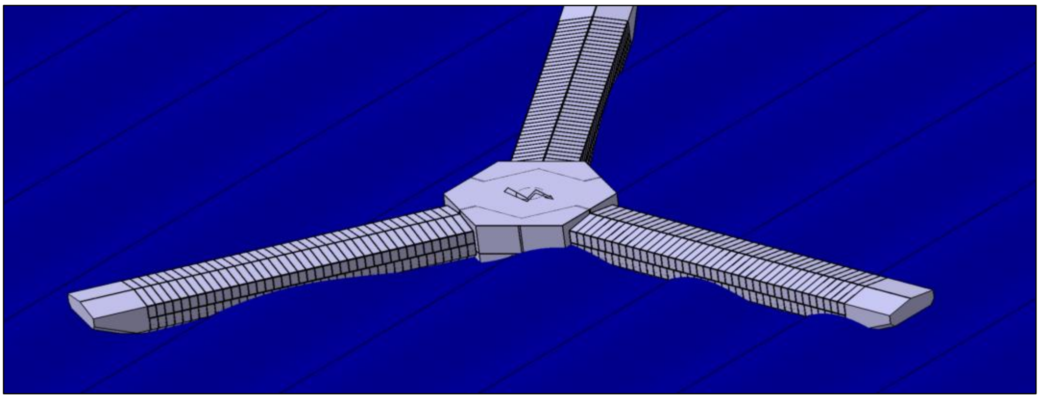

Figure 12: HACE 3 arm engine (diameter 60 m)

A second version of the engine is a floating barge propelled by the electricity produced. This is made possible by means of floaters. This engine is currently designed for test purposes. A similar free-floating module with “loose” mooring is planned as well. In the figure below, one can observe a system of submerged floaters

[102] A patent description can be found at https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2014023920 accessed 24 th November 2015

generating a diffraction or a concentration of the waves depending on the wave height - to optimize the wave potential in the collectors.

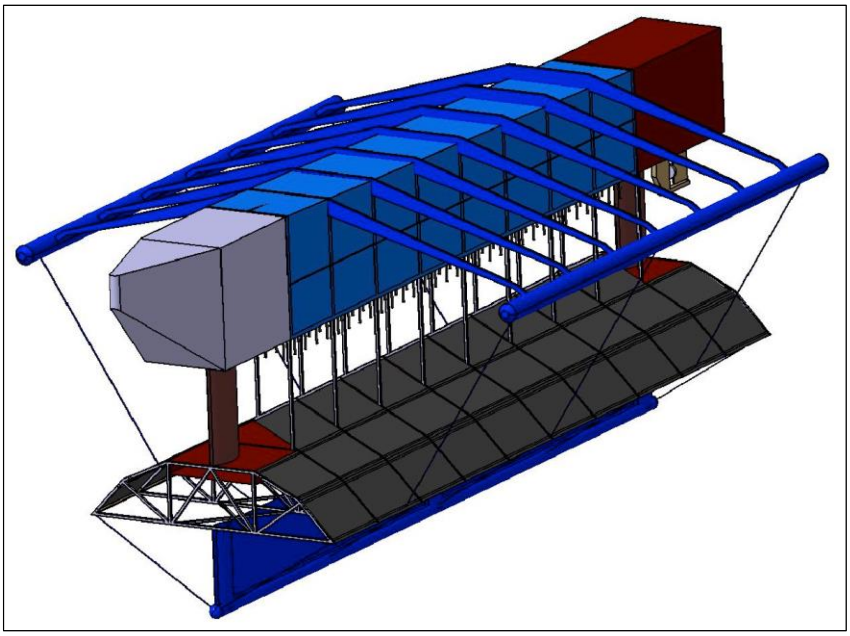

Figure 13: HACE floating engine

The basic concept is the same for all versions of the engine. A system of valves common to each water column generates air flow in the same direction, from a low pressure section to a high pressure section of the closed air tube. The figure below shows schematically how it works.

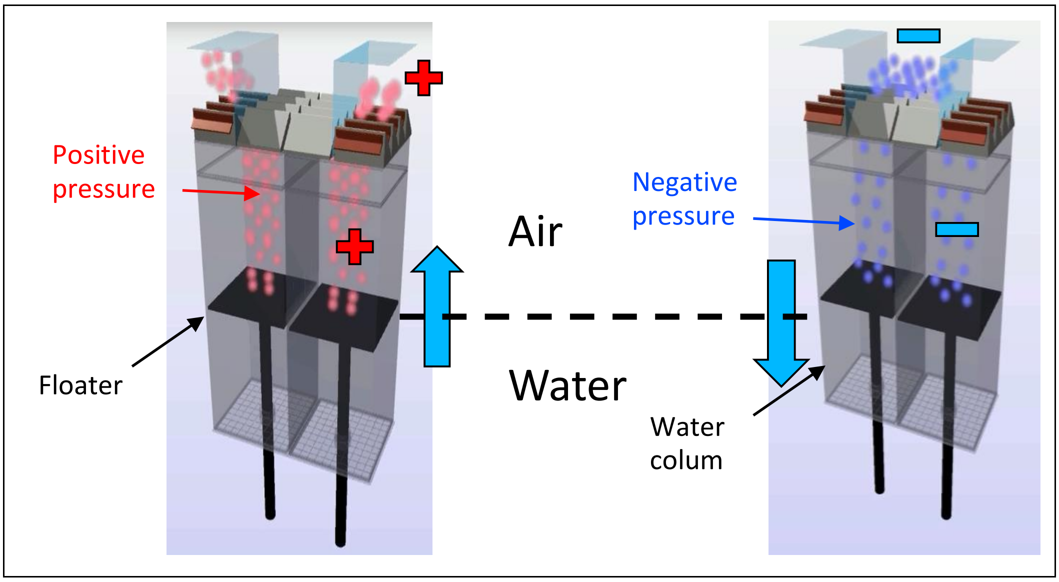

Figure 14: HACE basic concept

On the representation of the column on the left-hand side, the water level is going up in the water column which does not move itself, either because the engine is fixed to the seabed or because of submerged floaters at a depth where the wave has limited amplitude.

The floater in the water column is moving up, creating positive pressure and an air flow which is transmitted through the valves linked to the air container with positive pressure. The maximum pressure is reached at wave crest. At the same time, the valves linked to the air container with negative air pressure are closed. On the right-hand side, the wave is on its way down to the bottom of the wave amplitude, which results in the floater coming down and creates negative pressure on its way. Symmetrically the lowest pressure is reached at the bottom of wave. The valves to the positive pressure compartment are closed now and air is taken out from the low pressure compartment, as the valves of this compartment are now open. Each water column is linked to the two compartments, which are two parts of the same air container, so the whole system containing the air is closed. The two compartments are separated by the turbine, which is activated by the air flow generated between the two compartments. The whole air container is above sea level as one can observe looking at the schematic figure below.

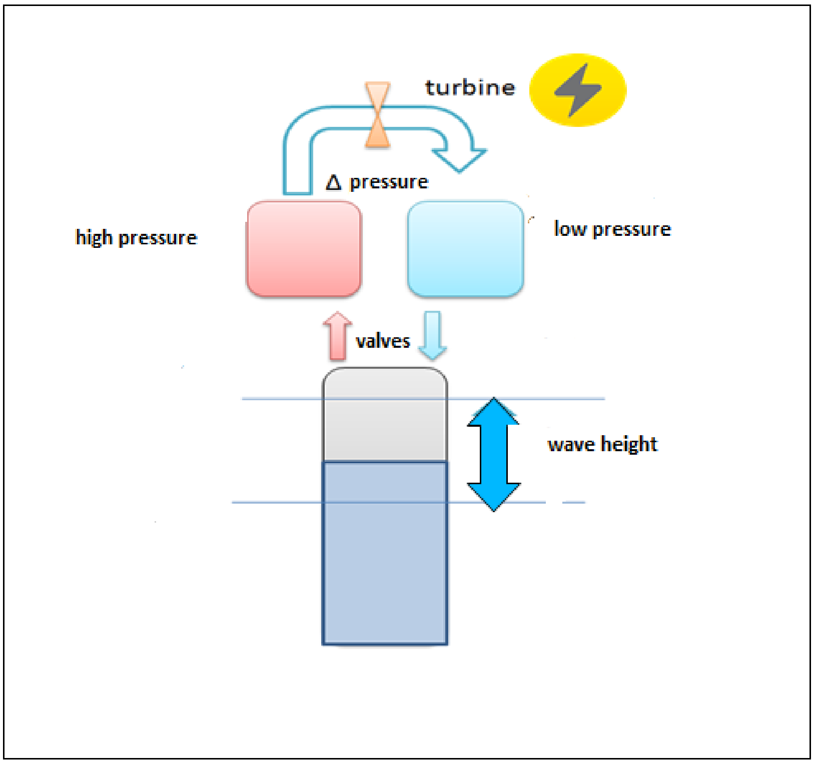

Figure 15: HACE schematic process description

The turbine and the power generator are also above sea level. The expected height above sea level of the engine is about 5 m. The system differentiates itself from other oscillating water column systems mainly by the following characteristics.

4.1.1 Floating lightweight engine

The whole system is kept simple with few mechanical and electrical parts - essentially only the turbine and the power generator - so there is no extra weight to carry. The main part of the construction is aluminum, which is quite common to ship construction. The air compartment and, obviously, the valves may be realized in different materials. The three arm 1 MW engine, with an arm dimension of 30m x 6m, should not exceed 50 t. The mooring of the engine will therefore be less demanding than for comparable engines. The Pelamis engine, for example, weighs 350 t for 350kW.

4.1.2 Efficient sea motion capture

The standard size of each water column is 0.5 m x 0.7m x 2.2 m. The 3 arm engine with 30m x 6m per arm contains 240 water columns per arm. The size of the water columns can be adapted to the sea condition of the site. The small size of the water column avoids a compensation phenomenon taking place within, which would occur with small waves with short period or with more erratic sea motion where several waves interfere. Indeed, in larger columns the water above normal sea level could be compensate by some water below normal sea level. Using smaller water columns avoids this compensation for the most part. The floater in the water column also assures a horizontal level of the water within the water column.

4.1.3 Simple water column maintenance

In addition to its function mentioned above, the floater prevents the water to reach the valves in case of larger waves. It protects the valves on the wave's way up and prevents the water from flowing into the space between the floater and the valves on the bottom of the waves, since it is kept in the water column. The floater also continuously cleans the water column in a simple conventional way in order to avoid fouling.

4.1.4 Optimal sizing to harvest the sea motion

The angle of an engine to the wave propagation should normally have a great impact on the energy produced. Indeed, if the wave crest were parallel to the engine, the water columns would either be all on high pressure or all on low pressure mode. The engine with three arms, though, can harvest waves coming from any direction, since regardless of which direction the wave is propagating, there will be water columns generating high pressure and others generating low pressure. In this way, a continuous air flow is generated. The free floating module obviously needs to be equipped with a tool which always turns the engine perpendicularly to the wave progression.

4.1.5 Site of operation - modularity

The HACE concept is modular and adaptable in the sense that it can be adapted to the site's conditions. The height of the water columns is adapted to the harvested range of wave height. If the cut-off level, for example, should be at a wave height of 2m, the height of the water column will be slightly more than 2m. The engine with three arms attached to the seabed is also designated to near shore sites with lower wave amplitude. Deeper water will require a floating version of the engine with a flexible mooring system. In addition, since the design of the engine is relatively simple, it is conceivable to adapt the design for different purposes. It could, for example, be implemented as a floating wave breaker since it has a dampening effect on the waves. It is also planned to use it in conjunction with jetties at marinas. Depending on the site location, the mooring system could be combined with a fish aggregating device. This flexibility of the concept qualifies HACE as an integral part of marine coastal policy. In particular, islands experiencing growing demand for marina capacity, persistent overfishing of local fish-species and high electricity costs due to fuel transportation costs should have great interest in such combined approaches. Along the same line of ideas, it is conceivable to use the engine in deeper waters in conjunction with fish farming. The mooring costs could be shared and the electricity production necessary to the farm would be assumed by the engine.

4.2 HACE: company history and management team.

The headquarters of the company are located in Bordeaux. The city of Bordeaux hosts a number of state of the art and high tech companies, universities and engineering research entities. An important branch of French aeronautical research is located in the area.

