



# **Lessons from existing cooperation initiatives, competing technologies and concepts**

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## ABOUT THE PROJECT

In the light of the EU 2030 Climate and Energy framework, *MUSTEC- Market uptake of Solar Thermal Electricity through Cooperation* aims to explore and propose concrete solutions to overcome the various factors that hinder the *deployment* of concentrated solar power (CSP) projects in Southern Europe capable of supplying renewable electricity on demand to Central and Northern European countries. To do so, the project will analyse the *drivers and barriers* to CSP deployment and renewable energy (RE) cooperation in Europe, identify future CSP *cooperation opportunities* and will propose a set of concrete *measures* to *unlock the existing potential*. To achieve these objectives, MUSTEC will build on the experience and knowledge generated around the cooperation mechanisms and CSP industry developments building on concrete CSP *case studies*. Thereby we will consider the present and future European energy market design and policies as well as the value of CSP at electricity markets and related economic and environmental benefits. In this respect, MUSTEC combines a dedicated, comprehensive and multi-disciplinary analysis of past, present and future CSP cooperation opportunities with a constant *engagement* and *consultation* with *policy makers* and *market participants*. This will be achieved through an intense and continuous *stakeholder dialogue* and by establishing a tailor-made *knowledge sharing network*.

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# 1 INTRODUCTION

The objective of this report is twofold. On one hand to review the current cooperative initiatives that have been launched over the past years in the European Union, study their characteristics and achievements, as well as the reasons they didn't manage to achieve after all the initially envisaged outputs, in case this was the outcome. Among the cooperation initiatives studied are included the North Seas Countries' Offshore Grid initiative, the Pentalateral energy forum, the Baltic Energy Market Interconnection Plan, the Desertec initiative, ENTSO-e regional groups and Electricity Regional Initiatives. All lessons learned from this review have been gathered and are presented at the end of Section 2.

The second objective is to assess competitive dispatchable RES technologies that could be utilised for achieving high RES penetration scenarios, especially if the long-term European decarbonisation strategy for 2050 is considered. To this end, three technological options are studied: CSP with storage, PV with storage and offshore wind with storage.

Section 3 establishes the technoeconomic assessment approach that was adopted in the current study and presents the results of an in-depth review of the values of all parameters identified to have an impact on the LCOE and NPV calculations of the technologies.

A detailed analysis of the impact each parameter has on the LCOE, followed by a sensitivity analysis, takes place in Section 4. Among the parameters studied, slightly diversified per technology, are the initial investment cost, the storage cost, the capacity factor, the discount rate, the annual fixed operation and maintenance costs, the annual variable O&M costs etc. A comparative assessment of all parameters per technology takes place at the end of this section.

Finally, Section 5 summarises the main conclusions from the study. As it will be presented, CSP with storage is competitive against the other two technologies for storage exceeding 4 hours in the case of PV, and for at least 4 hours for offshore wind.

## 2 LEARNING FROM RES COOPERATIVE INITIATIVES IN EU

### 2.1 Introduction

This section introduces some of the lessons learned from existing cooperative initiatives that have been launched in the EU in order to promote regional cooperation on electricity coming from renewable energy technologies. These cooperative initiatives should not be confused with the cooperation mechanisms in place for the promotion of RES among different countries, as they have been already analysed under MUSTEC deliverables 4.1 and 6.2.

The majority of the cooperative initiatives described hereunder were launched in 2009, when the ambitious EU targets for the 20-20-20 package were enacted in the legislation, while a couple of them were initiated as early as 2005. Regional cooperation between EU member states has had a long tradition on a number of issues.

The cooperation initiatives studied in the following paragraphs include the North Seas Countries' Offshore Grid initiative, the Pentilateral energy forum, the Baltic Energy Market Interconnection Plan, the Desertec initiative, ENTSO-e regional groups and Electricity Regional Initiatives. These collaborations can take various forms, from irregular intergovernmental meetings to full-fledged institutions with a legal mandate. A representation of these cooperation initiatives based on the main objectives they serve is presented under Figure 1.

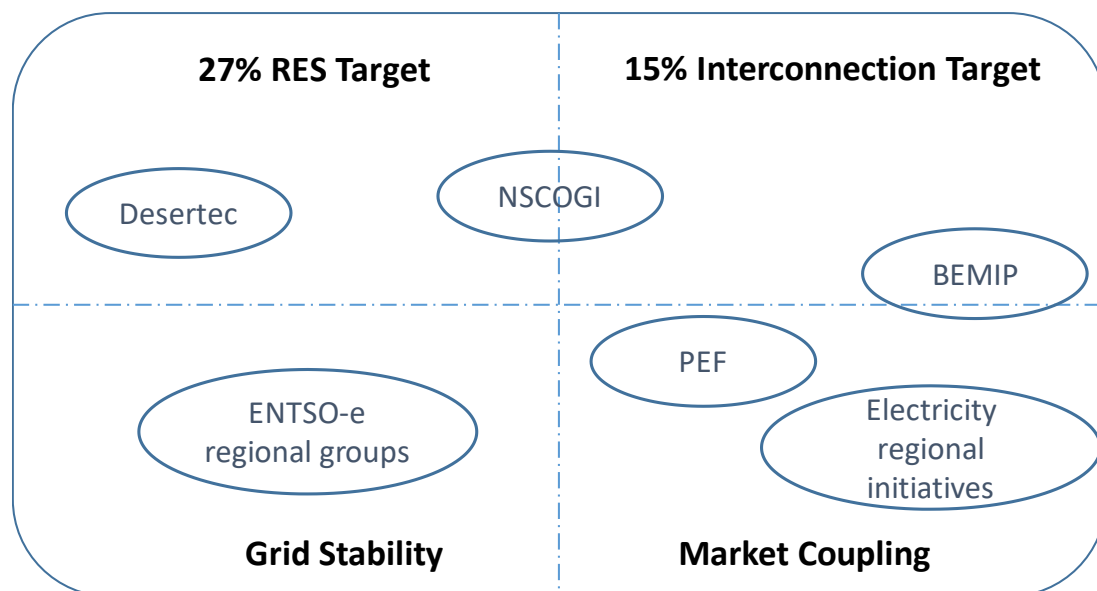


Figure 1: Cooperation initiatives in relation to 2030 policy objectives

Source: Adjustment of Figure I, Umpfenbach et al. (2015, Ecologic)

## 2.2 The North Seas Countries' Offshore Grid Initiative (NSCOGI)

The North Seas Countries' Offshore Grid initiative (NSCOGI) is an inter-governmental collaboration, the political declaration of which was signed in December 2009.

The main objective of this regional cooperation is to maximize the efficient and economic use of renewable energy resources as well as infrastructure investments. In order to achieve the ambitious EU renewable targets, the North Sea Countries' Offshore Grid initiative (NSCOGI) was formed as the responsible body to evaluate and facilitate the coordinated development of a possible offshore grid that maximizes the efficient and economic use of those renewable sources and infrastructure investments.

The political declaration was followed by a Memorandum of Understanding (MoU), which was signed on 3 December 2010 by the 10 countries (Belgium, Denmark, France, Germany, Ireland, Netherlands, Norway, Sweden, UK, Luxembourg) around the North Seas represented by their energy ministries, supported by their Transmission System Operators (TSOs), their regulators and the European Commission, together forming the NSCOGI (NSCOGI, 2014).

An overview of the NSCOGI structure in line with the above is provided in the below figure.

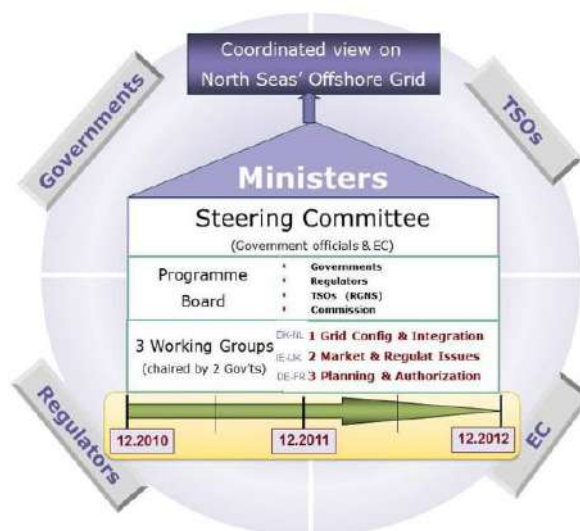
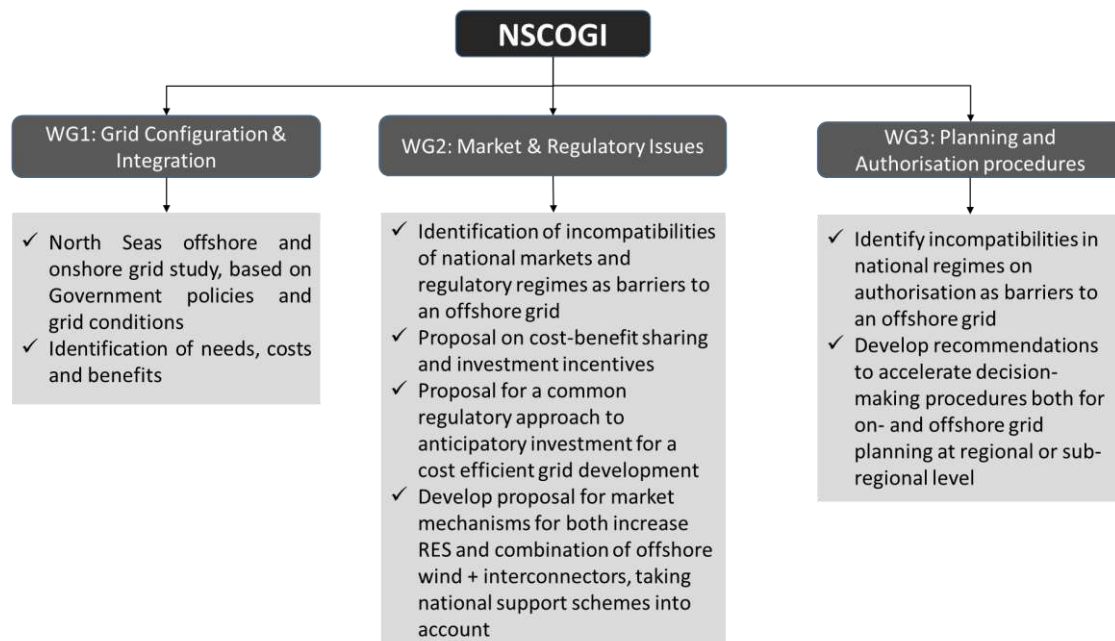


Figure 2: NSCOGI working structure

Source: [Benelux Secretariat](#)

Three Working Groups (WGs) were created by the MoU, with specific objectives each one of them, in order to take the overarching objective into a set of actions/ recommendations to be taken forward. Figure 3 below presents the NSCOGI working groups and their specific objectives.



*Figure 3: NSCOGI working groups and objectives*

*Source: The North Seas Countries' Offshore Grid Initiative, Final Report, WG1, 16<sup>th</sup> November 2012*

Each working group is chaired by representatives of two countries' energy ministries and coordinated by a programme board.

As evident from Figure 3, the focus of NSCOGI working groups is to identify needs, costs, benefits and barriers in the development and operation of an offshore grid network, as well as develop proposals and recommendations to address the different challenges and barriers for the elaboration of such a grid network, across the WGs' thematic areas. Therefore, all the produced outputs, as also presented below, do not represent plans or programmes of physical construction, investment decisions of Governments or TSOs, or construction decisions for offshore generation projects or connection routes (NSCOGI, 2012).

NSCOGI key outputs include among others:

- Market arrangements report (31 July 2014), to facilitate trading from across simple hybrid offshore structures (namely offshore renewable generation linked to interconnectors) in the context of the European Electricity Target Model.
- Cost allocation report (31 July 2014), outlining proposals for identifying how the costs and benefits of projects combining cross-border infrastructure and renewable generation may be shared fairly between multiple stakeholders and with due regard to investment incentives.
- North Seas Grid Study report (16 November 2012), aiming to compare and evaluate the possible advantages and disadvantages of the long-term development of an optimised, integrated (or meshed) offshore grid in the North Seas.