4.2.1 Management team

4.2.2 The company history

The company history is summarized in the following figure:

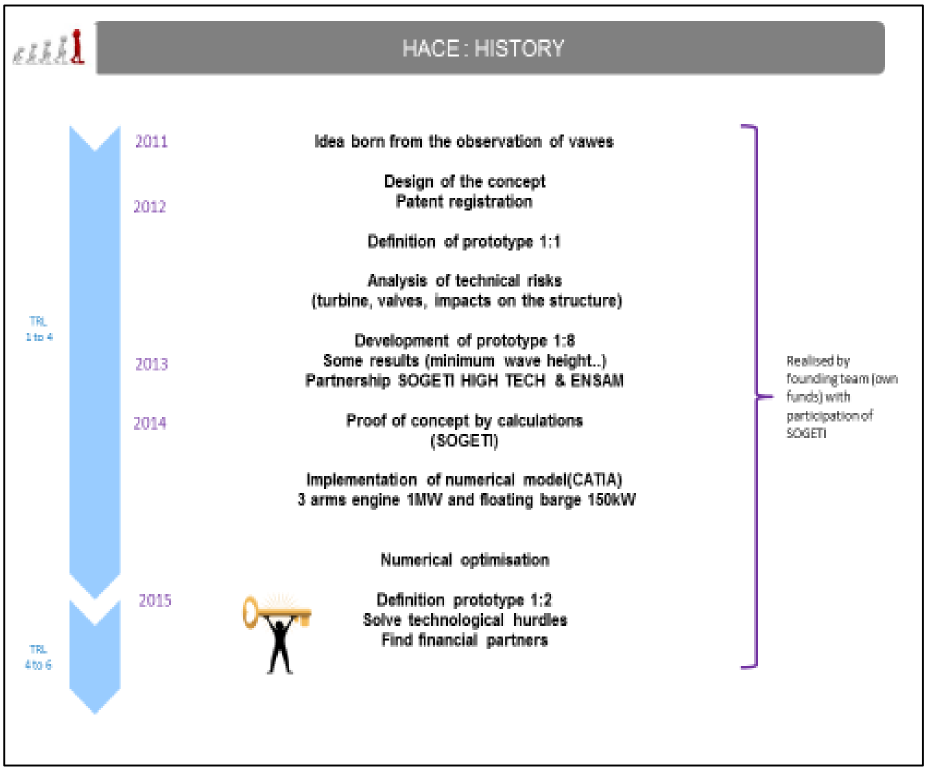

Figure 16: HACE history

The latest development step is the realization of the turbine for the TRL6 prototype on Dassault´s CATIA turbine design framework. Currently, all management team members still have another occupation, meaning project HACE is carried forward on an after-hours basis.

4.3 Engine efficiency: first evidence

The first numerical calculations conducted by Sogeti High Tech for a Taiwanese site with an average wave height of around 1.5 m are very promising. The 3 arm engine with 1.16 MW notional power is expected to yield more than 5500 MWh per year. The engine has been sized such as to optimize the set-up for a maximum air speed of 150 m/s in the air container. This level can be considered as a cut-off level of the electrical parts of the engine, though the other components are able to generate higher power levels. This calibration methodology explains why the expected capacity factor of the engine is higher than those of other WEC systems. The current state of the numerical projections for a 1.16 MW and an 11.6 MW engine are shown in the following table:[103]

Table 9: HACE LCOE estimations (Atlantic Ocean)

[103] The LCOE calculation has been performed with an interest rate of 8% and a period of 20 years.

Notional Power	Dimension (m)	Price (million €)	Ratio € per w installed	Capacity Factor	LCOE (ex. grid connection)
11.6 MW	3 x 6 x 100	25	2.5	54%	112 €/MWh
1,16 MW	3 x 6 x 30	3	3	54%	129 €/MWh

The calculation above uses the standard methodology, which consists of discounting the production amount using the same interest rate as applied to the real cash flows. This makes the value independent of the leverage ratio, while this one has an impact on the profitability of a specific project. In addition, the value is dependent on the period considered. The longer the period, the smaller the value is. The period of 20 years considered in the above calculation is conservative since the engine is constituted nearly in its entirety of standard components. Repair and maintenance are estimated at 5% of the device costs, so the device could be "replaced" once in twenty years. The LCOE value of offshore wind parks is expected to reach approximately 140 €/MWh by 2020.[104] Tidal power is expected to reach levels around 100 to 150 €/MWh once 1.5-5 GW of cumulative capacity has been installed and economies of scale reduce the current costs of implementation.[105] Wave energy LCOE predictions similarly foresee an aggregated amount of capacity of 2.5-10 GW before reaching an LCOE level of 100 €/MWh.[106] Although the grid connection costs are not taken into consideration in the calculation above, it proves that HACE can be competitive starting with the first devices installed, provided the forthcoming tests confirm the value of the capacity factor. The reason for this cost advantage lies in the standard components used. Since most of the parts are issued from aluminum boiler engineering, the engine will profit from currently low material prices from the start.

At present, the engine is making progress in the area of chaotic waves with low height above 30 cm. The aim is to maximize the range of useful wave heights and so qualify the engine as well for lower energy sites close to the coast. Another interesting result is the surface needed to produce the electricity. If we compare to off-shore wind power production, for example of the Alpha Ventus wind park, we obtain following results:

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104 (Offshore Wind Cost Reduction - The Crown Estate, 2012), p. vii

105 (2014 JRC Ocean Energy Status Report, 2015), p. 30

106 (2014 JRC Ocean Energy Status Report, 2015), p. 43

Table 10: Comparison Off-Shore Wind to Wave Energy: ratio production to area

	Alpha Ventus	HACE 1 MW engine
Yearly production (MWh)	248.000	5.256
Area	3,8 km²	11.310 m²
Area per MWh	15,32 m²	2,2 m²

So from the point of view of the required space to meet a certain electricity demand, the HACE solution is seven times less demanding as an off-shore wind park. The German island Sylt, for example, has a yearly power consumption of 170 GWh. This demand would be met by thirty 1.16 MW engine or three 11.6 MW engine if we suppose the same capacity factor of 54%. We probably have to lower the value of the capacity factor because of the bathymetry of the site, but even if five of the bigger engines were needed, the surface this would require seems to be very acceptable. From this point of view, the engine is predestined to assume a major part of the electricity production of islands.

4.4 HACE in the current landscape of wave energy converters

In order to evaluate the potential of the HACE concept, it should be compared to the other solutions that are currently already in use or in development. Five main engines have been identified with these criteria: the CETO from Carnegie, the engine of Marine Power Systems, the Penguin from Wello, Albatern’s WaveNET and the Wave4Power buoy. Besides the pure production numbers, there are some cost factors which will influence the potential of cost reduction due to future development of the considered engine. The main pure cost drivers identified are the onsite installation and transportation costs, the grid connection costs, and repair and maintenance costs. For the future profitability of the technology, the costs involved by adaptation of the engine to the site conditions, the potential of economies of scale and the ability to be part of an integrated marine policy are also important. These issues will be addressed in the continuation of the current point. In order to complete the strengths and weaknesses analysis, the different strategies and objectives of the technology providers will be highlighted in a subsequent section.

4.4.1 Installation and transportation cost

If the proportion of the transportation and installation cost of the engine in the total cost is high, then there is reduced potential for economies of scale, since they cannot be reduced at all. These costs are mainly driven by the size and transportability of the engine. Vessel cost can range from € 5000 per day for a small vessel to € 150.000 per day for big vessels necessary to carry large and heavy engines. The transportation and installation costs are usually very high in the tidal sector, where heavy turbines have to be installed on the seabed.

- The CETO is a submerged engine which requires a foundation on the ground and special mooring technique, unique to the engine. This engine is obviously the most expensive to transport and install.
- The engine from Marine Power Systems can be dragged by a small vessel, so is economic from that point of view. Nevertheless, the engine has to be fixed to the seabed as it is submerged when operating.
- Wello´s Penguin is floating by itself and thus it can also be dragged to the site. As the engine floats, it does not need to be fixed to the seabed with strong foundations as the CETO, for example, does. So the transportation and installation costs of the Wello engine are kept as low as possible.
- The Wave4Power buoy does not float like a boat and is relatively large, about 45 m, so it has to be carried, probably by small vessels, though these may have to be equipped with a powerful crane. Mooring on the seabed is done in similar way to weather and navigation buoys.
- The WaveNET developed by Albatern is designed in modules, part of the array of buoys. Each module can be carried as deck cargo by small vessels. A powerful crane is, however, needed to float the system.
- The HACE floating module engine can be dragged as well with a small vessel. The three arm engine can be transported by pieces by a small vessel. The mooring is dependent on the site. Special mooring techniques dependent on the depth of the site are under development and will be patented. HACE made first contacts with the Farinia group, which already provides ballast techniques for tidal turbines. The mooring will be more complex if near to shore conditions are prevalent. Ideal conditions are a depth of 30 to 35 m. The mooring costs of HACE should though be amongst the cheapest of the considered engines, because the engine is lightweight compared to the others.

In summary, while the CETO´s installation costs may be a problem to obtain economies of scale for the solution overall, the other solutions seem to be relatively economic with regards to the installation costs. This issue may be decisive when comparing wave energy to tidal energy where, in general, the installation costs are a high proportion of the overall CAPEX cost. The installation cost for a tidal site are, on average, 48% of the device cost compared to 21% for a wave energy project.[107]

4.4.2 Grid connection cost

These costs are usually not controlled by the technology provider. However, they are still dependent on the concept since they depend on the distance to the coast, the amount of engines to be connected and the type of connection used. From that point of view, all systems compare to each other when considering an off-shore connection. The Wave4Powers buoys may have higher connection costs because of the amount of buoys that have to be connected together before being connected to the grid. The HACE off-shore engine version has an advantage since the rated power per engine is high compared to the other solutions. The CETO 6 is targeted at 1 MW notional capacity, which is the same as the current version of the penguin. So compared to the 11.6 MW HACE engine, an array of CETO engines would need ten times more interconnections on the sea bed. The Marine Powers System has basically the same power than the HACE engine. The WaveNET is currently scalable to a 750 kW unit. Bigger engines are in development.

4.4.3 Operation and maintenance cost

These costs are not disclosed. According to the Ocean Energy Systems survey, they are about 30% of the LCOE.[108] Still, there are some remarks we can make about expected operation and maintenance costs. The submerged systems, such as the CETO or the Marine Power System device, are obviously more cumbersome to repair if this is necessary. They have to be brought to the closest harbor to be reviewed. This means transportation costs and a longer production disruption period. The same holds for the Wave4power, the WaveNET buoys and the Wello, which also have to be brought back to the harbor, but with less effort. Finally, the HACE concept foresees a highly modular system. Any part of a water column can be exchanged without stopping the engine from working, since there are enough other columns to continue producing. Even parts of the water columns themselves can be replaced on site. Of course, a problem with the turbine or the generator will lead to production intermittence. But

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[107] (International LCOE for Ocean Energy Technologies - Ocean Energy Systems, 2015) pp 22-34

[108] (International LCOE for Ocean Energy Technologies - Ocean Energy Systems, 2015) p.34

these parts can also be exchanged on site in order to minimize the efforts and costs involved. Since the air container, the turbine and power generator are above sea level in a closed area, it is possible to stock replacement parts in the engine itself.

4.5 Flexibility of concept, range of usage and future-proofness

As mentioned above, the wave resource is not evenly spread through the sea area and the marine territory is split amongst several areas reserved for a certain type of usage, like shipping, aquaculture or offshore wind energy generation. Thus, the access of these different areas may be restricted. Consequently, the ability of the concept to adapt to different physical conditions, along with its ability to be integrated into other facilities will be an advantage compared to other WEC solutions. In addition, the possibility to generate swift economies of scale in the future will enhance the viability of the concept.

4.5.1 Adaptation to the site condition

As there are a number of different sea conditions depending on the depth and the geographical location of the site, it is necessary to adapt the power curve of the engine to the site conditions. Different strategies can be implemented to solve this problem. It would be possible, for example, to develop several engines, each of which would be used in different site conditions. The second strategy would be to adapt the engine to the site conditions on demand. The concepts considered can be differentiated into two groups. The CETO, Wello and the Engine of the Marine Power Systems convert the wave power by means of mechanical parts. Adaptation to different sea conditions may lead to the use of different mechanical parts. This may lead the potential of economies of scale being reduced once commercial maturity is achieved. The Wave4Power buoy can be adapted to different wave conditions through calibration of the hydraulic pump. The WaveNET array of buoys is intended to be productive in a large range of wave conditions, so no adaptation is necessary. It is possible to adapt the power curve of the HACE engine by changing the aerodynamic profile of the air compartments, the valves and the characteristics of the turbine. The only mechanical changes possibly involve the turbine. In fact, there will probably be two types of set-ups, one for a standard small engine, adapted to most sites, and one tailor made solution, where the aerodynamic, diffraction and generator components will be adapted to the site. The power curve will then be optimized via numerical optimization of the aerodynamic profile, which has only a cost in terms of manpower, but does not change any mechanical part of the engine, so there is no hurdle from that side to generate economies of scale.

4.5.2 Integration into global marine policy and activity

The regulation of the sea resources often involves an interaction of different body of regulations concerning shipping areas, fishing areas, port and coastal areas, as well as regulations related to off-shore power generation issues, such as grid connection. One of the claims of the Ocean Energy Forum is, therefore, to develop a European wide common licensing guidance.[109] In any case the ability to combine the power production with another marine activity should be considered as a potential advantage, at least with regards to the licensing procedure. Considering the different Ocean Energy technologies, only the technologies operating at the sea surface could claim a joint usage with aquaculture and marina infrastructure. Amongst these technologies, HACE is the most promising concept, since its modularity allows the integration of the engine in the infrastructure of marina jetties and fish farms. This aspect of multi-use of space in the marine economy has been identified and addressed by MARIBE, a Horizon 2020 project.[110] Other multi-usage concepts of wave energy have strictly limited their usage in combination with off-shore wind farms. However, it remains to be seen if a good off-shore wind site is as well a high potential wave site. Especially when planning the wind farm, one is probably not happy to face high wave forces inducing higher foundation costs. Nemos, a German start-up is currently developing an engine to be used in wind parks[111] with foundations on the seabed. Though not a primary focus of the HACE concept, its ability to run within a large range of wave height, could make a joint use with off-shore wind turbines significantly more profitable than the only use of wind energy. The engine with multiple arms, in particular, could have a stabilizing effect on floating foundations for wind turbine, if integrated into the concept. The turbine could be located at the center of the engine.

4.5.3 HACE cost of production and economies of scale

The external production costs of the engine, once the conceptual work is done, are for the most part made up of material and boiler work for the water columns and the air compartments, the costs for the turbines, generators and electrical parts, and various costs related to the aforementioned. These various costs do include digital equipment for remote surveillance of the engine. Valves, turbine components and the structure itself will be monitored. In addition, there will be radar, audio and visual signalization of the engine to avoid any collision. In some cases, depending on the type of fish prevalent to the region, there will be a net protecting the submerged structure. Internal

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[109] (Ocean Energy Forum Strategic Roadmap, 2015), p.9

[110] http://maribe.eu/

[111] http://www.nemos.org/

costs include human resources and the machinery necessary to treat the material against corrosion, thanks to a technique developed by ENSAM, and to assemble the engines. Since aluminum is a very common raw material, economies of scale will be available very quickly when increasing production numbers. Turbines and valves though, may not generate economies of scale so quickly since some technological developments can be expected in the first generations of the engine. The first turbines will be realized in 3D printing and afterwards produced by casting.

4.6 Strategies and objectives.

4.6.1 Carnegie

Carnegie´s CETO is the least flexible technology considered in the current analysis. Carnegie is, however, soundly funded through its IPO on the Australian stock exchange. AUD 118 million have been spend to date on CETO according to their CEO.[112] In addition, CETO is the most advanced solution for the time being since Pelamis could not secure another round of funding, despite being part of the ESB Westwave project. The financial soundness of the company is a significant advantage when talking to utilities, project developers and public authorities. Carnegie’s strategy is aimed at taking advantage of that situation. It managed to secure a first license agreement with Edf énergies nouvelles, a business unit of the French utility company, EdF. The company is emphasizing on the European market because of strong government support, feed-in tariffs, grants, abundant wave resources and availability of the supply chain. There are currently five grid-connected, pre-consented and developed sites either operating, in construction or under development. At the same time, Carnegie is considering early commercial implementation of its technology at islands or off-grid coastal regions. The reason here is obviously a high local electricity price. Sawyer’s strategy is to get public support for the first generations of CETO implementation in order to realize economies of scale that would allow CETO to be price competitive.

4.6.2 Marine Power Systems

The WaveSub, the engine developed by Marine Power System, is still at the prototype stage. They have secured GBP 2 million of EU funding for testing a 1:4 scale prototype. They are expecting early commercial implementation in 2018. There is so far no observable strategy besides continuing to secure public EU or Welsh support in the current development stage.

[112] Presentation at (Ocean Energy Europe - Tim Sawyer, 2015)

4.6.3 Wello

The Penguin device was first connected to grid in Orkney in 2012. Wello is currently testing - in addition to the already connected sites - a 1:5 scale Penguin II prototype at Plocan test site off the coast of Gran Canaria. Since 2014, they have been in a cooperation agreement with the Scandinavian utility company, Fortum. Their joint € 25 million project at the UK site of Hayle is aimed to develop a utility scale solution. The joint strategy is the same as Carnegie´s. The difference, however, is that Wello relies on the support of Fortum, which will obviously be the first developer in case of successful results of the demonstration project ending 2020. The investors in Wello, apart from Fortum, include Finnvera, a specialized finance company owned by the state of Finland, and VNT management, a venture capital management company focusing on renewables. Wello thus has secured solid financing for the current demonstration phase of its engine.

4.6.4 Wave4power

Wave4power is launching a demonstration site at the Runde Island, close to Norway's west coast. Wave4power secured direct funding from Almi Invest, a Swedish regional investment company, and Per Selden Fastighets AB, a Gothenburg based real estate company. Similar to MPS, there is no observable strategy yet.

4.6.5 Albatern

A first demonstration array of the WaveNet has been deployed at Isle of Muck, off the west coast of Scotland. Funding partners to date include public Scottish authorities. Albatern has identified four different markets for its engine:

- Aquaculture: there are currently two demonstrator projects with Marine Harvest and Scottish Salmon company.
- Island and remote communities. No project so far.
- Offshore platforms for their own power consumption. No project so far.
- Utility scale projects: Albatern´s roadmap sets a target of 100 MW array by 2024 with an LCOE of GBP 100 – 150 per MWh.

To conclude the introduction of the HACE concept, we have summarized the comparative situation in the following table before progressing to build a business case in the next part:

Table 11: WEC producers - comparative analysis

	Assumptions made about industry	**Objectives and Strategy**	**Strengths**	**Weaknesses**
Carnegie	Projects only realizable through public support yet – privately funded projects only after economies of scale	Achieving economy of scales through subsidized projects – secure partners and licensees of international dimension Special focus on islands	Financial strength First licensee EdF Engine closest to maturity High credibility perceived by public authority	The concept induces own specific supply chain – economies of scale needs high number of installations
Marine Power Systems	As above	Reaching lower LCOE of 10p /kWh (ex. grid connection) with generation1 device in 2020	Secured public funding Engine installation and maintenance costs are low Economies of scale to be reached rapidly	Submerged engine so usage limited to utility scale projects on offshore sites far from the coast
Wello	As above	Fortum´s objective is deployment of large wave power parks – therefore improve performance of 1 MW engine till 2020	Financial strength through involvement of Fortum	No statement concerning LCOE or projected economies of scale yet

Table 11: (Continued)

	Assumptions made about industry	**Objectives and Strategy**	**Strengths**	**Weaknesses**
Wave4power	As above Specific demand from off-shore energy consumers	Launch of demonstration site for proof of concept	Secured public funding Small size power generation for off-shore consumption	No statemet concerning LCOE or economies of scale
Albatern	As above Specific demand from off-shore energy consumers	Working on a utility scale project with LCOE target 100 £/MWH Until then off-shore electricity consumers Islands a focus as well	Secured public funding Small size power generation for off-shore consumption	Economies of scale expected to be material only by 2024
HACE	As above Specific demand from off-shore energy consumers Joint use in Marinas and for near shore erosion protection	Working on a TRL 6 Prototype for proof of concept Islands as well a focus	Technical concept theoretically able to achieve faster reasonable LCOE. Engine adaptable to different site conditions and uses through modularity First contacts with island´s public authorities	Early stage of development No funding secured so far Development on after work basis Strategy and range of activities not clear yet

			(Seychelles, Philippines…)	

Part 5 HACE: Business Case and Value Proposition

Until now, we have been primarily focusing our attention on the economic value of the technology, although other aspects may be determinant of the success of a company. Indeed, considering more in detail the progress made by renewable energy, the only technology on track is Solar PV.[113] This is remarkable, especially because of the high proportion of residential and commercial distributed solar PV production. This fact may suggest that there is more value in the product renewable energy production than solely the price of the power produced. We shall nevertheless complete our financial analysis of the HACE technology before considering other alleged non-economic aspects.

5.1 Financial analysis

The investment decision in the development and implementation of a prototype is a challenging question in the context of renewable energies in general. The prototype results, which are important for the profitability of the technology, can be summarized in the capacity factor that the development team manages to reach with a given cost structure. The development phase of an engine until commercial maturity is usually evenly split into several prototypes of different size in order to minimize overall costs, with each prototype contingent on the test results of the preceding prototype. In that situation, the investment in one prototype can at each stage of the process be considered a binary option. Indeed, once the test results of the prototype are known, one has the option to pursue the process and finance the next prototype or to abandon the project. This iterative process can last until the last prototype before commercial production, where a final decision to launch production has to be taken. The methodology usually used in financial decision making under uncertainty is a decision tree approach[114]. Starting from today each prototype milestone is considered as a point in time with different outcomes, these outcomes being contingent on what has happened so far, i.e. dependent on the precedent results. It is possible to use this approach if the steps in the prototype test procedures are clearly defined in advance, especially concerning the actions triggered by possible outcomes. Though a very interesting and challenging task, the detailed examination of the test procedures would be by far beyond the scope of the present analysis.

However, in order to pursue the analysis with reasonable explanatory power, the prototype phase will be considered as one process with one-time step, providing an

113 (Tracking Clean Energy Progress 2015, IEA, 2015) p. 24

114 (Uwe Götze, 2015) pp 270 - 274

achievable capacity factor as a result of the tests. To be more realistic, a probability of occurrence will be attached to a given capacity factor.

In fact, the prototype or prototypes should provide us with more information in the specific case of wave energy conversion. In this context, it is necessary to provide a reliable power curve as a bi-variate function of the wave height and period distribution. Ideally, the tests should provide a power curve for different reference sites. In the present case, we would be interested in a near to shore site with lower resource abundance, and an off-shore standard site. Once the values for the power curves are reliable, the profitability of a standard site can be evaluated by using standard calculations providing average production numbers. These results, combined with the current European feed-in tariffs topology and the projected economies of scale, should provide the estimated sales figures for the coming years. Recalling the analysis performed in the second part of the Thesis, it is necessary to consider two cases at this stage. In the first stage, the profitability of projects benefiting from available support schemes should be evaluated using costs with no or early stage economies of scale assumptions. In a second stage, in order to estimate potential sales figures when public support will be only poor or even inexistent, one would have to compute the risk adjusted present value of the reference project or the risk adjusted rate of return in order to estimate potential sale figures. At this stage, a major part of expected economies of scale can be assumed to have materialized, since a number of projects should already have been installed, otherwise the technology would not have proven to be economically viable with public support and thus not previously developed.

After having determined the achievable sales figures for a given capacity factor, one should calculate the corresponding profit generated by the company. In fact, this is a more complex task than assumed in the statement above. Indeed, before estimating sales and profit numbers, one should define a business case and a strategy corresponding to the technical abilities proven by the prototype results; the capacity factor and cost structure. At the end, the potential investor would then evaluate the value of an investment in the company using standard valuation methodologies. One could use, for example, the expected return value, combined with the standard deviation of the return as a risk measure in a way in accordance with the internal rules, for an institutional investor, or with the personal preference, for an individual investor. This is a very complex multi-dimensional problem. In this multiple stage process, a lot of assumptions and simplifications have to be made in order to provide useful information. In addition, we still have not issued any value proposition or elaborated any business case so far, but merely are in the process of investigating the question of whether HACE has the chance of being competitive compared to other renewable energy technologies. Remember the well-known image of the elevator pitch. At the current stage of analysis, the building should rather be very high to have the chance of convincing your interlocutor of HACE’s profitability and unique selling proposition. Maybe you will even end in the underground levels, if this image is abided by. In addition to this, an investment proposition has to be formulated on the basis of the results of the financial analysis. The methodology for that purpose involves a two-step analysis. In the first step, as mentioned above, we consider a number of possible outcomes of the prototype phase. Outcomes are represented by capacity factors, which imply LCOE depending on the cost structure. For the first four exercises until 2020, we consider a cost structure given by the marginal cost of the fifth engine. This causes low margin for the first engine sold. This strategy is retained to obtain an attractive LCOE in comparison to the competition. We then estimated the number of installations sold until 2020 in accordance to the LCOE achieved. With this input, we will be able to estimate roughly the revenues and the funding needs in the different scenarios. In 2020, we suppose the investor will either sell his stake in the company or participate in the third funding round, which should be considered at that time to accelerate the expansion of the company. In order to determine the return on investment at this step, we use a common financial ratio, the price-earnings ratio. In fact, it would be necessary to develop the whole financial analysis for the period after 2020. As there are a lot of uncertainties about the feed-in tariffs and thus about the business model, we should try to use a meaningful and sensible method for this task. For this purpose, we will use a metric that takes into consideration the projected LCOE at the end of 2020, which then takes into consideration the economies of scale achieved until then. In order to do so, we will attribute a price-earnings ratio in the different scenarios that increases with the competitiveness of the company at that time. This means the lower the LCOE, the higher the PER one can expect from the company.