- Offshore Technology report (16 October 2012), prepared by ENTSO-E's Regional Group North Sea, outlines the current state of the main technology groups required for offshore High Voltage Direct Current (HVDC) transmission.
- Regulatory benchmark report (13 January 2012), aiming to identify the market and regulatory challenges (both national and EU-wide) of developing an integrated offshore network, and highlight some of the regulatory issues that could constrain or impact the development of these shared networks.

Based on the broadness of the thematic areas adopted, NSCOGI is one of the bottom up regional cooperation initiatives for RES deployment that focus on all relative aspects, namely electricity markets, infrastructure and grid operation, considering the profile of all engaged actors; this is one of its main differences from the other regional initiatives to be presented.

According to Umpfenbach et al. (2015, Ecologic), to have a concrete impact and potentially becoming a role model for similar cooperations elsewhere, NSCOGI would have to move on to developing concrete regulatory solutions and testing them on the ground through pilot projects. This next step would be significantly more challenging than the previous work as it would affect national regulation and thus would require political momentum from the ministerial level.

## 2.3 Pentalateral Energy Forum (PEF)

The Pentalateral Energy Forum (PEF) is an intergovernmental initiative, created in 2005 by Energy Ministers from Benelux, Germany and France to promote collaboration on cross-border exchange of electricity, and formalized through its Memorandum of Understanding, signed on the 6<sup>th</sup> of June 2007 in Luxembourg. Its aim is to reinforce the cooperation between all relevant parties and provide political backing in order to create a regional Northwest – European electricity market as an intermediate step towards one common European electricity market.

The main characteristic of this forum is its voluntary nature. It now includes Austria, Belgium, France, Germany, Luxembourg, and the Netherlands; Switzerland participates as an observer country. To this end, PEF is the framework for regional cooperation in Central Western Europe (BENELUX-DE-FR-AT-CH) towards improved electricity market integration and security of supply. The Ministers for Energy of the pentalateral countries meet regularly in order to discuss energy policy matters and give guidance to this regional cooperation (de Jong and Groot, 2013). The Pentalateral Energy Forum is subdivided in the so-called Support Groups (SGs), covering work on market integration (SG1) and on security of supply (SG2). Support Group on flexibility is currently on hold. The added value of this regional cooperation between Ministries, TSOs, the European Commission, Regulatory authorities and the Market Parties Platform, lies in its ability to move faster, to reach more specific recommendations and to act as a development center for new ideas.<sup>1</sup>

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<sup>1</sup> [Benelux secretariat website](#)

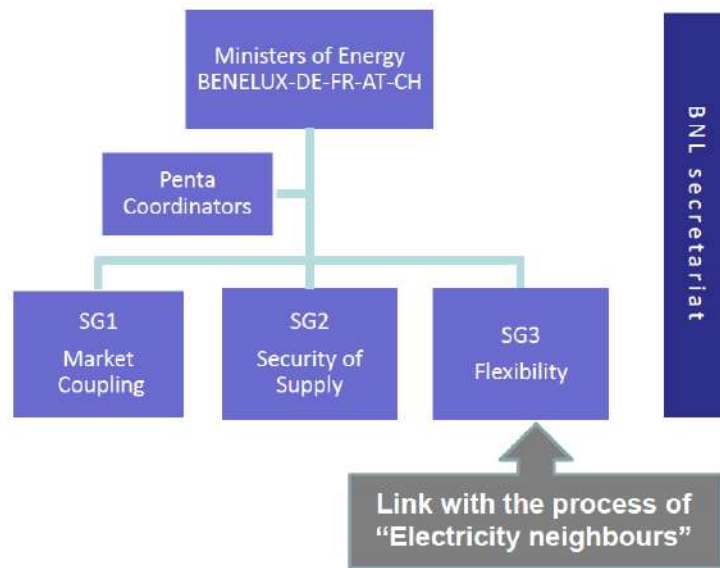


Figure 4: PEF working structure

Source: Tom Eischen presentation in the 16<sup>th</sup> Inter-Parliamentary meeting

The specific objectives of each SG, in line with the Directors' meeting in June 2016, are presented below.

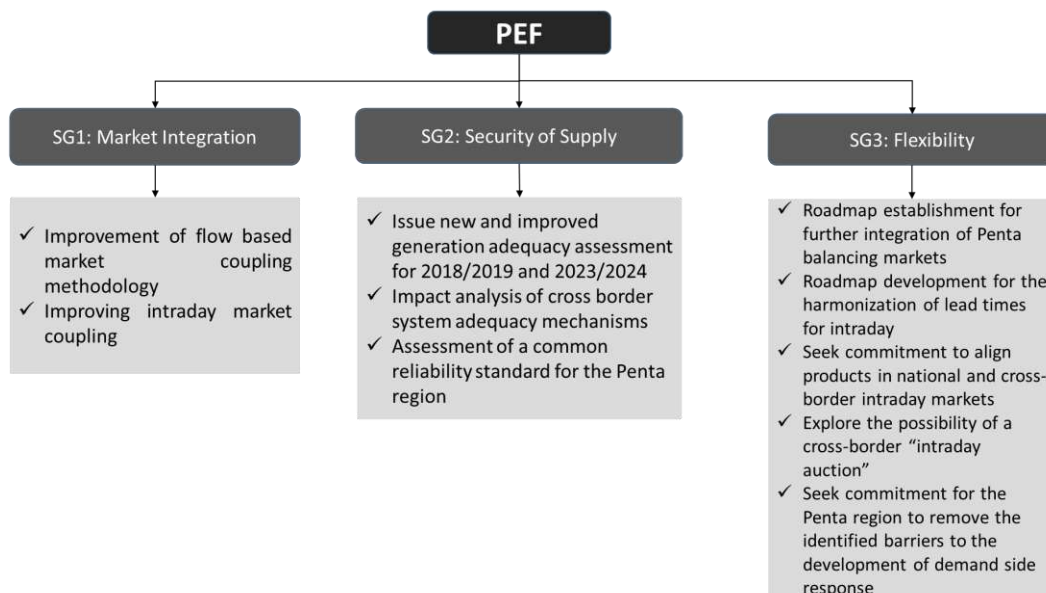


Figure 5: PEF Support Groups' Objectives

Source: PEF, June 2016

The Second Political Declaration in 2015 (PEF, 2015) established a Ministerial Conference as the governing body of the Forum, tasked to define main goals. It also set up a Coordinators' Committee

(representing the ministers), to meet at least twice a year in order to monitor the overall process. They have the duty of ensuring the consensus over the working programme and the follow-up of decisions.

Some of the most successful results of the Pentalateral Energy Forum include according to de Jong and Groot (2013), the following achievements:

- The PEF market coupling model has emerged as a standard for EU electricity target model for electricity market integration, now covering large parts of Europe.
- Additional results linked to the PEF include several industrial joint ventures offering cross-border services, such as the Cross-border Allocation Service Company (CASC), run by TSOs, as a central auction office for cross border transmission capacity. Also, TSOs and power exchanges established the European Market Coupling Company (EMCC), a separate company to allocate their cross-border capacities in the implicit auctions to operate the market coupling process, covering the Penta area and Scandinavia.
- The creation by some TSOs of a regional service company to monitor, forecast and coordinate cross-border flows in the region, enhancing supply securities and system adequacies for the whole Penta region, the UK and Italy.

Overall, the Pentalateral Forum was a more bottom-up process, springing from a decision by TSOs, national regulatory authorities and governments to establish specific market rules and institutions that would facilitate and stimulate market integration in the region in question. Their successful set-up later became the ‘target model’ for the wider EU (de Jong and Egenhofer, 2014).

Two of the lessons learnt from the PEF are:

- Highest political commitment is of the utmost importance to realize a regional cooperation;
- Basic structure and formalism needed to ensure the continuity of the process, the proper follow-up of decisions and a long-term vision.

## 2.4 Baltic Energy Market Interconnection Plan (BEMIP)

The Baltic Energy Market Interconnection Plan (BEMIP) was created in 2009 by the European Commission and participating Member States. It aims to create “a fully functioning and integrated energy market in the region, supported by the necessary infrastructure”. The BEMIP is partially funded by the European Commission (as part of the European Economic Recovery Plan -EERP) (Gephart et al., 2015).

The first Memorandum of Understanding (MoU) on the BEMIP initiative was signed on 17 June 2009 and focused on electricity and gas markets, infrastructure and power generation<sup>2</sup>. On the 8<sup>th</sup> of June 2015, the Members of BEMIP signed a MoU to strengthen regional cooperation. The signature of

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<sup>2</sup> [https://europa.eu/rapid/press-release\\_IP-09-945\\_en.htm](https://europa.eu/rapid/press-release_IP-09-945_en.htm)

the Memorandum marks the beginning of the implementation of the action plan, aiming to the development of a fully functioning and integrated energy market supported by the necessary infrastructures in order to strengthen energy security in the Baltic Sea Region. Finally, the Political Roadmap on the synchronisation of the Baltic States' electricity networks with the Continental European Network via Poland was signed in June 2018<sup>3</sup>.

BEMIP includes Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and, as an observer, Norway, cooperating in the following sectors (BEMIP, 2009):

- Internal market for electricity and gas;
- Electricity interconnections;
- New electricity generation capacity;
- Gas diversification of routes and sources;
- Oil.

The effective interconnection of the Baltic region was identified as one of six priority energy infrastructure projects in the Second Strategic Energy Review adopted by the Commission in November 2008. The BEMIP and the extension of the Nordic electricity market model to the Baltic States are also designated as flagship projects in the Commission's contribution to the Baltic Sea Region. It includes dedicated working groups, such as on infrastructure, markets, gas and electricity, security of supply, renewables and energy efficiency etc. The aim of these working groups is to prepare specific measures, projects and studies which are deemed necessary in order for the initiative to achieve its objectives and targets (Gephart et al., 2015).

The main conclusions of the BEMIP High Level Group final report cover the following three areas:

- Electricity market integration.
- Electricity interconnections and generation.
- Gas internal market and infrastructure.

The Electricity market design has been agreed, based on the Nordic electricity market model. A specific "Roadmap" has been proposed, describing practical steps on how to reach the new market model. It aims at removing the barriers for a regional electricity market in the Baltic States in conformity with the EU internal electricity market rules, covering for instance, removal of regulated tariffs, separation of TSO activities and roles, removal of cross-border restrictions, establishment of market based congestion management as well as common reserves and balancing power market, full opening of the retail market and establishment of common power exchange for physical trade in Nordic and Baltic area<sup>4</sup>.

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<sup>3</sup> [https://ec.europa.eu/energy/sites/ener/files/energy\\_solidarity\\_security.pdf](https://ec.europa.eu/energy/sites/ener/files/energy_solidarity_security.pdf)

<sup>4</sup> [https://europa.eu/rapid/press-release\\_IP-09-945\\_en.htm](https://europa.eu/rapid/press-release_IP-09-945_en.htm)

As part of the BEMIP implementation, a number of cross-border and domestic infrastructure projects called Projects of Common Interest (PCIs) have been completed across the Baltics, thus fostering the integration with the Nordic electricity market. The key electricity infrastructure projects, such as Estlink, Nordbalt and the LitPol Link, connecting the three Baltic States with Finland, Sweden and Poland respectively, have contributed to the Baltic countries' integration in the EU energy market, as well as their security of supply<sup>5</sup>.

In particular, the Baltic States are now amongst the best interconnected regions of Europe, with an interconnection level of 23%. However, additional interventions are required to complete their integration and synchronisation with European networks, develop a regional gas market, and make the most of the region's energy efficiency and renewable energy potential, both onshore and offshore. Given that the three Baltic States' electricity grid still operates synchronously with the Russian and Belarusian systems, a dedicated BEMIP working group steers work on achieving the synchronisation of the Baltics' grid with the continental European network by 2025. To this end, several high-level meetings have been organised on the synchronisation of the Baltic States network with the continental European network<sup>2</sup>.