5.1.1 Economies of scale

In the first step, an estimation of the cost breakdown of the installation of the engine, dependent on the numbers of engines per year sold, is performed using the provisional numbers provided by HACE for the first four years of the exercise. Their assumption is to produce a total of 10 engines in this timeframe. The numbers are then extrapolated using assumed economies of scale when producing 10, 20 and 100 units per year. The starting point uses the values for a production of the three first engines. The assumptions made are as follows:

Project development costs are estimated at 4% of total costs for the first units. They should slowly decrease after the first projects because of the "learning" effects, but still account for approximately the same proportion of the overall costs, since those will decrease as well. Transportation and installation costs are supposed to stay the same, because no economies of scale can be expected. Mooring costs will only decrease later because special anchorage techniques will be developed and so economies of scale will only appear late. Boiler work costs are supposed to decrease slowly when increasing the number of units produced per year. Ultimately, a 35% price discount is expected due to economies of scale in the production process of the supplier. The current price of aluminum is at its lowest for a long period of time. But, since the material cost for fifty tons of aluminum is below a hundred thousand euros, its proportion of the boiler work is very low, meaning a significant price increase due to the aluminum price is unlikely. Economies of scale of turbines, generators and valves production will only appear late, when their development is finished and when the turbines will be produced by casting. Ultimately, just over 25% economies of scale is projected. A cushion of 20% of the supply cost from external provider is taken into consideration for the first prototypes. This cushion is reduced linearly to reach 10% when a yearly production of 100 units is reached. The machinery, infrastructure and building costs are decreasing linearly with the numbers of units produced at the beginning. Sometime, when reaching 20 units per year, the plant size has either to be increased or another assembly unit has to be implemented. Economies of scales will materialize soon on salaries, especially for management and administration. Salaries of the productive head counts are supposed to decrease until the floor value reached when 20 units are produced a year. The last item, which is a cushion, including the margin earned by the producer of the engine, is supposed to decrease until a minimum of € 2 million per unit is reached. The following table illustrates the cost evolution.

Table 12: HACE cost breakdown

Cost breakdown 10 MW engine installation (thousands Euro)	Amount (th. Euro)	%	5 units p.a.	10 units p.a.	20 units p.a.	100 Units p.a.	%
Project development	1,000.00	4%	1,000.00	900.00	810.00	648.00	4%
Mooring	1,200.00	5%	1,200.00	1,200.00	1,200.00	960.00	6%
Transportation & installation	2,500.00	10%	2,500.00	2,500.00	2,500.00	2,500.00	16%
Engine:							
Boiler work	2,500.00	10%	2,375.00	2,256.25	2,030.63	1,624.50	11%
Turbines	5,000.00	20%	5,000.00	4,850.00	4,607.50	3,686.00	24%
Generators & electrical parts	1,500.00	6%	1,500.00	1,455.00	1,382.25	1,105.80	7%
Valves & couplers	900.00	4%	900.00	873.00	829.35	663.48	4%
Miscellaneous (20% of external costs at beginning to 10% at end)	1,980.00	8%	1,759.50	1,509.48	1,238.96	707.98	5%
Machinery, Infrastructure & buildings	3,000.00	12%	1,800.00	900.00	630.00	504.00	3%
Salaries management & administration	1,500.00	6%	900.00	585.00	351.00	280.80	2%
Salaries production staff	1,500.00	6%	900.00	720.00	504.00	504.00	3%
Other	2,420.00	10%	2,258.80	2,000.00	2,000.00	2,000.00	13%
Total Engine	20,300.00	81%	17,393.30	15,148.73	13,573.69	11,076.56	73%
Total cost per unit	25,000.00	100%	23,334.71	19,748.73	18,083.69	15,184.56	100%

The values estimated seem to be reasonable when comparing them to current numbers from wind turbine producers and projects. The revenues generated over the years 2012 to 2014 per MW produced are about € 1.15 million for Nordex and € 1.20 million for Vestas[115]. Since both company offer installation and turnkey projects, these values slightly overstate the amount paid for the engine only. In the projection in table 10, economies of scale drive the cost for the engine down to € 1.1 million per MW. The production of a total of 1000 MW would represent about 70% of the annual production of Nordex in 2014. Comparing the complexity of a wind turbine and its production process to the HACE engine, it seems very reasonable to estimate a similar cost of € 1.1 million per MW installed.

5.1.2 HACE technology risk mitigation

As pointed out earlier, the correlation properties of a power plant using a certain fluctuating renewable energy source to a power plant using another renewable energy source have an influence on the expected return one should require on the investment. In order to give an idea of the properties of HACE, a comparison to the photovoltaic production shape has been performed. For that purpose, the summer and winter wave data and irradiation data of the exemplary site of Antifer on the west coast of France

[115] See Appendix B

have been used. The wave data used is the frequency table of wave height and period, cumulated respectively for the summer and winter months[116]. Unfortunately, a more detailed data, which would have given more explanatory power to the analysis, is not freely available. There are some real time data of boys available, but these have to be collected over time, which was not possible in the timeframe of this study.[117] In order to derive the power production of the HACE engine, the frequencies of the wave height were first added over the different wave periods to obtain an overall frequency. In a second step, these values were multiplied by the corresponding value of the power curve provided by HACE, which does not differentiate the wave period, but gives an average value for the corresponding wave height. The values in the table below reveal a winter production about 10 to 15% higher during winter time.

Table 13: Antifer Summer / Winter Wave Resource

Wave Height	0.5	1	1.5	2	2.5	
HACE power curve (1 kWe)	349	558	684	798	770	Total
Occurrence summer	64.55%	23.82%	7.96%	2.57%	1.10%	100.00%
Summer production (kW)	987	583	238	90	37	1,935
Occurrence winter	43.01%	27.68%	13.90%	7.03%	8.39%	100.00%
Winter production (kW)	658	677	416	246	283	2,279

The electricity produced by 1 kWe of a photovoltaic installation is as shown in the table below:

[116] Data is freely available at http://candhis.cetmef.developpement-durable.gouv.fr/campagne/?idcampagne=67c6a1e7ce56d3d6fa748ab6d9af3fd7 accessed 12th December 2015

[117] See for example Saint Jean de Luz: http://candhis.cetmef.developpement-durable.gouv.fr/campagne/?idcampagne=6c8349cc7260ae62e3b1396831a8398f accessed 12th December 2015

Table 14: Antifer PV Production - source PVGIS-CMSAF[118]

Nominal power	1 kW (cryst. Sil.)			
combined PV losses	24.40%			
	inclination 32 deg., orientation 0 deg.			
Month	Ed: aver. daily	Em: aver. month.	Hd: aver. daily sum	Hm: aver. month
Jan	0.79	24.5	1.04	32.1
Feb	1.48	41.4	1.89	52.9
Mar	2.85	88.4	3.66	114
Apr	4.06	122	5.34	160
May	4.25	132	5.61	174
Jun	4.29	129	5.78	173
Jul	4.31	133	5.83	181
Aug	3.82	118	5.16	160
Sep	3.23	97	4.33	130
Oct	1.8	55.7	2.39	74.1
Nov	0.98	29.5	1.28	38.5
Dec	0.68	20.9	0.89	27.6
Year	2.72	82.6	3.61	110
Total for year		992		1320
	Winter	Summer		
Production	260.4	731.6		
irradiation (aver. per day)	1.86	5.34		

PV production is, according to the results above, nearly three times higher in summer than in winter. At the same time, wave energy production is more or less evenly distributed during the day, apart from summer time on near to shore sites where waves height tends to be higher in the night and in the morning. At first glance, the results seem to proof a large complementarity of the two renewable energy sources. Indeed, if we just add the two production figures (in real world one would optimize the ratio, of course) for 1 kWe each we obtain following production figures:

Table 15: Complementarity HACE and Photovoltaic

	Winter	Summer
PV 1 kWe	260.4	731.6
HACE 1kWe	2279.4	1935.0
Base load	2539.84	2666.56

As a matter of fact, if a more detailed analysis of the distribution of the power production of a wave energy converter, in general, and HACE, in particular, confirms

[118] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php accessed 5th December 2015

the above result, the combination of PV and the HACE technology is very likely to be close to the base load profile. Recalling the comments made at the beginning of our analysis related to the expected return of a renewable power project, a combination of PV and HACE technology should be close to a baseload profile and thus require a rate of return close to the one of the “market” portfolio. So adding a HACE wave energy converter to a portfolio of PV power plants is reducing the price risk occurred by the portfolio. Hence, the rate of return required for a project employing the HACE technology should be lower than the one required for a PV power plant. Following this argumentation, the expected return of a HACE project should even be lower than the expected return of the market portfolio, since one would require the expected return of a PV project to be higher than the one of the market portfolio. Though this line of argument is not strictly scientific, even just because the baseload profile is different from the one of the market portfolio, it seems heuristically acceptable to reward the diversification property of the technology and require a significantly lower return on investment than for a PV power plant.

5.1.3 LCOE scenario analysis

Starting from the cost analysis above, we do make following assumptions for the forthcoming calculations. We use an average cost value for our engine of €2.25 million which is a value reached after having produced between 5 and 10 engines, thus this is approximately the marginal cost, including sales margin, of the fifth engine. The discount rate used is 6% instead of the 8% used in the previous LCOE calculation because of the arguments presented in point 2. Another argument in favor of a lower value of the interest rate is the currently extremely low level of interest rates in general. In order to give our analysis enough granularity we consider seven possible outcomes for the capacity factor, from 30% to 60%. The probability of the different outcomes is obviously “skewed” towards the low values of the capacity factor, since it is always easier to obtain lower than higher values.

The results of the different scenarios are shown in the table below. The LCOE according to the capacity factor will determine which European markets will be available for the engine. In the case of a capacity factor of 30%, the LCOE of 157 €/MWh will only be supplanted by the tariffs prevailing in Ireland. With an LCOE of 135 €/MWh, projects in France and the UK will be possible as well. Indeed, the UK authorities will proceed by auctions per group of renewable energy technologies. Wave energy will be in the same group as off-shore wind. So HACE has to be competitive when compared to off-shore projects. This seems to be the case starting with the LCOE at 135 €/MWh since off-shore LCOE is expected to reach 100 to 140 €/MWh in 2020, as previously mentioned.

Table 16: Capacity Factor – Scenarios

Probability of occurrence	19%	23%	16%	14%
Probability to be at or above CF	100%	81%	58%	42%
Capacity Factor	30%	35%	40%	45%
Yearly production per MWe (MWh)	3048	3557	4065	4573
Present Value costs per MWe (thousand of €)	4831	4831	4831	4831
Total useful production per MWe (MWh)	30681	35794	40908	46021
LCOE (€/MWh)	157	135	118	105
Feed in Tariffs above LCOE	Ireland	Ireland, UK depending on CfD auction level, France	Ireland, UK (contingent on auction level), France, Germany (<500 kW)	Ireland, UK, France, Germany (<500 kW)
Number of installations until 2020	2	4	6	8
Average installation cost 10 MW engine (thousand of €)	22,500	22,500	22,500	22,500
Unit sales margin (% of installation cost)	neg.	5%	5%	6%
EBITDA (thousands €) over the period	neg.	4,500	6,750	10,800
Total investment of the period (thousands €)	12,500	12,500	12,500	12,500
Total amortization (thousands €)	3,700	3,700	3,700	3,700
EBIT	neg.	800	3,050	7,100
Maximum external cash amount needed (thousands €)		15,000	12,750	10,000
Equity amount (beginning of period)		10,000	8,000	7,000
Loan amount (beginning of period)		5,000	4,750	3,000
Interest rate		15%	12%	11%
Total interest period		3,000	2,280	1,320
EBT		-2,200	770	5,780
Installation cost end of period (2020 - thousand €)			22,500	21,000
LCOE (2020)			118.09	101.71
PER assumption			3.00	6.00
Market Value of HACE (thousand €)			578	8,670
Proportion of equity				80%
Return on Investment			-93%	65%
Net present value end of period (discounted at loan rate)			-6,797	6,018

Table 16: (Continued)

Probability of occurrence	12%	10%	6%
Probability to be at or above CF	28%	16%	6%
Capacity Factor	50%	55%	60%
Yearly production per MWe (MWh)	5081	5589	6097
Present Value costs per MWe (thousand of €)	4831	4831	4831
Total useful production per MWe (MWh)	51135	56248	61362
LCOE (€/MWh)	94	86	79
Feed in Tariffs above LCOE	Ireland, UK, France, Germany (<500 kW)	Ireland, UK, France, Germany (<2MW)	Ireland, UK, France, Germany (<2MW), Denmark, Norway
Number of installations until 2020	8	10	15
Average installation cost 10 MW engine (thousand of €)	22,500	22,500	22,500
Unit sales margin (% of installation cost)	6%	7%	8%
EBITDA (thousands €) over the period	10,800	15,750	27,000
Total investment of the period (thousands €)	12,500	12,500	12,500
Total amortisation (thousands €)	3,700	3,700	3,700
EBIT	7,100	12,050	23,300
Maximum external cash amount needed (thousands €)	10,000	8,000	8,000
Equity amount (beginning of period)	7,000	5,000	5,000
Loan amount (beginning of period)	3,000	3,000	3,000
Interest rate	11%	10%	10%
Total interest period	1,320	1,200	1,200
EBT	5,780	10,850	22,100
Installation cost end of period (2020 - thousand €)	21,000	20,000	19,000
LCOE (2020)	91.54	81.44	73.02
PER assumption	8.00	12.00	20.00
Market Value of HACE (thousand €)	11,560	32,550	110,500
Proportion of equity	75%	35%	25%
Return on Investment	86%	204%	563%
Net present value end of period (discounted at loan rate)	8,622	34,455	115,545

The expected number of installations is then estimated in accordance with the competitiveness of the LCOE. We recall that the industry is expecting a cumulative capacity of 850 MW by 2020 for ocean energy as a whole.[119] So in the most optimistic case of 15 engines of 10 MWh power, HACE would have a market share of above 17%. We feel quite comfortable with these numbers because - in case the LCOE of the engine proves to be below 80 €/MWH - we believe the overall installed capacity to be then well above 850 MW because of excess demand for the HACE engine. Loan and equity amounts have been adapted to the overall funding requirements induced by the scenarios. Interest rates charged for loans are similarly aligned to the scenarios and their inherent risk. In order to determine a plausible price-earnings ratio, we consider the current average price-earnings ratio in the wind turbine producer industry. The average PER of the industry was at 21.5 on the 10th December 2015[120]. We normed our scenarios using a maximum PER of 20 for the best case scenario of an LCOE at 73 €/MWH in 2020, because we estimate that at that time it will be at a comparable level with the best turbine producer. The values retained are conservative since any potential investor would do the same to be sure not to overvalue the investment. The amount of assumptions and simplifications, however, is quite significant, meaning that the results can only be taken as a rough indication. But nonetheless, there are quite a few interesting conclusions that we can draw from the values in the table:

- In the first three cases, with the highest LCOE, representing 58% of the total estimated probability, the investment does not generate a positive value at the end. In the first scenario, there is no investment carried out after the prototype results since the company fails to generate positive revenues before interest payments and taxes[121]. The second case would generate negative earnings before taxes, while the last one fails to generate a positive net present value after the fourth exercise. In reality, one might continue to operate in the last case if significant progress is expected, either in the capacity factor or in cost reduction. We retain the rule to only proceed with the investment, after the prototype test results, if a positive net present value can be obtained at the end of the period of the four exercises following the prototype test results.

- The proportion of the capital held by the investor is supposed to be variable depending on the outcome of the prototype tests. This is due to the fact that the investor is, by no doubt; rather ready to accept a low stake if the expected return is high. At the same time, HACE has to show it is confident to reach

119 (Ocean Energy Forum Strategic Roadmap, 2015) p.14

120 See appendix C – Financial ratios of wind turbine producers

121 The previously mentioned financial difficulties of Pelamis and Aquamarine Power confirm the high risk associate with technology development at prototype stage

high capacity factor values, and therefore, ready to give up more equity if they fail to reach the target. Such an agreement needs to be put in place to avoid the investor insisting on having a large part of the stake at the beginning, before the prototype has been financed.

- The leverage effect of the LCOE is very high. Indeed, the price competitiveness of the technology is a major factor in the projected sales figures, and thus in the success of the company, at least as long as no other concrete business model has been conceived.

- There is a very high probability to suffer a total loss event from the point of view of the early stage investor. Indeed, an investment after the prototype testing phase would be much less risky. In return, a potential early stage investor may ask for a very high average return on investment. Thus, on the opposite, the technology provider has interest to prove high confidentiality in its projection. From that point of view, it may be advantageous to split this phase in several milestones and investment amounts to lower the amount invested at once, and to increase the validity and certainty of the results. This reduces the probability of total loss at each milestone of the process.

The expected NPV and ROI values and the standard deviations are as shown in the following table:

Table 17: Estimated NPV and ROI profile after prototype test results

Probability of occurrence	58%	14%	12%	10%	6%
NPV	0	6,018	8,622	34,455	115,545
ROI	0	65%	86%	204%	563%
Expected NPV	12,255				
Standard deviation NPV	27,992				
Expected ROI	74%				
Standard deviation ROI	139%				

The expected values are high in spite of the high probability of total loss. This is due to the high extreme values with low probability of occurrence. Additionally, the standard deviation is high for the same reasons.

As the funding of the prototype can be interpreted as a call option on the NPV flows represented above, the option premium should be the value one is ready to pay for the investment after the prototype results are known. In the financial theory, the call option premium is worth the expected value of the pay-out profile at expiry of the option, using the so-called risk neutral distribution[122]. The current case cannot be numerically solved this way since the strike price, the second round investment of the investor after completion of the prototype tests, is dependent on the outcome of the tests. In addition, the option theory assumes that risks can be constantly hedged because of the characteristics of the underlying asset, which is supposed to be liquid and tradeable, and this is obviously not the case here. For instance, the investment in a technology firm like HACE is not easily mitigated as there is limited comparable investment opportunities. Hence, one cannot use the framework of risk-neutral valuation, and so the value of the option remains dependent on the individual preferences of the potential investor.

However, we should still notice that the volatility is due to the extreme positive values and therefore has a positive impact on the value of the option. The economic value of this option is very likely to be much higher as the required amount of € 3 to 4 million for the 1 MW prototype. But ultimately, the investor is left with the metrics given in the table, and, especially with the question how much weight he should give to the total loss event, which we estimated at 58% likelihood. This leads us to the concluding comments on this financial analysis, which confirms earlier observations with regards to potential investors:

- The potential investor should put much more emphasis on the exceptional potential of the technology in the case the targeted capacity factor can be reached. This is obviously the case for an investor who does not have to report to a hierarchy in case of a total loss event. Family offices of wealthy individuals, for example, are responsible of their own money, so do not risk their job or bonus in such an event.

- The investor possibly has a strong interest in gaining a technological edge over the competition. This could be the case for utility companies.

- The support policy of the European Union concerning early stage support does not seem adequate to generate a large impetus for new technology in this area. We reiterate earlier suggestions after the financial analysis performed above. The best way to help early-stage funding is to find instruments limiting the impact of the total loss event.

- This recommendation holds as well for technology innovators who ask for early stage funding. They should take into consideration this point in their

[122] A simple introduction to expectation pricing can be found in (Baxter & Rennie, 1996), p. 4

business proposal. This guides us to the next point discussing non-financial aspects of the technology.

5.2 Business model and value proposition

In the precedent parts of this work, the position of the HACE technology compared to the competition has been extensively investigated. Special emphasis has been given to the financial aspects. If we refer to Porter[123] though, there are mainly three strategies one can follow to convince customers to buy the product: cost leadership, product leadership or differentiation and focus on a narrow competitive scope. So far, we have examined the ability of HACE to assume cost leadership. The following analysis of the potential markets for the HACE technology should either identify niche market segments for a focus strategy or elaborate strategies appropriate to product leadership for a certain broader type of customers. The examination should, in particular, focus on specific non-monetary advantages to customers induced by using WEC, in general, or even better by the specific HACE technology. Especially the success of the PV expansion through retail roof installations and small size power plants reminds of the concept of marketing 3.0, when thinking about possible differentiation aspects.[124] As a matter of fact, this marketing concept approaches the consumer as human being in its entirety, so her or his moral values are addressed as well. Renewable energy obviously carries an image of being environmental friendly and as such a means to make the world a better place. In order to find out if such qualities can be exploited in any market segment, it is necessary to study the market environment in more detail. The political environment has already been examined in part 3 and the positioning of HACE in the landscape of WEC technology providers has been undertaken in part 4 above. The next point focuses on the economic and social aspects of the marine and coastal environment.

5.2.1 Marine and coastal environment

According to Eurostat, a coastal region is defined as region with either a sea border or without a coastline but where more than half the population lives within 50 km of the sea. The EU coastline consists of the Baltic Sea, the North Sea, the North East Atlantic Ocean, the Mediterranean Sea, the Black Sea and the outermost regions. There are a total of 1294 regions in the EU, of which 439 are coastal regions as shown in the figure below.

[123] (Porter, 2004), pp 11-12

[124] (Konzeptionelle Überlegungen zur Vermarktung von Erneuerbaren Energien- Herbes, Carsten; Friege, Christian, 2015), pp 4-5

	Non coastal regions	Coastal regions			Total
		with sea border	without sea border	total	
EU-27	855	375	64	439	1 294
Belgium	30	5	9	14	44
Bulgaria	25	3	0	3	28
Czech Republic	14	0	0	0	14
Denmark	0	11	0	11	11
Germany	372	30	10	40	412
Estonia	1	4	0	4	5
Ireland	1	7	0	7	8
Greece	7	40	4	44	51
Spain	28	31	0	31	59
France	70	30	0	30	100
Italy	41	62	7	69	110
Cyprus	0	1	0	1	1
Latvia	3	3	0	3	6
Lithuania	9	1	0	1	10
Luxembourg	1	0	0	0	1
Hungary	20	0	0	0	20
Malta	0	2	0	2	2
Netherlands	18	15	7	22	40
Austria	35	0	0	0	35
Poland	58	7	1	8	66
Portugal	13	13	4	17	30
Romania	40	2	0	2	42
Slovenia	9	1	2	3	12
Slovakia	8	0	0	0	8
Finland	9	9	1	10	19
Sweden	7	14	0	14	21
United Kingdom	36	84	19	103	139
Iceland	0	2	0	2	2
Norway	2	17	0	17	19
Croatia	14	7	0	7	21
Turkey	53	28	0	28	81
Based on NUTS 2010 and population grid 2006					

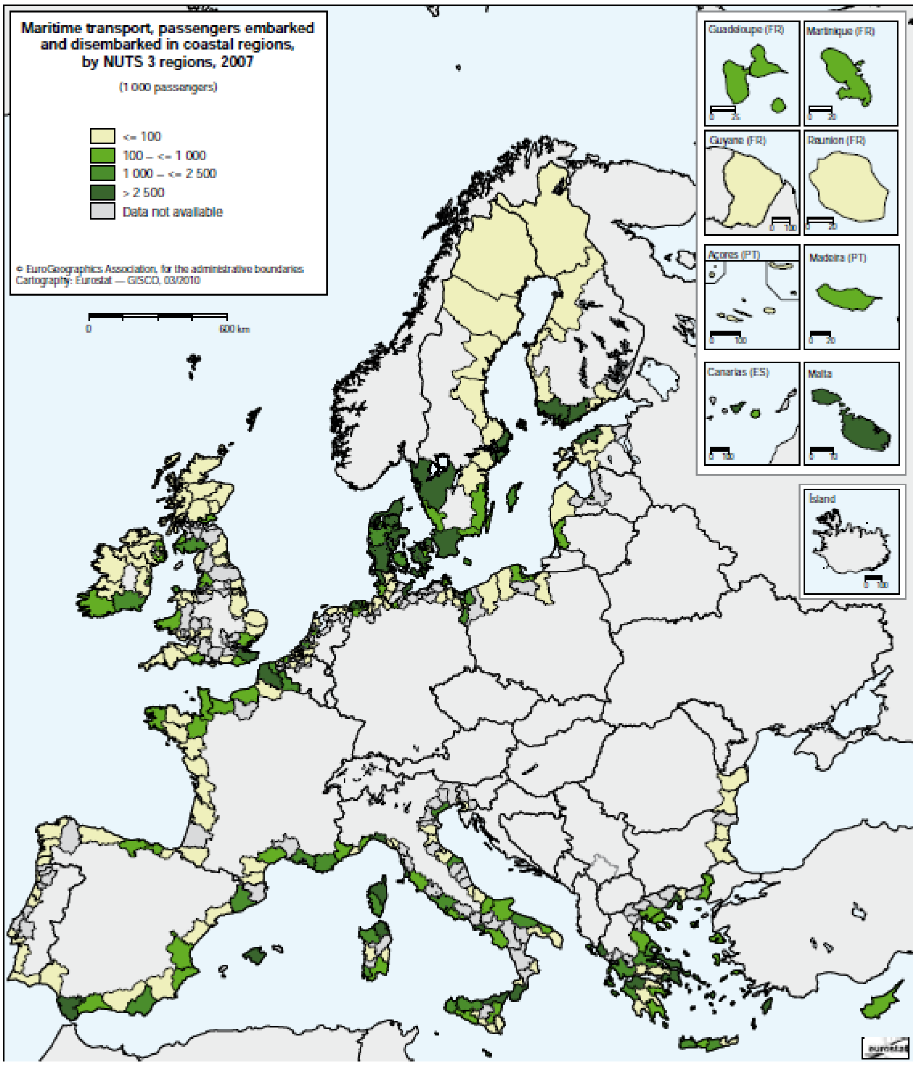
Figure 17: EU-27 coastal regions - source Eurostat

In 2007, 196 million people lived in the coastal regions, which is about 43% of the population of the 22 EU-countries with a sea border. There are 194 cities with more than one hundred thousand inhabitants with less than 50 km to the sea border. The GDP generated by this population amounts to other 30% of the total GDP of the EU. In 2006, approximately 66 million people were employed in the coastal regions, 70% of them being employed in the service sector[125] , though with a high geographic disparity. The density of tourism capacity is concentrated in the southern coastal regions of the EU. A more detailed investigation and categorization of the seafront

125 (Eurostat regional yearbook 2010, 2010), p. 229

cities would be necessary to gain a more precise picture of the local urban conditions. Nevertheless, a total of 1246 Marinas with grid access could be identified.[126]

The passenger transport facilities are similarly disparate. In 2007, there were around 410 million sea transport passengers, concentrated on a limited number of regions, as shown in the figure below.