Major PCIs on gas in the Baltic region include the Gas Interconnector Poland – Lithuania (GIPL), the Balticconnector project, and the development of infrastructure between the Baltic States. In particular<sup>2</sup>:

- The GIPL aims to connect the Baltic and Finnish gas networks with the continental European gas network by the end of 2021.
- The Balticconnector will provide an important gas link between Finland and Estonia and will connect the Finnish gas network with the continental European Network, thus addressing Finland's gas isolation from the rest of mainland Europe. Both will Finland and the Baltic States will be given the opportunity to achieve a greater diversify of their gas sources. The emergence of alternative routes as well as the reinforcement of the security of gas supply and energy market integration in the region are expected to enhance competition on the market and help consumers benefit from a cheaper and more stable gas supply.

## 2.5 Desertec Initiative

The Desertec Industrial Initiative was founded in 2009 and constitutes a private industry joint venture. It aims at producing power from the sun and wind in the deserts of North Africa and the Middle East for local and European demand; its long-term goal is to meet about 15% of Europe's electricity demand by 2050. To help accelerate the implementation of the DESERTEC idea in EU-MENA, the non-profit DESERTEC Foundation and a group of 12 European companies led by Munich Re founded an industrial initiative called Desertec Industrial Initiative (Dii GmbH) in Munich on 30

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<sup>5</sup><https://ec.europa.eu/energy/en/topics/infrastructure/high-level-groups/baltic-energy-market-interconnection-plan>

October 2009. Shareholders include, among others: ABB, Siemens, Deutsche Bank and E.ON. Desertec and Medgrid concluded an MoU in 2011, establishing close cooperation between RES production and energy transmission. This cooperation between the two private industry initiatives is deemed pivotal in the frame of the promotion of a renewable energy partnership between the EU and countries in the southern Mediterranean, introducing a concrete perspective of solar and wind energy produced for the joint benefit of European, Northern African and Middle Eastern markets (de Jong and Groot, 2013).

Like the DESERTEC Foundation, Dii GmbH did not intend to build power plants itself. Instead it focused on four core objectives in EU-MENA:

- Developing long term perspectives towards 2050 through investment and financing guidance.
- Conducting targeted in-depth studies.
- Fostering renewable energy and interconnected grids in EU-MENA through a framework for feasible investments.
- Initiating reference projects to prove feasibility.

Dii GmbH was focalised on achieving a positive investment climate for renewable energies and interconnected power grid in North Africa and the Middle East, by fostering the necessary technological, economic, political and market frameworks. Dii GmbH has initiated selected reference projects to demonstrate overall feasibility and reduce system overall costs<sup>6</sup>.

In this context, the development and trading of energy from renewable sources would boost economic development in these regions. In this way, MENA countries, including those with oil and gas resources, would be given the opportunity to establish a new economy with new jobs as well as tackle brain drain. In turn, the European states would achieve their goals of reducing CO<sub>2</sub> emissions relatively quickly and relatively cheaply, since CSP imports provide a reliable alternative to power from fossil fuels. As a result, the whole of EU-MENA would benefit from the trade in clean power from deserts (Desertec Foundation, 2009). Nonetheless, a number of uncertainties remain, as some major partners have left the project in recent years (de Jong and Groot, 2013).

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<sup>6</sup> <https://www.greentalents.de/science-forum/science-forum2011/dii.php>

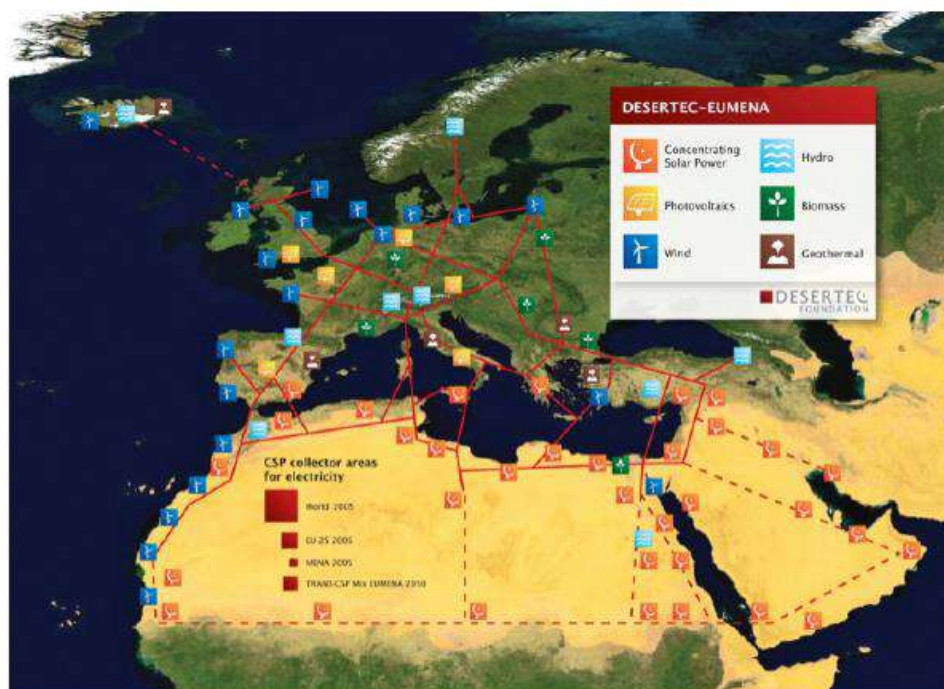


Figure 6: The DESERTEC concept

Source: de Jong and Groot, 2013

In addition, it should be noted that regional energy cooperation in the Mediterranean region is not focalised on the conventional fossil fuels, but more on renewable energy, particularly solar energy. Moreover, the industrial and regulatory partnerships are also focusing on infrastructures and markets. Therefore, this regional setup is comparable to what is happening in the NSCOGI project (de Jong and Groot, 2013).

Critics of Desertec questioned the viability of a project to generate 100GW by 2050 at a cost of €400 billion, and doubts multiplied when founding shareholder Siemens pulled out of the venture. In addition, Dii failed to get the support of the financially-strapped Spanish government for a 500MW CSP demonstration project in Ouarzazate, Morocco. European electricity players expressed their doubts concerning Dii's initial business model, supporting that its export-focus was incompatible with current levels of grid interconnectivity between the Maghreb and Europe as well as within Europe itself. The fact that the market was already facing difficulties in absorbing additional renewable energy capacity had been pointed out as well (Bissinger and Bouraee, 2014). Hence, the Desertec Industrial Initiative abandoned its strategy to export solar power from the Sahara to Europe, although the industrial alliance was set up to develop renewable energy supplies in the Maghreb to feed up to 20% of European electricity demand by 2050<sup>7</sup>.

<sup>7</sup><https://www.euractiv.com/section/trade-society/news/desertec-abandons-sahara-solar-power-export-dream/>

## 2.6 ENTSO-E's Regional Groups

ENTSO-E is the European Network of Transmission System Operators and was established by the EU's Third Legislative Package for the Internal Energy Market in 2009, which required TSOs to found cooperation structures to ensure system stability in the European grid as well as provide the technical basis for market integration. ENTSO-E promotes closer cooperation across Europe's Transmission system operators (TSOs) to support the implementation of EU energy policies (Gephart et al., 2015; Umpfenbach et al., 2015) and represents 43 electricity TSOs from 36 countries across Europe<sup>8</sup>.

The common objectives of ENTSO-E members include setting up the internal energy market and ensuring its optimal functioning as well as supporting the ambitious European energy and climate agenda. The current agenda encompasses critical issues, such as the integration of a high degree of Renewables in Europe's energy system, the development of consecutive flexibility, and the development of a much more customer-oriented approach than in the past. In this context, ENTSO-E is committed to develop the most suitable responses to the challenge of a changing power system while maintaining security of supply. Therefore, emphasis is given on a market-based approach, customer focus, stakeholder focus, security of supply, flexibility and regional cooperation<sup>8</sup>.

To this end, the organisation hosts five different types of regional groupings in accordance with ENTSO-E's different functions: system operations, systems development and market solutions. To begin with, in order to address operational uncertainties, TSOs need to provide certain services, enabling them to tackle, among others, balancing challenges, voltage variations, restoration planning, and transmission losses. Moreover, grid congestion solutions are required, based on transmission capacity allocation rules and procedures. The ENTSO-E Systems Operations Committee provides proposals for network codes and promotes operational coherence among regions. The formulation of regional groups based on synchronous areas ensures compatibility between system operations on the one side and market solutions and system development on the other. Furthermore, technical and operational aspects specific to interconnected system operation can also be addressed. There are five permanent regional groups covering Continental Europe, the Nordic region, the Baltic, Great Britain and Ireland-Northern Ireland. These groups have strict geographic boundaries. However, this can have a negative impact, since the Continental Europe group in particular hosts a large group of 24 countries (21 are EU member states), operating under very different conditions (Umpfenbach et al., 2015). The ENTSO-E regional groups can be seen in the following Figure.

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<sup>8</sup> ENTSO-E [website](#)



Figure 7: ENTSO-E regional groups

Source: Gephart et al., 2015

Although the Baltic and the Nordic region seems adequate for a top-down definition of the geographical scope, the region of Continental Europe cannot compose a practical region, as this region would have to deploy by far the largest share of RES in Europe. An effective coordination within this region does not seem practical due to infrastructural barriers, as it includes countries like Spain, Portugal and Poland in one region as well as countries that are not part of the EU. Exploiting ENTSO-E's Development Committee in combination with its regions would have the advantage of defining regions based on infrastructure issues, which is deemed pivotal in regard with increased RES shares (Gephart et al., 2015).

Concerning system development, planning and developing a secure, efficient and economic electricity transmission system is ENTSO-E's priority, under the auspices of the Development Committee. In contrast to the Operational Committee, ENTSO-E's Development Committee is in charge of TSO cooperation regarding the network development and planning. Outcomes of this cooperation include, for instance, the Ten Year Network Development Plan (TYNDP) (Gephart et al., 2015). Market and network planning also require detailed analysis at the regional level. To this end, six regional groups have been formed, in order to identify and address challenges for grid development and the integration of new generation at a regional level via a structure compatible with regional particularities and needs. The groups cover Continental South West, Continental Central South, Continental South East, Continental Central East, the Baltic and the North Sea (Umpfenbach et al., 2015).

In addition, the categorization of European countries into four larger regional groups facilitates the ranking of candidates for the Projects of Common Interest (PCIs), a list of EU priority infrastructure projects for electricity and gas set out in Regulation EU 347/2013 on guidelines for trans-European energy infrastructure. The four groups are broadly in line with the priority electricity corridors set out in the Regulation. Representatives from member states, the Commission, TSOs, project promoters, and NRAs as well as ACER are included in these groups (Umpfenbach et al., 2015).

The respective regional scope can be seen in the Figure below. As can be seen, the most striking difference to the operational groups is that regions in the development committee are seemingly more balanced, with no region covering a significantly larger part of Europe than another. Moreover, several countries are included in more than one regions (e.g. France is part of three regions). This reflects that this country shares specific infrastructural characteristics with three regions. However, this might be a disadvantage as countries would have to be part of several regional structures (Gephart et al., 2015).