Source: Eurostat (mar_pa_aa).

Figure 18: Maritime passenger transport - source Eurostat

Maritime goods handled in the EU coastal regions tallied 3613.8 million tons. There is a high concentration in the most important ports, as shown below in figure 19. Seaports have a high environmental impact through their activity and their compounds in general. Cargo vessels and cruise ships, for example, substantially contribute to harmful emissions in the port, due to long berthing times. Port authorities are becoming more and more conscious of this problem and, in particular, about the

126 http://marinas.info/yachthafen/stromanschluss accessed 18th December 2015

public image of port installations and activities. There are several initiatives aimed at more sustainable and environment friendly infrastructure planning. The European Sea Port Organisation, for example, initiated the EcoPorts network, setting-up quality standards with a port environmental review system.[127]

	Gross weight of goods handled, 2010 (million tonnes)	Change in gross weight of goods handled, 2007-2010 (%)	Coastal region (NUTS 3 regions) with the highest gross weight of goods handled, 2010	Port with the highest gross weight of goods handled, 2010
EU-27	3 641.0	-7.5	Groot-Rijnmond (NL335)	Rotterdam
Coastal regions:				
EU-27 coastal regions	3 613.8	-8.2	Groot-Rijnmond (NL335)	Rotterdam
Belgium	228.2	-3.4	Arr. Antwerpen (BE211)	Antwerpen
Bulgaria	22.9	-7.8	Burgas (BG341)	Burgas
Denmark	87.1	-20.6	Sydjylland (DK032)	Fredericia (Og Shell-Havnen)
Germany	276.0	-12.4	Hamburg (DE600)	Hamburg
Estonia	46.0	2.4	Põhja-Eesti (EE001)	Tallinn
Ireland	41.8	-22.7	Dublin (IE021)	Dublin
Greece	124.4	-24.3	Attiki (GR300)	Agii Theodori
Spain	363.5	-14.8	Cádiz (ES612)	Algeciras
France	315.5	-9.0	Seine-Maritime (FR232)	Marseille
Italy	492.2	-8.4	Reggio di Calabria (ITF65)	Genova
Cyprus	7.0	-7.5	Kýpros (CY000)	Limassol
Latvia	58.7	-3.9	Riga (LV006)	Riga
Lithuania	37.9	29.4	Klaipėdos apskritis (LT003)	Klaipeda
Malta	6.0	14.3	Malta (MT001)	Marsaxlokk
Netherlands	538.7	6.2	Groot-Rijnmond (NL335)	Rotterdam
Poland	59.5	13.5	Trójmiejski (PL633)	Gdańsk
Portugal	65.9	-3.4	Alentejo Litoral (PT181)	Sines
Romania	38.1	-22.1	Constanţa (RO223)	Constanţa
Slovenia	14.6	-8.0	Obalno-kraška (SI024)	Koper
Finland	109.3	-4.8	Itä-Uusimaa (FI182)	Skoeldvik
Sweden	179.6	-3.0	Västra Götalands län (SE232)	Göteborg
United Kingdom	500.9	-13.9	North & North East Lincolnshire (UKE13)	Grimsby & Immingham

(1) Ireland, Spain, France and the United Kingdom, data for 2009 and growth rates for 2007-2009; EU-27 coastal regions, latest period calculated using the information available for each Member State (either 2009 or 2010), with the growth rate (2007-2010) also based on this aggregate.

Source: Eurostat (online data code: mar_go_aa)

Figure 19: Maritime Goods handled in the EU – source Eurostat

The Hamburg Port Authority together with the cities authorities responsible for environment and energy, launched the "smartport energy" initiative.[128] The aim of this project is for Hamburg to become a "flagship port" for renewable energies, lowering energy consumption and emissions, and promoting innovative and eco-friendly mobility.

Aquaculture is another important sector of the blue economy. The EU is currently the 8th biggest producer in terms of volume, with 85,000 people directly employed through 14,000 local enterprises. The majority of 90% of these enterprises employ less than 10 persons. Currently, 24% of the consumption of seafood in the EU comes from aquaculture.[129] This proportion is set to grow significantly in the future since fisheries

127 http://www.ecoports.com/ accessed 18th December 2015

128 (smartPort Energy - Hamburg Port Authority, 2013)

129 http://ec.europa.eu/fisheries/documentation/publications/2015-aquaculture-facts_en.pdf accessed 15th December 2015

alone will not meet a growing demand for seafood without endangering the wild fish stock.

Climate change is particularly challenging for European coastal areas. The cost of climate change is estimated at around € 6 billion until 2020[130]. The EU commission adopted a new initiative on Maritime Spatial Planning and Integrated Coastal Management to bundle the efforts and coordinate the application of different policies. Coastal erosion is increasingly threatening the EU coastline. In 2004, about twenty thousand kilometers of coasts faced serious impact.[131] The cost of protecting the coast is high. In the Netherlands, for example, thirty-five million cubic meter of sand are required every year for the protection of the coastline.[132] Special emphasize is given to coastal erosion and innovative techniques to counter its effects. Marcel Stive´s ”sand engine” is worthwhile mentioning as a dynamic solution using wave directions and specific understanding of local bathymetry in that context.[133] The German state of Schleswig-Holstein is spending around € 40 million a year on coastal protection.[134] The island Sylt on its own is allocated € 5.3 million and this is not enough, since a foundation dedicated to its coastal protection has been initiated by local stake holders[135].

5.2.2 Differentiation strategies

With the big picture of the market environment having predominantly been drawn, attention should now be turned to the question of whether product differentiation or a focused market strategy appears more promising. In the following section, we proceed using the common differentiation of retail or business to business market segments. At first, it is evident that the technology provider will not do business with the end consumer of the electricity. Indeed, there is no case where it is imaginable that a consumer would install a HACE engine in his backyard, even if he is the owner of a piece of coast. This means that formally, in any case, we are dealing with a business to business situation

[130] http://ec.europa.eu/environment/iczm/state_coast.htm accessed 15th December 2015

[131] http://ec.europa.eu/environment/iczm/coast.htm accessed 18th December 2015

[132] http://www.welt.de/wissenschaft/umwelt/article134190984/Niederlande-bauen-Straende-gegen-den-Klimawandel.html accessed 18th December 2015

[133] https://www.youtube.com/watch?v=gjQ6lEbsE-I accessed 18th December 2015

[134] http://www.schleswig-holstein.de/DE/Landesregierung/LKN/_documents/aufgabenZustaendigkeiten.html%20Küstenschutz%20 accessed 18th December 2015

[135] http://www.sylt.de/entdecken/stiftung-kuestenschutz.html

Nevertheless, one could consider small urban entities and marinas as retail-like customers. Indeed, recalling the importance of cooperative initiative in the growth of renewable power generation in Germany, it seems logical to consider these kinds of entities as retail or small business customer. As mentioned before, a more detailed analysis of these small urban entities is necessary to judge if a substantial demand can be expected in this market segment. The owners of marinas, and so the urban entities close, or contractually tied to them, should be inherently interested in the eco-friendly image related to renewable energy. In the current situation marinas are often missing space for berths, in particular during short periods of time at high season. There is as well a demand for electricity from the boats during their anchor time. In larger marinas there may be other services as restaurants and bars which require electricity. So there is a potential market for a jetty that combines the HACE engine with a normal jetty. If we consider a 3 arm version of the engine moored at a certain distance of the existing marina, additional anchor places could be implemented at the side of the two arms were the wave is coming out of the engine. This would allow the marina to significantly increase the number of anchorage places without having to increase the coast space used, which may be expensive or even not available. The revenues induced by the product would then be twofold: the anchorage dues and the proceeds of the electricity sold. Hereby the electricity could first be sold to the consumers in the marina, probably at comfortable price level, the excess being sold to the grid at local feed-in conditions. In this situation the investment costs are shared for two different purposes, so that the capital expense cost allocated to the electricity producing part may be lower than for a HACE engine totally dedicated to the power production.

In the same line of ideas, large ports like the one of Hamburg have an inherent interest in finding eco-friendly solutions to their multiple environment challenges, as the smart port initiative confirms. Since the space for renewable energies in port areas is limited, there is only limited potential for on-shore wind turbines. PV installations are possible on the buildings but do not cover the electricity demand during the night. Since the HACE technology is more flexible and uses less space than off-shore wind power plants, its integration in a global set-up plan should be significantly easier than for off-shore wind. In this configuration there is no share of capital expense since the technology is exclusively used for electricity generation. Nevertheless, the electricity provided to meet the demand inherent to the port activities can certainly be priced at comfortable level, well above wholesale market price. The HACE engines could even be installed by the local utility, which would in return get the proceeds from the electricity sold to the different consumers located in the port. In the specific situation of the city of Hamburg, the grid has been bought back by the city[136], which proves that there is a great interest of the local authorities to manage the energy production and distribution. This should obviously happen in an eco-friendly way, at least to satisfy the voting population.

Aquaculture is the fastest growing activity in the food industry. In order to comply to the high quality standards required by the European customer, the farming conditions have to be as close as possible to the conditions in freedom. In particular, this implies to locate the farm as far as possible from the coast in order to ensure fresh water quality and sufficient spacing. There are currently considerations to use space dedicated to off-shore wind parks for the aquaculture, since these areas are free of shipping activity.[137] A number of research activities are happening in this area and, since most of the enterprises of the sector are of small size, it needs cooperation platforms to implement research across the different competence areas required. There are several projects related to aquaculture at ttz Bremerhaven for example.[138] The concept of the HACE engine could be extended to a full size off-shore fish farm. The engine would provide all the electricity required for the farming activity. It could even be considered to leave the farm floating and self-propelled by means of the produced electricity. As well cooling and first treatment of the seafood could be assumed off-shore before delivery. In this situation, the conditions for profitability calculations are completely different. The whole set-up has to prove competitive in the context of aquaculture, which means the production cost for the seafood raised has to be at or below market level.

In the context of erosion management, there is still a number of progress to be made and a lot to be learned about the erosion phenomenon to understand how to manage it in a necessary integrated approach. As proven by Marcel Stive´s solution, local characteristics have to be taken into consideration to find an optimal solution. A wave attenuator engine like HACE could be in many case part of an integrated erosion management policy. The usage of the engine would allow lowering the overall cost of the protection measures, due to the proceeds of the electricity produced. In this case, initial investment could be divided in the part dedicated to power production and the one dedicated to erosion management. The proportion attributed to the erosion management would then depend on the attenuation properties of the engine.

[136] http://www.taz.de/!5039819/ accessed 18th December 2015

[137] http://www.deutschlandradiokultur.de/aqua-farming-in-der-nordsee-fischzucht-unterm-windrad.976.de.html?dram:article_id=329242 accessed 19th December 2015

[138] http://www.ttz-bremerhaven.de/en/research/environment/research-projects/1357-flav.html accessed 19th December 2015

5.2.3 Business models

Before identifying potential business cases, there is two situations where the financial conditions do change. Indeed, in the case of a product designed for marinas or erosion protection, the initial capital expense is shared with another usage of the product. In the following the LCOE numbers are computed again in dependence of the proportion of CAPEX assumed by the power producing part of the engine.