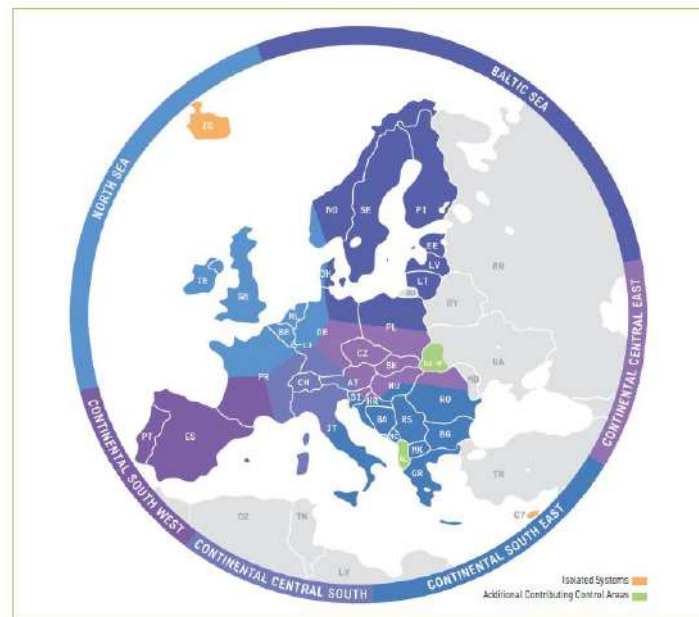


Figure 8: ENTSO-E's development committee regional groups

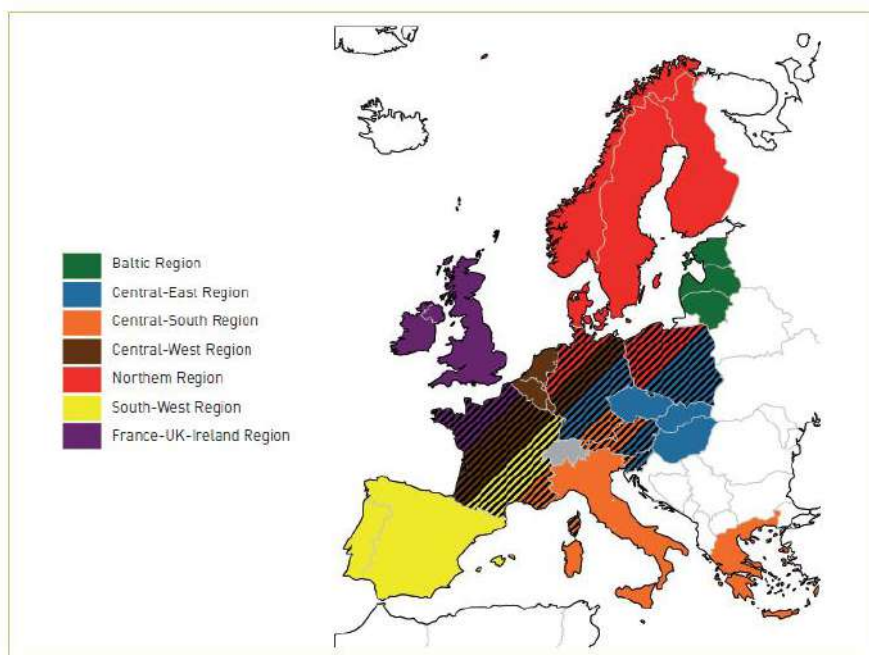
Source: Gephart et al., 2015

## 2.7 Electricity Regional Initiatives

In the spring of 2006, the European Regulators' Group for Electricity and Gas (ERGEG) established regional platforms for gas and electricity with the aim to create regional markets able to set the groundwork for the emergence of a single EU-wide market for electricity (Umpfenbach et al., 2015). The Electricity Regional Initiatives facilitate the interconnection and cooperation of regulators, companies, Member States, and the European Commission "to focus on developing and implementing solutions to improve the way in which regional energy markets develop". The respective agendas are based on their specific regional challenges and needs, as well as regions can serve as testbeds for solutions that - if successful – can be exported (Gephart et al., 2015; Umpfenbach et al., 2015).

Besides infrastructure, markets constitute an equally fundamental prerequisite for higher RES shares and thus the Electricity Regional Initiatives are seemingly a good starting point. Being related to electricity markets, RIs can have a vital contribution to the formulation of the future of energy in

the EU, given that cross-border capacity is increasingly included into the wholesale market process at the electricity exchanges (through “market coupling”), making thus cross-border electricity trade easier and much more efficient. In particular, regional cooperation is crucial in order to enhance access to cross-border capacities efficiently, thus fostering RES penetration as well as boosting the security of supply required in this context. To this end, seven regions have been defined across Europe (Gephart et al., 2015).



*Figure 9: Geography of the seven electricity Regional Initiatives*

*Source: Umpfenbach et al., 2015*

As years of cooperation experience have clearly shown, cross-border interconnections are able to provide the established basis for achieving RES deployment up to or beyond 27% in Europe. On the other hand, the participation of several countries in more than one regional initiative (e.g. Germany is part of the Central-South and Central-West region) is deemed as the main drawback of such efforts, as challenges are likely to emerge in regard with regional RES targets (Gephart et al., 2015). Another noticeable feature of RIs is their intentional overlap in continental Europe, aiming to ensure that each border is covered in one group. Moreover, countries included in more than one group can support the development of regional solutions compatible across regions (Umpfenbach et al., 2015).

Overall, the RIs were considered the “main vehicle for coordinating the practical implementation of the new European cross-border regulatory framework”, as well as an important platform for a) the identification of best practices, b) the support of regions on how to improve market integration, c) implementation of EU network codes, and d) enhancing the compliance with EU legislation (Umpfenbach et al., 2015). Nonetheless, these Regional Initiatives mainly focused on regulatory

issues. Underlying policy issues can also have a very significant impact, whence some political direction was deemed necessary. Besides the experience of Nordic countries, stemming from their wider political cooperation in the frame of the Nordic Council of Ministers, a similar political umbrella was formed by Spain and Portugal in parallel with the development of a common Iberian market (de Jong and Groot, 2013).

## 2.8 Lessons Learned

This section aimed initially at the mapping of the existing RES cooperative initiatives in the EU. All things considered, a multitude of initiatives for regional cooperation in the energy sector already exists in the EU. As there is no uniform format and the delineations vary depending on the mandate, a more intense cooperation in fora with government involvement can be observed in specific parts of Europe. More precisely, Northwest Europe and Scandinavia have already progressed towards electricity market integration through regional bodies of cooperation. In Continental Europe, which is characterized by region overlaps, countries such as Germany, France and Poland are members of more than one initiatives and groups at the same time (Umpfenbach et al., 2015).

It is not uncommon that the drive observed at the implementation level is not adequate to the expressed ambitions to coordinate at the European level. This phenomenon is mainly attributed to national policymaking, which deprives many countries of crucial cross-border benefits (de Jong and Groot, 2013). In this context, regional cooperation can be a catalyst for achieving the required coherence between national policies. Therefore, the European Commission should a leading role in relation to regional cooperation in policy planning, exploiting the experience in cooperation opportunities and benefits (Gephart et al., 2015). For example, Commission leadership and coordination was reported to have contributed significantly to facilitating regional cooperation in the case of BEMIP (Umpfenbach et al., 2015).

Besides market failures, government failures and the role of policy interactions should also be investigated thoroughly in order to achieve an internal energy market and a more sustainable energy system in a mutually consistent way (de Jong and Groot, 2013). In contrast to policy-making at EU or national level, the main asset of regional cooperation lies in the ability of the involved actors to co-ordinate more efficiently. Sharing information in smaller groups and fostering interactive procedures can help address the gap between the European and the national level as well as boost the effectiveness of policymaking. Moreover, regional fora can serve as platforms for discussing dissent between neighbouring countries. Such groups provide a fruitful alternative to EU policymaking, as the involved countries cannot be impeded by their less ambitious peers, being thus able to directly proceed to the implementation phase after reaching consensus in intergovernmental fora like PLEF and NSCOGI (Umpfenbach et al., 2015).

However, regional solutions face the risk of fragmentation if the regions simultaneously develop incompatible solutions. In addition, it is often noticed that ambivalent or technically challenging issues, such as the harmonisation of capacity mechanisms are not given the required attention.

Finally, concerns have also been raised regarding the lack of transparency in cooperation fora (Umpfenbach et al., 2015). As mentioned before, besides the significant work that has been already achieved, more is required to address issues related to the further deployment of RES from 2020 to 2030, such as the most efficient use of RES potential, electricity market design affecting RES deployment, as well as RES support costs and Member States cooperation on envisaged energy mixes (Gephart et al., 2015). More specifically, the main conclusions of the review are the following:

- Fostering cooperation requires the development of concrete regulatory solutions and related pilot projects.
- Underlying policy issues should also be taken into consideration; highest political commitment is of vital significance.
- Synchronisation with European networks and Commission leadership can play a significant role in facilitating regional cooperation.
- Compatibility issues are a critical parameter for the interconnection of Europe with other regions.
- Region overlaps in continental Europe can enhance the emergence of compatible solutions across regions, but involved countries should share specific infrastructural characteristics.
- RIs were seen as the main vehicle for coordinating the practical implementation of the new European cross-border regulatory framework.

## 3 TECHNOECONOMIC ASSESSMENT APPROACH

### 3.1 Introduction

One of the most frequently used indicators by investors to assess the economic performance of different technologies is the Levelised Cost of Electricity (LCOE), combined with additional metrics such as the Return on Investment (ROI), the Net Present Value (NPV), the Internal Rate of Return (IRR) or the Payback Period (PP), in order to make optimum informed decisions.

According to Musi et al. (2017), comparing LCOE and IRR demonstrates that there is an inverse relationship between the two; a higher IRR (better project) has a lower LCOE and vice versa. In general, newer projects have higher IRR, however some recent projects have low IRR which may be as a result of governmental grants or low-cost loans not disclosed in the literature. When comparing LCOE and NPV the results are less clear. A project can have a low LCOE and a negative NPV. A similar story can be seen with ROI, whereby low LCOE does not always lead to positive return on investment, which highlights how important it is not to rely on one sole metric when comparing projects.

Ueckerdt et al. (2013) highlights Joskow's (2011) characterization of LCOE as a flawed metric for comparing the economic attractiveness of variable renewable technologies with conventional dispatchable generating technologies, based also on previous works such as the ones by Lamont (2008), Borenstein (2008) and Fripp and Wiser (2008). LCOE is not taking into consideration the market value, while LCOE alone does not say anything about competitiveness or economic efficiency of a specific technology. As presented by Ueckerdt et al. (2013), the market value of variable renewable technologies decreases when their penetration level increases, due to the intermittent nature of electricity generation, which makes the use of LCOE even more difficult. Moreover, Hirth et al. (2016) provides a rigorous and general discussion of heterogeneity and its implications for the economic assessment of electricity generating technologies, based on their market share and respective market values, introducing the system LCOE.

Aim of this study is to realise a technoeconomic assessment of competing renewable energy technologies, such as CSP, PV and offshore wind. Renewables such as hydro, biomass etc. have not been taken into account, as due to the dispatchability offered by the source utilized, they are not considered fully comparative with technologies utilizing wind and solar energy, which are intermittent sources by nature. In this way, although the LCOE is used as a metric, besides its flaws, it is considered that it properly serves its scope for the assessment of the above mentioned technologies. As we will be gradually moving forward to higher RES penetration scenarios, in line with the EU Energy strategy for decarbonisation in sight of 2050, a portfolio of RES technologies will have to be utilized. Therefore, this study focuses on assessing the intermittent technological options that are most promising to serve a higher RES penetration scenario, where dispatchability, at least to some extent, is required.

Considering that the real added value of CSP plants is dispatchability, Schöniger and Resch (2019) stress that storage sizes of at least 8 hours are considered as realistic for the future. Based on the above, and especially the difficulty of comparing dispatchable with intermittent technologies, CSP with storage is compared on an equal basis with PV and offshore wind systems, coupled with storage options. Identifying the market value of these technologies is quite a challenging task. Nevertheless, as the comparison will be realised across dispatchable renewable technologies, the market values calculated for CSP with storage in Schöniger and Resch (2019) will be assumed in the calculations.

To this end, the assessment of the technologies will be realised based on two complementary metrics, the LCOE and the NPV.

Some more details on each one of these indicators is provided in the sections below.

### 3.1.1 Levelised Cost of Electricity

Levelised Cost of Electricity (LCOE) can be defined as “the fictitious stable electricity price needed to make the present value of the sum of all costs and all revenues over the entire operational life of the unit equal to zero” (Belderbos et al, 2017). Although it is often used as an indicator for the average price that an electricity generating asset must receive in a market to break even over its lifetime, the LCOE for a given energy source is highly dependent on the assumptions, financing terms and technological deployment analysed (Branker et al., 2011).

LCOE is given by the following formula:

$$LCOE = \frac{\text{total costs over lifetime}}{\text{total electricity generation over lifetime}} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \quad (1)$$

Where:

$I_t$ : Investments made in the year  $t$

$M_t$ : Operation and maintenance in the year  $t$

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

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

$r$ : Discount rate

$t$ : Number of time periods

$n$ : Expected lifetime of system or power station

More specifically, as the fuel expenditures are equal to zero for RES projects, the final form for LCOE can be seen below:

$$LCOE = \frac{\sum_{t=1}^n \frac{It + Mt}{(1 + r)^t}}{\sum_{t=1}^n \frac{Et}{(1 + r)^t}} \quad (2)$$

The LCOE is estimated over the lifetime of the energy-generating technology. The discount rate is dependent on the cost and the source of the available capital, considering a balance between equity and debt financing, as well as an estimate of the financial risks entailed by the project (Ragheb, 2017).

### 3.1.2 Net Present Value

Net present value (NPV) applies to a series of cash flows occurring at different times and is equal to the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The present value of a cash flow depends on the interval of time between now and the cash flow. It also depends on the discount rate. NPV accounts for the time value of money, providing thus a method for evaluating and comparing capital projects with cash flows spread over time (Khan and Jain, 2018).

The following formula is used for the calculation of NPV:

$$NPV = \sum_{t=1}^n \frac{Rt}{(1 + r)^t} \quad (3)$$

$R_t$ : Net cash flow in the year  $t$

$r$ : Discount rate

$t$ : Number of time periods

$n$ : Expected lifetime of system or power station

### 3.1.3 Key Parameters

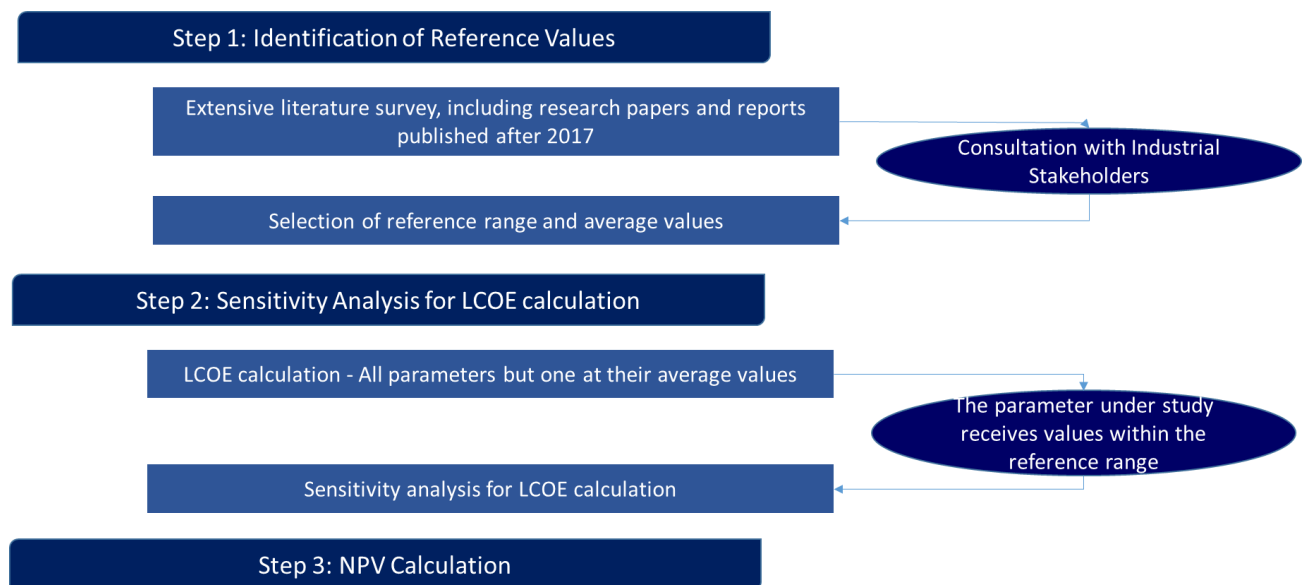
Capital investment cost or capital expenditure (CAPEX) refers to financing used by companies in order to secure physical assets or upgrade current ones, without taking into account the financial costs (interest rates) or the structure of financing (equity (Weighted Average Cost of Capital - WACC) vs. debt) (Damodaran, 2010). In this study where renewable technologies with dispatchable dimension are assessed, the storage investment cost is also included in the overall capital investment cost.

Operating expenditures (OPEX) encompass the ongoing cash flows required for running a facility, namely outlays which show up on the profit and loss account and relate to expenses incurred on an ongoing basis (Damodaran, 2010).

Revenues from dispatchable renewable electricity's production are identified across two levels; on one hand, the production of electricity itself, and on the other hand the contribution to the provision of ancillary services. Ancillary services are the specialty services and functions provided by the electric grid that facilitate and support the continuous flow of electricity so that supply will continually meet demand. Ancillary services provide two essential functions: balancing electrical supply and demand, and maintaining power quality. As variable generation replaces conventional generation from the system, at some point they should also take part in providing ancillary services for operational, economic and security reasons. Moreover supply of ancillary services may provide an additional revenue stream for dispatchable renewable generators – and may in the future result in penalties for those not delivering (Holttinen et al., 2012; Joos et al., 2000).

## 3.2 Adopted Approach

The approach adopted for the technoeconomic assessment of each one of the three selected technologies (CSP with storage, PV with storage, Offshore wind with storage) is graphically presented in the following figure.



*Figure 10: Technoeconomic assessment adopted approach*

Initially, for each technology, the identification of reference values in line with the literature survey for each one of the parameters engaged in the LCOE calculation is conducted. Following consultation with Industrial Stakeholders, the most representative range for each one of these parameters is selected.

The above mentioned literature survey is limited to studies and research papers published after 2017, till the date of this study's publication, in order to ensure that the comparative analysis has been realised based only on the latest data available. Considering the number of available studies on the evolution of CSP technologies, but also the storage options available for PV and wind, one of the aspects of the added value of this report focuses on the technoeconomic assessment of these technologies, based on the latest available information.

In order to realise the sensitivity analysis, each studied parameter receives a series of values within the selected reference range, while the rest of the parameters are kept at the average value of their selected reference range. For the different LCOE values calculated as a result of the varying parameter under study, a correlation diagram between the two is developed. To complete the sensitivity analysis, the impact of the percentage change of the parameter under study on the LCOE percentage change is depicted in a second diagram.

The third step is the calculation of the NPV for the low and high end of the reference range. Finally, the break-even point for which the NPV is zero, is also calculated.

### 3.3 CSP with Storage Related Data

Based on the representative projects selected by ESTELA (Souza, 2018), all including storage, the range of installed capacity cost for selected CSP technologies and projects, ranges from 4,720€/kW\* for DEWA IV in Dubai (expected to be operational in 2020), to 7,226€/kW\* for Xina Solar One (operational in 2017 in South Africa) and 5,380€/kW for Noor III (launched in 2018 in Morocco). Lilliestam and Pitz-Paal (2018) highlight that the cost for Aurora is 2,820 €/kW\*.<sup>9</sup> According to Kost et al. (2018), the installation costs of CSP systems with integrated storage for 8 hours was between 3,600 and 4,000 €/kW at the beginning of 2018. Lazard (2017) claims that according to their estimates, the CSP capital investment costs range around 3,370 €/kW to 8,870€/kW\*. According to IRENA (2019), the global weighted average total installed costs for CSP in 2018 range between 2,800€/kW and 5,930€/kW\*. Feldman et al. (2018) from NREL mentions a recent analysis by New Energy Update, which demonstrates that CAPEX of CSP projects with 6 to 16 hours of storage are now almost half to those from projects installed during 2013-2015, ranging from 3,300€/kW to 5,400 €/kW.\* In line with the same reference, CAPEX costs for 6 projects of the CSP fleet (Khi Solar One, Noor III, Ashalim Plot B, Goldmud, Shouhang Dunhuang, Supcon Delingha) that would be operational in 2018 were between 3,780 €/kW and 7,890€/kW. As regards the CSP fleet (Atacama 1, Aurora, DEWA CSP Unit 1, Redstone, Gansu Jinta and Yumen Huahai) with storage from 8h to 18h, to be operational between 2019 – 2021, the costs range between 3,380€/kW and 9,850€/kW\*.

The Capacity Factor for the CSP plants that went operational in 2018 ranges from 30% to 60% according to IRENA (2019), while the global weighted average capacity factor has increased from

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<sup>9</sup> \* Costs are provided in USD /kW. When the conversion year is not explicitly mentioned in the publication, for the appropriate exchange rates to be used, the values have been converted to euro using the exchange rates applicable for the publication year (2017-2019).

37% in 2017 to 45% in 2018. In Lazard's (2017) analysis, a capacity factor of 43%-52% has been assumed.

For the operation and maintenance (O&M) costs, Lilliestam and Pitz-Paal (2018) consider them to be approximately 1.5% of the installation costs; if the range of 2,800 to 6,000 €/ kW is considered for the installation costs, based on the above mentioned references, this translates to a range between 42 to 90 €/kW. Lazard (2017) assume a fixed O&M cost of 66.5- 70.9 €/kW and no variable O&M costs. IRENA (2019) refer to a variable O&M cost between 1.7-3.4 eurocents per kWh.

Finally, an average lifetime of 25 years for the above mentioned CSP projects has been taken into consideration. The values to be used in the technoeconomic assessment are summarized in the table below.

*Table 1: Summary of CSP with storage related data*

|                | Investment Cost (€/kW) |       | O&M fixed costs (€/kW) |      | O&M variable costs (€/kWh) |       | Capacity Factor (%) |      |
|----------------|------------------------|-------|------------------------|------|----------------------------|-------|---------------------|------|
|                | Low                    | High  | Low                    | High | Low                        | High  | Low                 | High |
|                | 2,800                  | 6,000 | 65                     | 71   | 0.017                      | 0.034 | 30                  | 60   |
| <b>Average</b> | 4,365                  |       | 68                     |      | 0.026                      |       | 45                  |      |

### 3.4 PV with Storage Related Data

As regards the installation costs for PV, without the storage component, IRENA (2018) highlights the significant reduction of 70-80% that has been achieved at the utility scale in the majority of the countries globally (besides the United States where the reduction is lower), between 2010 -2017. The installation costs in these countries range from approximately 995€/kW to 1,270 €/kW (excluding the US and Japan, where the costs are significantly higher). This is also evident in the updated publication on the generation costs (IRENA, 2019), where a range for the installation costs between 680-2,330€/kW\* is provided at the global scale, with the prevailing price of 1,025 €/kW. Feldman et al. (2018) from NREL mentions investments costs at the utility scale between 1,470 – 1,915€/kW\*; these costs are closer to the high end of globally observed prices, due to the significant price gap between the USA and the rest of the world. Fu et al. (2017) mention costs between 915-985 €/kW\* depending on the technology applied (fixed tilt or one axis tracker). Kost et al. (2018) highlight a cost between 600-800€/kW, while Lazard (2017) assumes a cost ranging between 975-1,220€/kW\* and Yousif et al. (2019) mention a cost of 1,200 €/kW\*. Also, Lazard (2018) provides an overall investment cost for a PV system with storage between 1,300-1,830€/kW\*. Following consultation with industrial stakeholders, the representative reference range for PV installation costs in Europe, without the storage component, is selected to be 600-1,200 €/kW.

The cost of storage is also a significant component of the CAPEX. In line with IRENA (2017) depending on the Li-Ion battery technology to be utilized, which is the most frequent type in this kind of applications, the cost ranges between 117 and 1,117 €/kWh. Fu et al. (2018) mention a cost of 322 to 760€/kWh, while Mongird et al. (2019) highlight a cost of 170€/kWh. Based on the above, a cost

range of 200 – 900€/kWh will be considered in this study. The most frequent value of energy to power ratio (E/P ratio) for electric batteries in the literature (Fu et al., 2018; Mongird et al., 2019) is equal to 4.

The values for O&M fixed costs for PV modules range in the literature. Yousif et al. mention 29€/kW annually, IRENA (2018) highlight a cost between 9-16.2€/kW, while in IRENA (2019) this cost is raised to 9-17.1 €/kW. Fu et al. (2017) refer to costs between 13.7 and 16.4€/kW and Kost et al. (2018) highlight prices between 15 and 20 €/kW.

For the fixed operation and maintenance costs of storage systems, the only price identified was in Mongird et al (2019), ranging from 5 to 12 €/kW.

The Capacity Factor for PVs in line with the available references lies within 21-32 % according to Lazard (2017), 13-27% (IRENA, 2019) with an average value of 18%, 17.6% (IRENA, 2018) and 17.5% (Fu et al., 2017).