Table 18: LCOE in a joint application set-up

Probability of occurrence	19%	23%	16%	14%	12%	10%	6%
Probability to be at or above CF	100%	81%	58%	42%	28%	16%	6%
Capacity Factor	30%	35%	40%	45%	50%	55%	60%
Yearly production per MWe (MWh)	3048	3557	4065	4573	5081	5589	6097
Present Value costs per MWe (thousand of €)	4831	4831	4831	4831	4831	4831	4831
Total useful production per MWe (MWh)	30681	35794	40908	46021	51135	56248	61362
LCOE (€/MWh)	157	135	118	105	94	86	79
LCOE for CAPEX share of:							
90%	150	129	113	100	90	82	75
80%	143	122	107	95	86	78	71
75%	139	119	104	93	83	76	70
70%	135	116	102	90	81	74	68

The previous calculations revealed that an LCOE of less than € 105 per MWh is necessary to generate a positive return on investment. The probability to reach this level was 42%. This time, in the case 25% of the CAPEX can be charged to the second product usage, this value is reached in 58% of the cases. LCOE level below € 80 per MWh can be reached with 16% likelihood according to our estimates.

Table 19: Profitability at 75% CAPEX level

Probability of occurrence	42%	16%	14%	12%	16%
NPV (thousand €)	0	6,018	8,622	34,455	80,000*
ROI	0	65%	86%	204%	388%
Expected NPV (thousand €)	19,104				
Standard deviation NPV	36,551				
Expected ROI	109%				
Standard deviation ROI	137%				

* capped because of reduced potential

The table above draws a new picture of the profitability, since there is a shift of the LCOE distribution towards lower values. It has to be pointed out, though, that in the case considered it remains to be proved that there is the same potential for revenues than in our general considerations, when the market was not limited to a specific segment. This means the NPV value in the most optimistic case above would be overstated if we kept the initial numbers of table 15. We assumed arbitrarily a maximum NPV value of € 80 million in order to keep our argument valid. The revenue profile of the new business case is significantly less risky, since the probability of total loss is now reduced to 42%. It has to be noticed, though, that this probability of occurrence is still very high. At the same time, the expected return on investment is more than 50% higher, though the maximum value case is lower. Further calculations reveal that both business cases would have same expected return if the NPV value of the most optimistic case is about € 38 million. To complete the analysis, it is worthwhile to notice that at some level of NPV value, depending on individual preference or investment guidelines, one would have equal preference for both business models.

In the current case, we can conclude that a differentiation strategy leading to a CAPEX reduced by 25% or more is very likely to improve profitability in a very significant way, so leading to a better value proposition for the investor. However, the probability of total loss remains high, which reduces the number of potential investors. We have identified two possible versions of the HACE engine being able to generate share of initial investment, the solution for marinas and the engine as part of erosion management. The latter would definitively need extensive testing and research before being at commercial level. Therefore, this application, though extremely interesting, should only be considered at a later stage, unless external partners mention their interest (and so open their wallet) to develop such a solution. A strategy could then be to apply for support at the Maribe project under the EU horizon 2020 program. Developing an engine as extensions for marinas seems to be a viable business case. Indeed, looking at the benefits from the customers´ view, the marinas owner, the only negative issue could be the price. But it is imaginable to propose the power producing part of the investment to either the local utility, if there is, or as a preferred investment opportunity to the local population or even the urban authorities. This could be packaged as a public private partnership where, for example, the local authorities grant and assume grid access for a certain period of time, in exchange of which a certain capped amount of electricity is delivered at preferred condition to the local authorities, or the grid operator, if the grid is owned by the municipality. The remaining part of the electricity production would then be sold at the marina users first and, at last, to the grid for more comfortable conditions, in order to generate acceptable returns for the local investors. In such a constellation, any stake holder seems to be on the gaining side and the customer empathy map is on the bright side of live, so to say.[139] The engine concept for larger port infrastructure could be included in this business model, since the distance from shore is similar on one hand, and the port authority is looking at the cost of electricity production in comparison to on- or off-shore wind, in case the electricity has to be produced by renewable energies, on the other hand.

At last, HACE in the context of aquaculture could turn out to be a unique selling proposition, since it would introduce new possibilities for the fish farming industry. The product itself, though, would be a different one than originally conceived by HACE. So the development of a business case exceeds the scope of the present work.

5.3 The way forward

We have so far identified one possible business case that exhibits more or less an acceptable return on investment profile. But still, considering the amount of 1200 marinas in Europe, it is doubtful a potential investor enthuses for that value proposition. As a matter of fact, if we recall the success of retail PV installations and small size on-shore wind farms, we would like to widen the business case at least to the small and medium size municipalities close to the sea border. Especially small municipalities, or their inhabitants, may not have the financial background or the right area available at affordable cost to invest in a PV plant or a wind farm. On the other hand, the local population should have equally high preferences for eco-friendly solutions than the rest of the population. In this context, it is conceivable to use a similar concept than SunEdison does in the area of industrial estate. The concept could be as explained before. The municipality would make the sea space and the grid connection available for a certain period of time to the project. In return, a certain amount of the electricity produced would be delivered free of charge to the municipality, for example to cover part of the consumption of the public buildings. These rights would be laid down in a contract with a special purpose vehicle. The SPV would then finance the engine and get the proceeds from the rest of the electricity sold. Ideally the electricity is consumed locally and paid for, either at feed-in tariff or at retail price level, which should secure a profitable set-up. This business model may be implemented by a business partner, with a certain track record in the project development field, contractually tied by a license agreement. There are enough

[139] The empathy map is a concept due to Osterwalder et al (Osterwalder & Pigneur, 2010) loc 1811 (Kindle edition)

companies in the market with this kind of competence, so there is no need for HACE to build non-core competence.

To a certain extent, we are still in the same position than before our market analysis. We have worked out one possible business case with improved profitability compared to the cost leadership strategy. But this one seems to have limited upside potential. The other applications of the concept, in combination with aquaculture and erosion protection, though extremely promising at first glance, would require even more prototypes and tests before a sound judgment can be made with regards to the profitability. To complete the picture, we remind that we do not have considered the specific market segment of islands, which is very promising for wave energy conversion in general for the reasons already mentioned earlier.

Taking into consideration all the insights we have got so far the next steps in order to issue a business proposition should be as follow:

- Complete the market research for the two important customer segment not yet sufficiently scrutinized: European small and medium size urbanities very close to the coast and as many islands as possible.
- Recalculate the profitability figures completed with the new findings.
- Identify the potential investors taking into consideration the high risk profile of the investment. Consequently, focus on utilities, family offices and foundations. Eventually other technology provider interested for diversification and complementarity reasons.
- Prepare technical planning of prototype tests and link to the capacity factor. Prepare positive scenario of capacity factor “distribution” supported by technical arguments. Eventually define milestones and different time steps to split the investment at different decision points.
- Prepare a business plan addressed at each type of investor and do the same for public or semi-public help schemes like the KIC InnoEnergy where the 2016 Call for Innovation Proposals is open from 15th January to 4th April
- Examine the market participants in aquaculture area. Look for a partner to develop and license a solution in this market segment. The partner could be given a temporarily free license to use the HACE concept in exchange of the prototype funding.
- Do the same for the marina market.
- Establish contact to initiatives related to erosion management. Promote the HACE concept and look for a partner to get funding to test a prototype in that context.

Part 6 Renewable energy innovation, a long journey to success: concluding comments

The innovation process in the context of renewable energies proved to be very challenging, due, in particular, to its dependence on public policy. As a matter of fact, the success of a specific RE technology depends both on the rules governing the electricity markets and the subvention schemes in place. The examination of the European electricity market in part 2 revealed an inherent contradiction in its design. Particularly in Germany, the success of renewables, originated by means of feed in tariffs and the priority right for electricity from renewable energy, led to falling electricity prices in the wholesale market. Periodically appearing excess of supply, due to the fluctuating renewable energy sources like PV and to a larger extend on-shore wind, even generates negative electricity prices. The limit of useful power generation has, thus, been reached in the current constellation. At the same time, the switch from conventional power production to RE is irreversible, due to the lower marginal cost of power generation for renewables. Indeed, new investments in conventional power plants are not profitable in this situation. The recent aspiration of the big German utilities to separate their RE and commercial entities from the rest of the company - new from old in a certain sense - is a symptomatic reaction to this state of facts.

A deeper analysis of possible alternative market design would be of great interest, but exceeded by far the scope of the present work. In particular, the trade-off decision between development of power storage and European grid interconnection is a crucial question, considering the amount of money involved. A market design with no feed-in tariffs, for example, would implicitly provide a market price for storage. This price could then be compared to the cost of implementing high voltage grid connections in a large area. The public authorities are, though, currently opting for a grid extension to avoid mismatches between consumption and supply from fluctuating RE sources. The rationale behind this policy relates to the geographic diversification properties of RE generation.

The lessons to draw for a developer of new RE technology are twofold. Though RE is very likely to win the competition, the profitability of RE projects from a given technology is still dependent, in the short term, on subventions. In a near future, with the absence of FiT, the value of a specific RE project from fluctuating RE source will depend on its electricity generation costs, on its production profile through time and on electricity storage costs, if storage is available at all. For a potential early stage investor in a new technology to be developed, this means, in any case, increased risks. Indeed, the short period of time left to the new technology to access competitive level increases the unpredictability of future revenues, unless the technology can be tied to a business model immune to the future power grid design. Under these circumstances, typical early-stage financial investors like venture capitalist and institutional investors, such as insurance companies and pension funds, avoid this industry in the start-up phase. At the same time, institutional investors are extremely active in the RE project field, taking advantage of feed-in tariffs and the implicit state guarantee attached to them[140]. In this situation, IPPs and project developers remain preponderant in the development of new technologies. The analysis, furthermore, identified the correlation properties of the RE considered to other RE sources, as an important investment criterion to take into consideration, besides usual profitability indicators.

The investigation of the state of the Ocean Energy market confirmed these first deductions. Although the European commission identified ocean energy development as major focus in its target setting, the number of business creations is limited. The European ocean energy industry is organized around the different public support schemes available. Public aid is, thereby, predominantly directed at flagship projects for the time being. Thus, EU grants do in most cases profit to companies with proven track record and creditworthiness. Small innovators are, therefore, forced to secure funding from utility companies, from local public authorities or private investors other than professional venture capitalists. The EIB´s InnovFin is the only direct support scheme of the European institutions. The EIB, though, attributes the seed-money through designated professional venture-capitalist. One can wonder why these institutions would decide to invest into a company in the name of the EIB, if they would not invest themselves according to their investment criteria. The ideal design of direct public support to small innovative companies remains an interesting question to investigate. The US department of energy, for example, organizes the DOE wave energy price competition with $ 1.5 million attributed to the winner.[141] Another possibility would be to introduce financial instruments reducing the likelihood of total loss in case of direct investment in the company. A first loss equity tranche subscribed by the public budget, for example, would be one alternative. The subscription of the tranche could be tied to some conditions, such as the obligation to share test results with other companies benefiting from direct public aid.

[140] Allianz Global Investors, for example, employs a whole department in charge of RE projects. http://acs.allianz.com/files/8214/1389/5075/incubator.pdf accessed 26th December 2015

[141] http://waveenergyprize.org/newsroom/press-release-06jul2015-wave-energy-prize-92-teams accessed 29th December 2015

The conception of a business case for a specific technology, in this context, turned out to be unusually challenging. The HACE showcase highlighted a particularly risky profile for the early stage investment, prior to commercial maturity, when prototype testing is still needed. A thorough evaluation of the profitability of any new renewable energy technology requires considering a scenario where subsidies disappear at some point in the future. This scenario implies a high likelihood of total loss, because of sharply increasing cost requirements in this near future. Even a high expected value of the future company cannot compensate for this, unless the preference profile of the potential investor does not penalize such a risk-reward profile.

At this point of the reasoning, the previous considerations confirm the Bill Gates statement about the exceptional research effort to be made in RE technology. This viewpoint was also adopted by the Breakthrough Energy Coalition initiative launched during the Paris COP21 meetings[142]. Indeed, a joint effort from public and private funding is needed to cross the "Valley of death between promising concept and viable product". Nevertheless, the best format for this effort to reach its aim remains to be determined. The development of HACE´s particular business case pointed at the particular risk profile of the prototype and test phase of the RE technology. In the present Thesis, we have considered a prototype development in one step. The division of the prototype timeframe into several time steps with investment decisions attached at each time step of the process would again change the risk-reward profile – and the amount - of each investment. This time steps should, of course, correspond to technological milestones of the product development. It is conceivable to use this phenomenon for the implementation of an investment platform, for example. This platform would offer different investment possibilities at different stage of the technology development, such as to offer multiple risk-reward profiles. In addition, the platform should provide standard evaluation methodologies, in particular for test results, to make different investment opportunities comparable. It is possible to imagine this platform being partly financed by public money, under the condition that the beneficiaries of this grants share their test results. This platform could even function as a staff recruitment vehicle, since not all companies will be successful, but those who are will need adequate and numerous staff.