*Table 2: Summary of PV with storage related data*

|                | PV Investment Cost (€/kW) |       | PV Storage Cost (€/kWh) |      | PV O&M fixed costs (€/kW) |      | Storage O&M fixed costs (€/kW) |      | Capacity Factor (%) |      |
|----------------|---------------------------|-------|-------------------------|------|---------------------------|------|--------------------------------|------|---------------------|------|
|                | Low                       | High  | Low                     | High | Low                       | High | Low                            | High | Low                 | High |
|                | 600                       | 1,200 | 200                     | 900  | 9                         | 20   | 5                              | 12   | 13                  | 27   |
| <b>Average</b> | 900                       |       | 550                     |      | 14.5                      |      | 8.5                            |      | 20                  |      |

## 3.5 Offshore Wind with Storage Related Data

IRENA (2019) states that the total installed costs of offshore wind projects commissioned in 2018 were 5% lower than those commissioned in 2010. According to the same study, the global weighted average installation costs in 2018, without including the storage component, ranged between 2,370 – 4,580€/kW\*, with the costs lower than 2,500 €/kW\* observed for Chinese projects, while the European ones were between 3,400-5,100€/kW\*. IRENA (2018) mentions an installation cost for European offshore wind projects in 2016 equal to 4,250 €/kW.\* Kost et al. (2018) highlight an investment cost of 3,100 – 4,700€/kW. Stehly et al. (2018) refer to a cost among 3,850 and 4,750 €/kW\*, while Yousif et al. (2019) have utilized in their study a cost of 3,215€/kW\*. As an overall result, a range between 3,100-5,100€/kW will be considered in this study.

The installation and O&M costs relevant to storage are the same as mentioned under the previous section, for the PVs.

With regards to the wind offshore O&M, Stehly et al. (2018) refer to prices between 76 and 128 €/kW approximately on an annual basis for fixed O&M, while Yousif et al. (2019) refer to 66 €/kW. IRENA (2018) highlight prices of 99-127 €/ kW on an annual basis for fixed O&M, as well as 0.01 – 0.045€/kWh for variable operational costs. Kost et al. (2018) utilize in their study a fixed O&M cost of 100€/kW and a variable O&M cost of 0.005 €/kWh.

The Capacity Factor in 2018 was a weighted average of 43%, ranging between 25% and 50% (IRENA, 2019). In line with the same reference, the CFs observed for Europe in 2017 and 2018 were higher than 40%, reaching values of even 55%. In 2017, the weighted average offshore capacity factor for newly commissioned plants reached around 42%, according to IRENA (2018). Kost et al. (2018) conduct their study for CFs between 37-52%. Following validation with industrial stakeholders, a capacity factor between 40 and 55% was selected in this study as representative of the European reality.

*Table 3: Summary of Wind Offshore with storage related data*

|                | Wind Investment Cost (€/kW) |       | Wind Storage Cost (€/kWh) |      | Wind O&M fixed costs (€/kW) |      | Wind O&M variable costs (€/kWh) |      | Storage O&M fixed costs (€/kW) |      | Capacity Factor (%) |      |
|----------------|-----------------------------|-------|---------------------------|------|-----------------------------|------|---------------------------------|------|--------------------------------|------|---------------------|------|
|                | Low                         | High  | Low                       | High | Low                         | High | Low                             | High | Low                            | High | Low                 | High |
|                | 3,100                       | 5,100 | 200                       | 900  | 75                          | 130  | 0.01                            | 0.02 | 5                              | 12   | 40                  | 55   |
| <b>Average</b> | 4,100                       |       | 550                       |      | 102.5                       |      | 0.015                           |      | 8.5                            |      | 47.5                |      |

## 4 TECHNOECONOMIC ASSESSMENT RESULTS

### 4.1 Assumptions for the technoeconomic assessment

The current section focuses on presenting the results of the technoeconomic assessment for a series of dispatchable renewable energy technologies, namely CSP with storage, PV with storage and Offshore Wind with storage. Besides the assumptions for the low and high ends of the reference range for all the parameters used in the LCOE calculation and presented under Section 3, this paragraph presents some additional assumptions utilised, affecting all three technologies.

As mentioned before, the two indicators selected for the technoeconomic assessment are the LCOE and the NPV, as there is complementarity between them. A common life duration of 25 years in all technologies has been considered, and a zero-salvage value.

As regards the discount rate selected, this is largely varying in the literature, with many researchers pointing out values around 3%. Nevertheless, following discussions with industrial stakeholders, a more representative range for the discount values of projects implemented in Europe was selected to be 6-9%. Also, one of the main assumptions is that this discount rate range is not differentiated between the three different technologies, although certain variations are experienced in real life projects.

As far as the revenues are concerned, no PPA price has been taken into consideration and only the wholesale electricity market price was adopted. According to EC (2017), the average electricity market price ranges between 54 to 64 eurocents / kWh, while EC (2019) demonstrates a range of the electricity price for 2017 between 40 to 60 eurocents / kWh. In Schöniger and Resch (2019), the reference value for the electricity spot price in Spain has been considered 49 cents/ kWh, while the quarterly reports by DG Energy for the second quarter of 2018 and 2019 make reference to 34 – 60 eurocents / kWh and 34 to 64 eurocents / kWh respectively. The low and high values of the electricity market price have been selected in this assessment to be 40 and 60 eurocents / kWh respectively, with 50 eurocents / kWh as an average price.

Also, considering that dispatchable renewable energy technologies are in the position to offer ancillary services to the market, the NPV has been calculated taking into consideration the average cost of ancillary services, which could bring additional revenues to these technologies, especially as we are moving towards high RES penetration scenarios. Currently these ancillary services are paid by the TSOs, mainly to conventional electricity producers. One of the main assumptions of this study is that the ancillary services are paid as well to the Dispatchable Renewable Electricity Producer, who can provide them utilizing the storage possibilities. To this end, the CSP is considered a fully dispatchable technology, which receives the amount of ancillary services for the total quantity of electricity produced. Two storage options are considered for the PV and Offshore wind, namely two and four hours; as such, only the quantity of electricity provided via storage for these two technologies is considered to receive the ancillary services price.

According to EC (2017), currently only in a few countries the generators pay grid charges that comprise a specific contribution for the cost related to balancing services, ranging from as low as 0.087 €/MWh in Sweden, to 2.81 €/MWh in Austria and 3.65 €/MWh in Bulgaria (only for wind and solar generators). ENTSO-E (2018) presents the average cost for the provision of ancillary services in the EU countries, with the average price being 2.5 €/MWh. Based on the above, the average price for ancillary services considered in this analysis is 2.5€/MWh, with a low end of 1€/MWh and a high end of 4 €/MWh.

With regards to the market value, it should be noted that a first comparative analysis of the NPV is realised assuming a market value of 103%, in line with Schöniger and Resch (2019), as representative of the current status for all three technologies. It should be highlighted that this market value was a result of a modelling analysis conducted for CSP with storage, and that PV and wind without storage demonstrated market values in the range of 70%. Nevertheless, since the PV and offshore wind technologies considered in this study are assumed to have a partly dispatchable behavior, due to lack of any other data, besides the initial assessment with 103%, the behavior of these technologies with a market value of 100% is also examined. The market value refers to the price an asset would fetch in the marketplace. This concept is most commonly invoked in inefficient markets or disequilibrium situations, where the existing market prices are not reflective of true underlying market value (Hirth & Ueckerdt, 2013).

Finally, as regards storage for PVs and Offshore wind, there are two scenarios considered in the analysis conducted herein. The first scenario focuses on installed storage capacity of 0.5kW per 1 kW PV, while the second one considers 1kW storage capacity per 1 kW installed PV. In both scenarios, the following assumptions apply:

- The energy to power ratio is considered constant and equal to 4.
- The life duration of the battery is 10 years and will have to be replaced. Considering the technological improvements, it is assumed that the second battery will have a life duration of 15 years and its cost will be 60% of the initial battery's installation cost (Kost et al., 2018).

As a result, the first scenario offers 2 hours of storage, while the second one offers four hours. It should be highlighted that these options cannot compete with the dispatchability offered by CSP with storage, which in the current analysis offer storage capacity between eight to sixteen hours. Nevertheless, four hours are assumed the maximum of the storage capacity that can be currently offered for such configurations (PV with storage, offshore wind with storage).

## 4.2 CSP with Storage assessment results

The calculation of the LCOE for the data presented under Table 1, as well as the previous section, was realised, accompanied by the conduction of a sensitivity analysis for all engaged parameters. The first parameter whose impact on LCOE is studied is the CSP investment cost, which has already embedded the storage related costs.

#### 4.2.1 Impact of CSP Investment Cost

In the first analysis presented below, the LCOE was calculated for the average values of O&M fixed and variable costs, as well as the discount rate, and for different prices of the investment costs, within the Low-High range provided above, in line with Table 4.

It should be noted though that due to the interrelation of the CSP investment cost with the Capacity Factor, on the account of the solar multiple and storage capacity utilized in order to increase the CF, a different approach has been adopted in this case. First of all, only the investment cost is correlated to the LCOE, since it already has embedded the connection with the CF and the electricity produced.

As a result, a further disaggregation of the overall investment cost for three specific ranges, for which different capacity factors are assumed to apply, has been considered. More specifically, in line with an analysis conducted of the data in the CSP guru database, as well as IRENA (2012), for a storage of less than 6 hours, the CF has been assumed to range between 30 to 40%. The CF of 40 to 50% is assumed for a storage over 6 hours and less than 9, while for a storage capacity of 9 to 12 hours, the CF is considered to range between 50-60%. The three above mentioned ranges in the storage hours and consequently the capacity factor, are matched with the three ranges of the investment costs considered, as presented in Table 4.

*Table 4: Correlation with Investment Cost*

| Investment Cost (€/kW)                                                                                                                                                  | O&M fixed costs (€/kW) | O&M variable costs (€/kWh) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------------------|-------------------|---------------------------|----------------------------|
| Increase of 200€ in three ranges: <ul style="list-style-type: none"> <li>• 2,800≤Cost&lt;4,000€</li> <li>• 4,000≤Cost&lt;5,000€</li> <li>• 5,000≤Cost≤6,000€</li> </ul> | 68                     | 0.026                      | 7.5               | 0.05                      | 0.025                      |

The LCOE results for an investment cost between 2,800 and 4,000€ and an average CF of 35% are ranging between 0.13 and 0.1589 €/kWh. For costs between 4,000 and 5,000€, and an average CF of 45%, the LCOE is calculated to be between 0.134 and 0.152 €/kWh, while for higher CFs (namely 55%) and costs over 5,000€ and less than 6,000€, the LCOE is between 0.1327 and 0.1513€/kWh.

Considering the unclear interrelation between the two parameters (investment cost and capacity factor), as the literature available data from projects implemented cover a rather broad range, the above-mentioned results demonstrate that depending on the project specificities, the LCOE for different storage capacities is expected to vary between the 0.13 to 0.159 €/kWh range for recent and planned projects. Also, based on the above analysis, the trend of slightly lower LCOE emerges, as the investment costs and capacity factors increase. These conclusions are aligned with the in-depth analysis conducted by Lilliestam (2018) on a case by case basis, where LCOEs for recent CSP plants are in the above range, while higher storage hours ensure a lower LCOE.

The NPV was also calculated for the varying prices of the investment cost, in line with Table 4 data, and the results derived were not positive. The investment cost below which the NPV is positive is close to 2,000€/kW, and more specifically 1,995€/kW for a CSP plant with at least 6 hours of storage. Considering that the learning rates achieved so far (Lilliestam, 2018) by CSP projects with large storage, especially parabolic troughs, are very high, approximately 43%, this cost might be achieved rather quickly in the coming years.

As mentioned above, since the LCOE and NPV are complementary indicators, it is not unusual a low LCOE to not necessary be accompanied by a positive NPV.

#### 4.2.2 Impact of CSP O&M Fixed Cost

The next parameter whose correlation with LCOE is examined is the O&M fixed costs, and Table 1 is formulated to Table 5.

Table 5: Correlation with O&M Fixed Costs

| Investment Cost (€/kW) | O&M fixed costs (€/kW)                  | O&M variable costs (€/kWh) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|------------------------|-----------------------------------------|----------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 4,365                  | Increase of 0.5€ in the range of 65-71€ | 0.026                      | 45                  | 7.5               | 0.05                      | 0.025                      |

The LCOE results for different values of the O&M fixed costs between 65 and 71 €/kW are calculated to be between 0.1421 and 0.1437€/kWh, thus the impact of this parameter on LCOE is almost negligible.

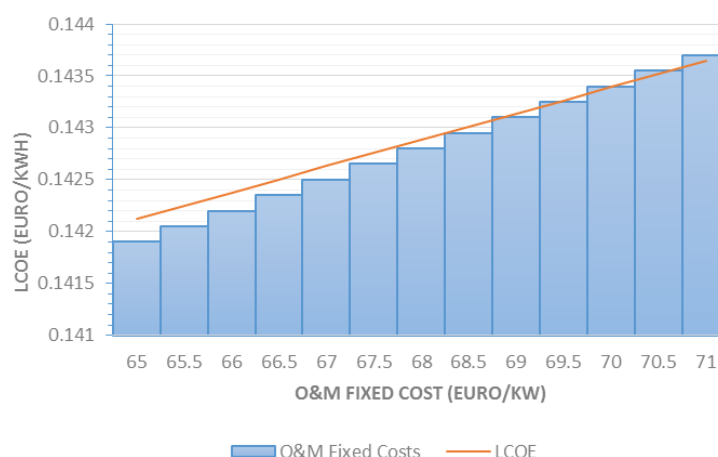


Figure 11: LCOE correlation with O&M Fixed Cost

The above mentioned conclusion is validated from the sensitivity analysis conducted and presented in Figure 12, as a change of 4.4% in the O&M costs results in 0.5% change in the LCOE.

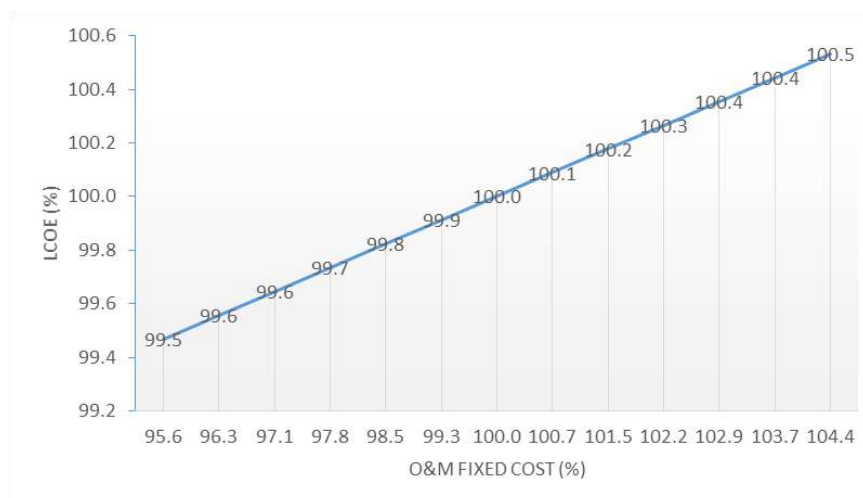


Figure 12: LCOE sensitivity analysis with O&M Fixed Cost

The relation between LCOE and O&M fixed cost follows a linear association, but as mentioned above the impact of the parameter's change on LCOE is negligible. Moreover, the NPV calculation for the values in Table 5 is negative, not only for the selected reference range of the parameter, but even for values of the O&M fixed costs equal to zero.

#### 4.2.3 Impact of CSP O&M Variable Costs

The next parameter studied is the correlation between the LCOE and the O&M variable costs. More specifically, the LCOE is calculated for a step increase of O&M variable costs by 0.001€/kWh, while the rest of the parameters are kept at their average values, in line with Table 6.

Table 6: Correlation with O&M Variable Costs

| Investment Cost (€/kW) | O&M fixed costs (€/kW) | O&M variable costs (€/kWh)                         | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|------------------------|------------------------|----------------------------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 4,365                  | 68                     | Increase of 0.001€ in the range of 0.017 to 0.034€ | 45                  | 7.5               | 0.05                      | 0.025                      |

The LCOE results for different values of the O&M variable costs between 0.017 and 0.034 €/kWh are calculated to be between 0.134 and 0.154 €/kWh, as depicted in Figure 13; thus the impact of this parameter although low, is considerable.

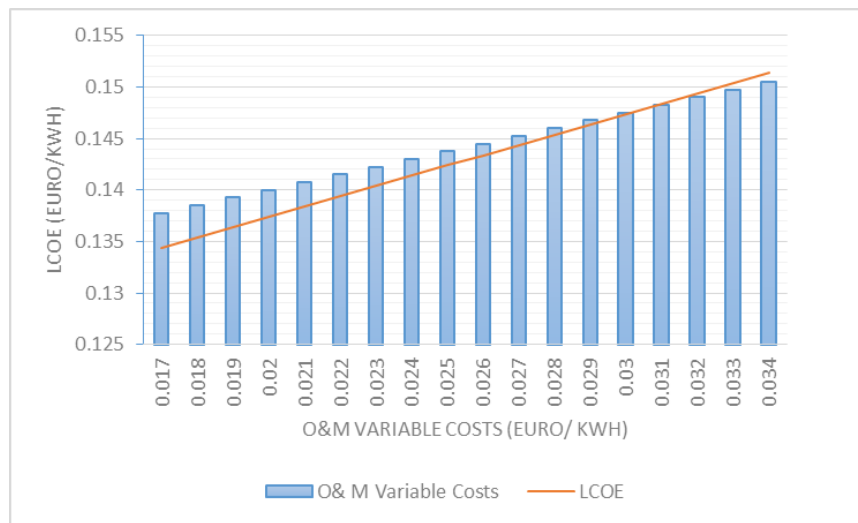


Figure 13: LCOE correlation with O&M Variable Cost

The above results are also validated through the sensitivity analysis conducted and presented under Figure 14.

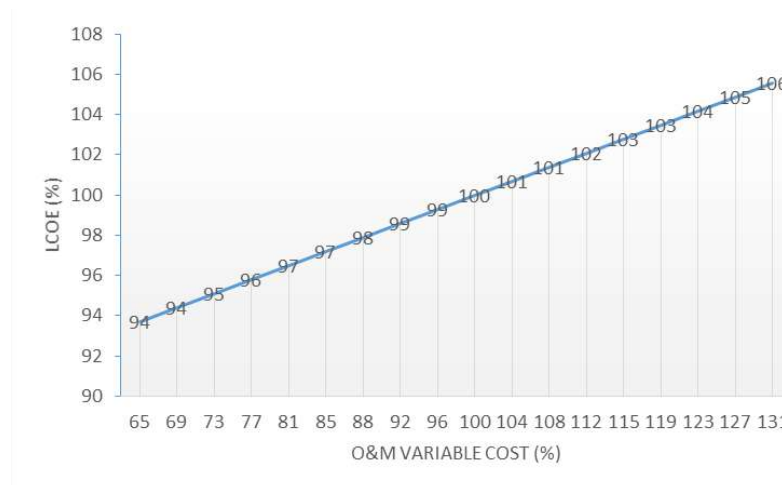


Figure 14: LCOE sensitivity analysis with O&M Variable Cost

Again we are discussing about a linear association between the two parameters, where a 35% differentiation in this parameter leads to a 6% change in the LCOE value.

As mentioned above, the impact of O&M variable costs is low. As a result, it cannot really affect the NPV values, and the basic results are applicable here as well, namely a negative NPV value.

#### 4.2.4 Impact of the Discount Rate

The analysis of LCOE evolution with the last parameter, namely the discount rate, takes place in line with the data presented in Table 7.

Table 7: Correlation with the Discount Rate

| Investment Cost (€/kW) | O&M fixed costs (€/kW) | O&M variable costs (€/kWh) | Capacity Factor (%) | Discount rate (%)                     | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|------------------------|------------------------|----------------------------|---------------------|---------------------------------------|---------------------------|----------------------------|
| 4,365                  | 68                     | 0.026                      | 45                  | Increase of 0.1% in the range of 6-9% | 0.05                      | 0.025                      |

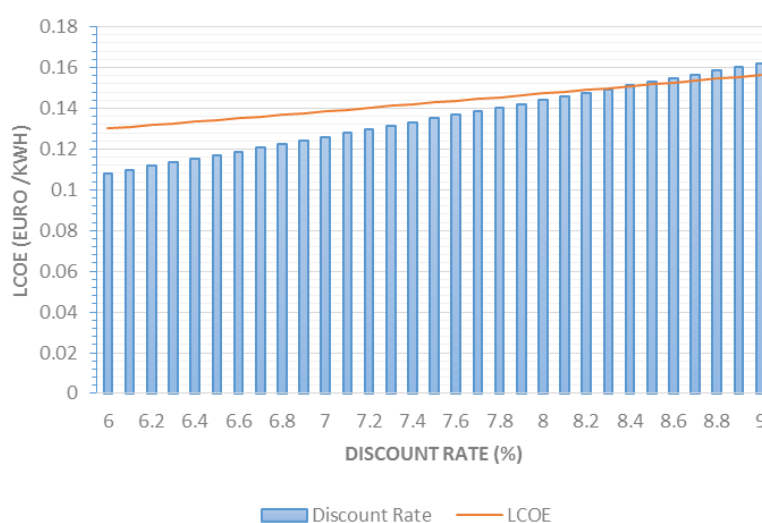
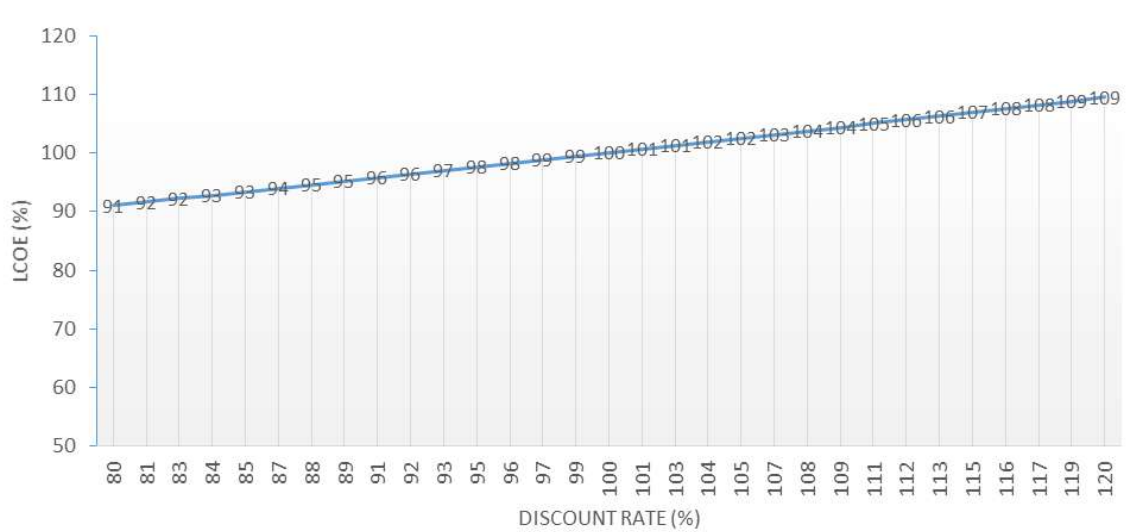


Figure 15: LCOE correlation with the Discount Rate

The correlation of LCOE with the discount rate demonstrates a linear association and moderate impact of this parameter on the average production cost. More specifically, for values of the discount rate between 6-9%, the LCOE values are calculated to be 0.1301-0.1564€/kWh. This is also validated from the sensitivity analysis conducted, where a change in the discount rate by 20% results to a LCOE differentiation by maximum 9 % (see Figure 16).

Also, the NPV calculation for any discount rate, even lower than the reference range, returns a negative value.



*Figure 16: LCOE sensitivity analysis with the Discount Rate*

Besides the analysis of the above-mentioned parameters, the impact of the electricity price and ancillary services' cost on the feasibility of a CSP project was analysed.