Eventually, the examination of possible business cases using the HACE concept revealed some promising properties of the engine. It is conceivable to use the technology as marina extension, or, to provide power for port infrastructure and

[142] http://mission-innovation.net/wp-content/uploads/2015/11/Breakthrough-Energy-Coalition-Investment-Principles.pdf accessed 26th December 2015

activities in near to shore areas. It is, additionally conceivable to develop a product dedicated to aquaculture. Finally, its wave attenuation qualities should be investigated in conjunction with erosion management measures. The last application of the engine points at another inadequacy of the current support policy. Considering the important amount of money engaged for the erosion management, they should be some interaction between the different support schemes regardless of their purpose, such as to identify, or at least permit, to bundle the efforts when a joint application possibility is identified. It is imaginable, for example, that the development of a new technology, which induces savings in other areas of the public budget, would benefit of part of the savings.

Despite this overall still challenging circumstances for people like Jean-Luc Stanek, we shall conclude this thesis with an optimistic outlook. Why not get inspired by the words of the famous novelist Jules Vernes, “Rien ne s´est fait de grand qui ne soit une espérance exagérée”[143], and think about remote-controlled engines cruising around, controlling the oceans´ fish stock, cleaning the sea-bed near shore or even serving as power refill station to e-powered ships.

[143] “nothing great has ever been created, without exaggerated aspiration”

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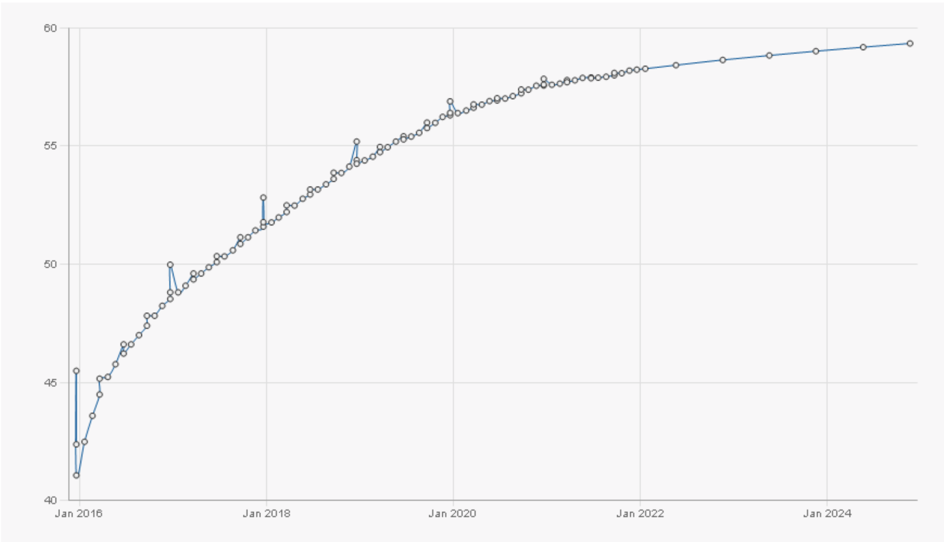
Appendix A

Share value of wind turbine producer Nordex (2011-2015)



Brent forward curve

Appendix B

NDX1 GY € 32.365 -.235 Y32.365 / 32.40Y 443 x 108

Um 10:26 Vol 175,634 E 32.685Y H 32.845Y T 32.305Y Wrt 5.725M

NDX1 GY Equity 96) Aktion 97) Ausgabe 98) Einstellung Finanzanalyse

Nordex SE Perioden 10 Jahresbericht Währung EUR

1) Wichtigste Daten 2) GuV 3) B 4) CF 5) Ratios 6) Segmente 7) Zusätzl. 8) ESG 9) Nutzerdef. 10) Geteilt

11) Wind Energy 12) Benchmark 13) Vertragsverpflichtungen 14) Optionen 15) Mehr...

In Millionen EUR, außer bei Ang. p. Akti	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
12 Monate, endend am	12/31/2009	12/31/2010	12/31/2011	12/31/2012	12/31/2013	12/31/2014
Windturbinen, produziert&versendet	1,059.50	--	--	--	--	--
Auftragseingang (USD)	734.0	836.0	1,107.0	1,268.0	1,502.9	1,753.9
Produzierte Windturbinen (MW)	983.00	1,032.00	779.00	909.00	1,342.00	1,417.00
Fertigungkapazität für Windturbinen	--	909.20	969.90	919.70	1,254.40	1,489.00
Aufträge im Rückstand (USD)	1,970.0	411.0	698.0	1,049.0	1,258.7	1,462.0
Windturbine, Herstellererlöse	1,182.8	972.0	916.8	1,075.3	1,429.3	1,734.5

Zoom 100%

Australia 61 2 9777 8600 Brazil 5511 2395 9000 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2015 Bloomberg Finance L.P.
SN 331852 G854-1799-0 08-Dec-15 10:27:39 CET GMT+1:00

Nordex turbine production – source Bloomberg

VWS DC DKK 458.90 -.40 C458.80 / 459.00C 490 x 295

Um 10:18 d Vol 204,610 E 459.30C H 463.00C T 457.00C Wrt 94.027M

VWS DC Equity 96) Aktion 97) Ausgabe 98) Einstellung Finanzanalyse

ADJ Vestas Wind Systems A/S Perioden 10 Jahresberichte Währung EUR

1) Wichtigste Daten 2) GuV 3) B 4) CF 5) Ratios 6) Segmente 7) Zusätzl. 8) ESG 9) Nutzerdef. 10) Geteilt

11) Wind Energy 12) Benchmark 13) Vertragsverpflichtungen 14) Mehr...

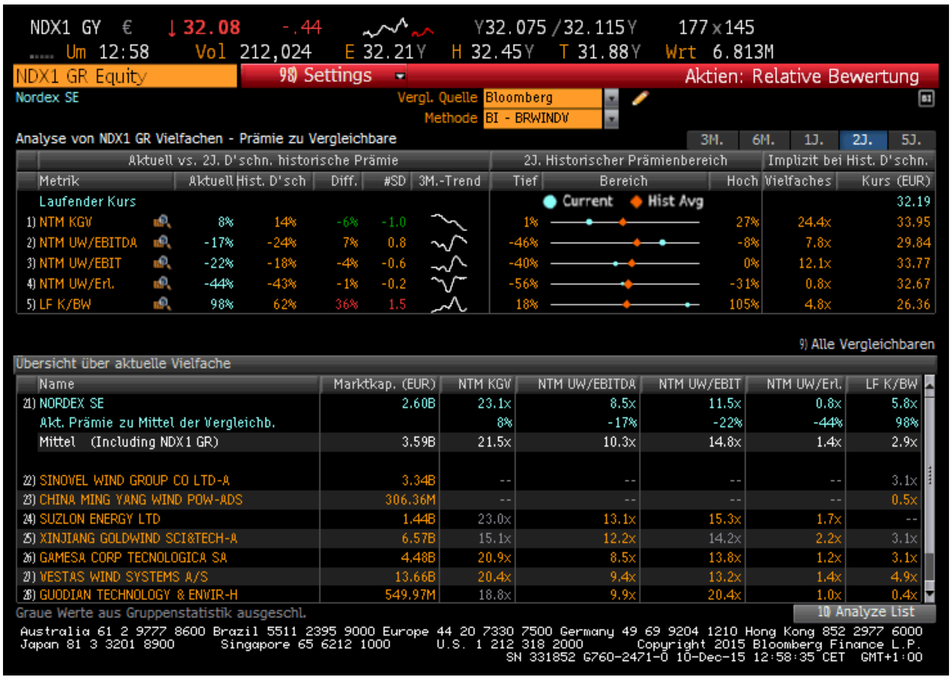
In Millionen EUR, außer bei Ang. p. Aktie	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
12 Monate, endend am	12/31/2009	12/31/2010	12/31/2011	12/31/2012	12/31/2013	12/31/2014
Windturbinen, produziert&versendet (MW)	6,131.00	4,057.00	5,054.00	6,171.00	4,513.00	6,125.00
Windturbinen, produziert&versendet (Anza	3,320	2,025	2,571	2,765	2,025	2,527
Windturbine Auftragsaufnahme (MW)	3,072.00	8,673.00	7,397.00	3,738.00	5,964.00	6,544.00
Auftragseingang (USD)	3,200.0	8,600.0	7,300.0	3,800.0	5,800.0	5,800.0
Produzierte Windturbinen (MW)	6,131.00	4,057.00	5,054.00	6,171.00	4,513.00	6,125.00
Windturbinen, produziert (Anzahl)	3,320	2,025	2,571	2,765	2,025	2,527
Auftragsrückstand für Windturbinen (MW)	5,015.00	7,622.00	9,552.00	7,156.00	7,417.00	7,513.00
Aufträge im Rückstand (USD)	5,400.0	7,700.0	9,600.0	12,400.0	13,500.0	13,700.0
Kumulative Installierungen (MW)	38,303.00	44,114.00	49,332.00	55,370.00	60,232.00	66,484.00
Kumulative Installierungen (Anzahl)	40,659	43,433	46,143	48,950	51,147	53,743
Windturbine, Herstellererlöse	5,079.0	6,920.0	5,836.0	7,216.0	6,084.0	6,910.0

Zoom 100%

Australia 61 2 9777 8600 Brazil 5511 2395 9000 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2015 Bloomberg Finance L.P.
SN 331852 G854-1799-0 08-Dec-15 10:34:08 CET GMT+1:00

Vestas turbine production – source Bloomberg

Appendix C



NDX1 GY € ↓32.08 -.44 Y32.075 / 32.115Y 177 x 145
Um 12:58 Vol 212,024 E 32.21Y H 32.45Y T 31.88Y Wrt 6.813M
NDX1 GR Equity 98) Settings Aktien: Relative Bewertung
Nordex SE Vergl. Quelle Bloomberg
Methode BI - BRWINDV

Analyse von NDX1 GR Vielfachen - Prämie zu Vergleichbare 3M. 6M. 1J. 2J. 5J.

	Aktuell vs. 2J. D'schn. historische Prämie					2J. Historischer Prämienbereich			Implizit bei Hist. D'schn.	
Metrik	Aktuell	Hist. D'sch	Diff.	#SD	3M.-Trend	Tief	Bereich	Hoch	Vielfaches	Kurs (EUR)
Laufender Kurs							Current Hist Avg			32.19
1) NTM KGV	8%	14%	-6%	-1.0		1%		27%	24.4x	33.95
2) NTM UW/EBITDA	-17%	-24%	7%	0.8		-46%		-8%	7.8x	29.84
3) NTM UW/EBIT	-22%	-18%	-4%	-0.6		-40%		0%	12.1x	33.77
4) NTM UW/Erl.	-44%	-43%	-1%	-0.2		-56%		-31%	0.8x	32.67
5) LF K/BW	98%	62%	36%	1.5		18%		105%	4.8x	26.36

9) Alle Vergleichbaren

Übersicht über aktuelle Vielfache

Name	Marktkap. (EUR)	NTM KGV	NTM UW/EBITDA	NTM UW/EBIT	NTM UW/Erl.	LF K/BW
21) NORDEX SE	2.60B	23.1x	8.5x	11.5x	0.8x	5.8x
Akt. Prämie zu Mittel der Vergleichb.		8%	-17%	-22%	-44%	98%
Mittel (Including NDX1 GR)	3.59B	21.5x	10.3x	14.8x	1.4x	2.9x
22) SINOVEL WIND GROUP CO LTD-A	3.34B	--	--	--	--	3.1x
23) CHINA MING YANG WIND POW-ADS	306.36M	--	--	--	--	0.5x
24) SUZLON ENERGY LTD	1.44B	23.0x	13.1x	15.3x	1.7x	--
25) XINJIANG GOLDWIND SCI&TECH-A	6.57B	15.1x	12.2x	14.2x	2.2x	3.1x
26) GAMESA CORP TECNOLOGICA SA	4.48B	20.9x	8.5x	13.8x	1.2x	3.1x
27) VESTAS WIND SYSTEMS A/S	13.66B	20.4x	9.4x	13.2x	1.4x	4.9x
28) GUODIAN TECHNOLOGY & ENVIR-H	549.97M	18.8x	9.9x	20.4x	1.0x	0.4x

Graue Werte aus Gruppenstatistik ausgeschl. 10) Analyze List

Australia 61 2 9777 8600 Brazil 5511 2395 9000 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2015 Bloomberg Finance L.P.
SN 331852 G760-2471-0 10-Dec-15 12:58:35 CET GMT+1:00

Financial ratios: source Bloomberg

Statutory declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Frankfurt am Main, 28.12.15

City, Date Signature