The NPV for an average cost of ancillary services at 0.025€/kWh and a wholesale market price ranging between 0.04-0.06€/kWh was calculated to be negative for all prices. The same phenomenon is observed for an average wholesale electricity price of 0.05€/kWh, and a price for ancillary services between 0.01 and 0.04€/kWh. Nevertheless, considering the price in the wholesale electricity market constant at 0.05 €/kWh and a market value of 103%, the revenues from the ancillary services need to reach at least 0.0885 €/kWh, in order for the NPV to be marginally positive. This means that for average values of all parameters engaged in the calculation of the NPV, revenues of at least 0.1385€/kWh are needed in order for the NPV to be above zero.

## 4.3 PV with Storage assessment results

The calculation of the LCOE for the data presented under Table 2 was realised, accompanied by the conduction of a sensitivity analysis for all engaged parameters. Also, the impact on the NPV, besides the LCOE, has been examined for all studied parameters. The analysis presented below is based on two (2) hours of storage, in line with the assumptions under Section 4.1. The cumulative results for four (4) hours of storage are presented under Section 4.5 and the comparative analysis conducted.

### 4.3.1 Impact of the PV Investment Cost

The correlation results of PVs' LCOE with the investment cost for PV modules (not including the storage investment cost) are presented in the following figures, based on the values in Table 8. As described above, the LCOE is calculated for PV investment costs increasing gradually by 50€, in the range between 600-1,200, while the rest of the parameters are kept constant at their average values.

Table 8: Correlation with PV Investment Cost

| PV Investment Cost (€/kW)                   | PV Storage Cost (€/kWh) | PV O&M fixed costs (€/kW) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|---------------------------------------------|-------------------------|---------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| Increase of 50€ in the range of 600- 1,200€ | 550                     | 14.5                      | 8.5                            | 20                  | 7.5               | 0.05                      | 0.025                      |



Figure 17: LCOE correlation with the PV Investment Cost

As evident from the above figure, there is a linear relationship between the PV investment cost and the LCOE. Moreover, although there is a considerable impact of the PV investment cost on the LCOE, nevertheless this doesn't manage to affect the LCOE price with more than 12%, for a parameter change of 33% (see sensitivity analysis under Figure 18). This means that for a PV cost ranging between 600-1,200€/kW, the LCOE is between 0.0798 – 0.1015 €/kWh.

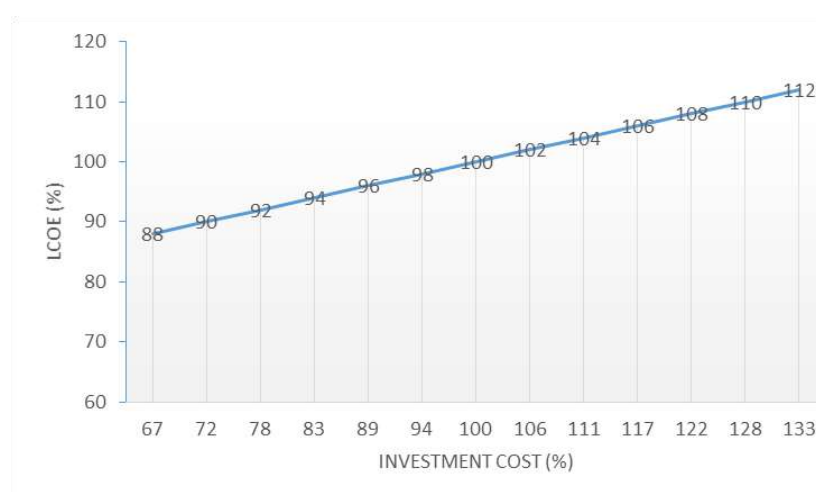


Figure 18: LCOE Sensitivity Analysis with the PV Investment Cost

As in the case of CSP, the NPV has been calculated negative for the PV investment costs initially studied. Also, considering the relatively high cost of storage, combined with the low prices of wholesale electricity and ancillary services, it is understandable why the NPV doesn't return a positive value for any initial investment cost, for both market values of PV electricity produced.

#### 4.3.2 Impact of the PV Storage Investment Cost

Since it wasn't possible to identify from the literature technoeconomic trends for the investment cost of PVs including storage, and considering that due to the maturity of the PV technology, the storage cost is the one envisaged to have a significant impact on the LCOE, this parameter is studied separately from the PV investment cost, in line with the Table 9 data.

Table 9: Correlation with Storage Investment Cost

| PV Investment Cost (€/kW) | PV Storage Cost (€/kWh)                  | PV O&M fixed costs (€/kW) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|---------------------------|------------------------------------------|---------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 900                       | Increase of 50€ in the range of 200-900€ | 14.5                      | 8.5                            | 20                  | 7.5               | 0.05                      | 0.025                      |

As expected, although the LCOE correlation with the PV investment cost is rather significant, it is no match to the strong relationship with the storage investment costs, as presented in the following figures. Figure 19 presents how the investment cost required for storage affects the LCOE of the PV electricity produced overall.

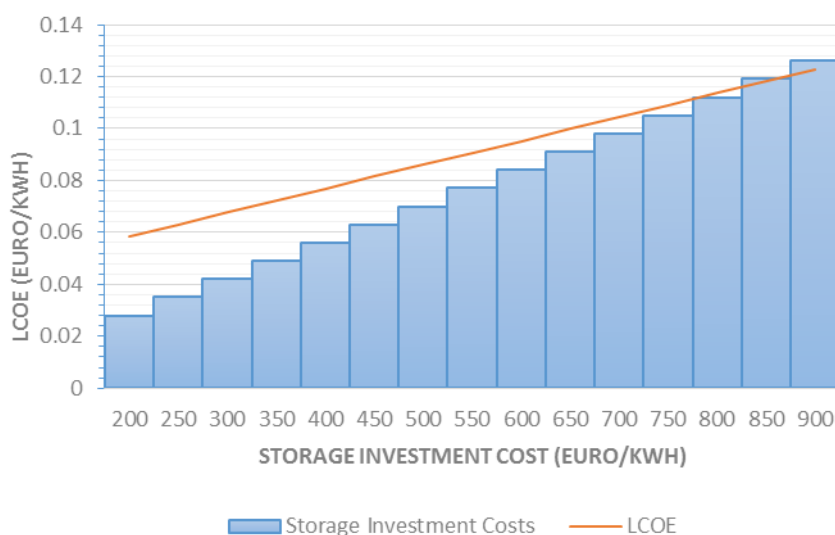


Figure 19: LCOE correlation with the Storage Investment Cost

For an investment cost for storage ranging between 200 and 900 €/kW, the LCOE is calculated to be 0.0585 and 0.1228 €/kWh. This means that for a 64% change in the storage investment cost, the

LCOE deviates around 35%. To make it more comparable to the PV investment cost, where the LCOE price is not impacted more than 12%, for a parameter change of 33%, the same parameter change in the storage investment cost leads to approximately 18% change in the LCOE (see Figure below).

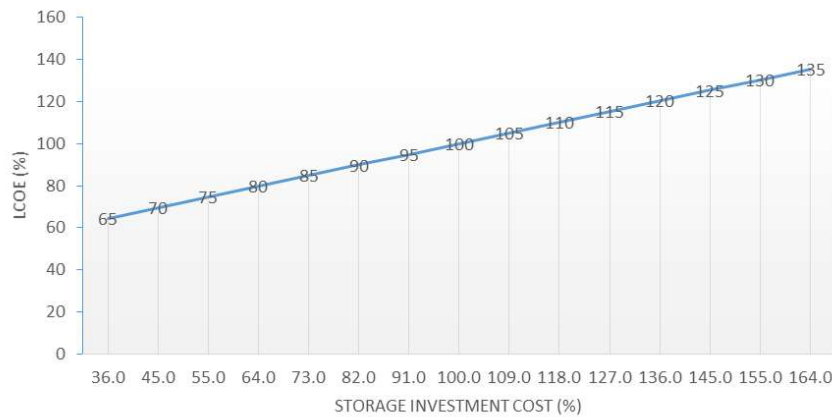


Figure 20: LCOE Sensitivity Analysis with the Storage Investment Cost

Considering this strong relationship between the two parameters, it is more probable that low values of the storage investment cost will lead to positive NPVs. More particularly, the NPV has been calculated positive for storage investment costs less than 24€/kWh for a market value of PV electricity of 103%, and 21€/kWh for a market value of 100%. This cost is really low compared to the current market prices, and only significant technological progress might lead to its attainment; as such, it is not considered that this can be financially viable in the short-term horizon.

#### 4.3.3 Impact of the PV O&M Fixed Cost

Moving on to the next parameter, the relationship between the LCOE and the fixed O&M costs for the PV modules is analysed, in line with the values presented under Table 10.

Table 10: Correlation with PV O&M Fixed Cost

| PV Investment Cost (€/kW) | PV Storage Cost (€/kWh) | PV O&M fixed costs (€/kW)               | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|---------------------------|-------------------------|-----------------------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 900                       | 550                     | Increase of 0.5€ in the range of 9- 20€ | 8.5                            | 20                  | 7.5               | 0.05                      | 0.025                      |

As evident from the Figure 21, the impact of this parameter on the LCOE is rather negligible, as the LCOE ranges between 0.0884 and 0.093 €/kWh.



Figure 21: LCOE correlation with the PV O&M Fixed Cost

The above mentioned conclusion is also validated through the sensitivity analysis conducted, where it is evident that even a change of 38% of the parameter doesn't trigger a change of more than 2.4% approximately.

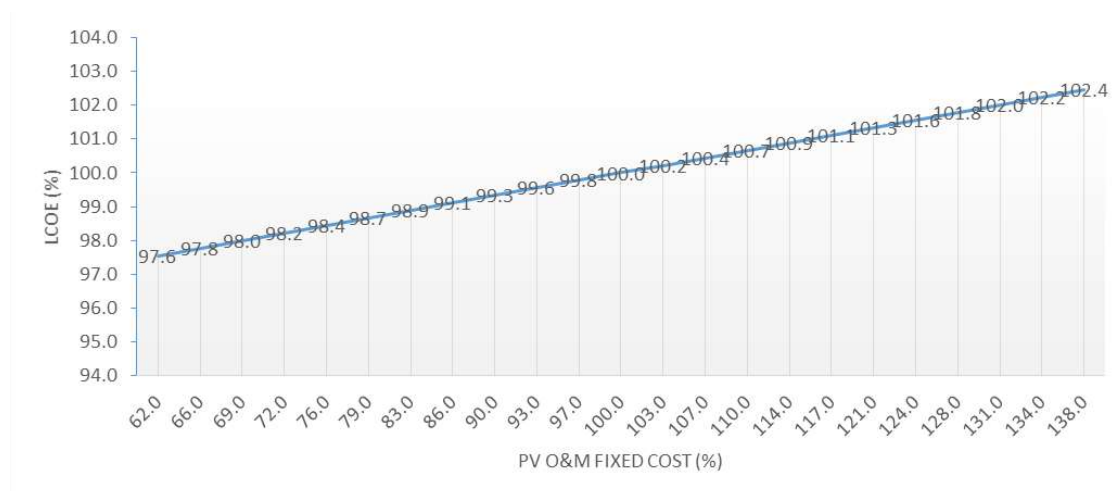


Figure 22: LCOE Sensitivity Analysis with the PV O&M Fixed Cost

Due to the low impact of PV O&M fixed costs on the NPV calculations, there is no value for which the NPV breaks even.

#### 4.3.4 Impact of the Storage O&M Fixed Costs

Besides the O&M costs related to the PV modules, the next parameter to be studied concerns the O&M fixed costs related to the storage component, in line with Table 11 data.

Table 11: Correlation with Storage O&M Fixed Cost

| PV Investment Cost (€/kW) | PV Storage Cost (€/kWh) | PV O&M fixed costs (€/kW) | Storage O&M fixed costs (€/kW)          | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|---------------------------|-------------------------|---------------------------|-----------------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 900                       | 550                     | 14.5                      | Increase of 0.5€ in the range of 5- 12€ | 20                  | 7.5               | 0.05                      | 0.025                      |

As in the case of PV O&M fixed costs, the impact of this parameter on the LCOE is even more negligible, as the LCOE ranges between 0.0899 and 0.0913 €/kWh.

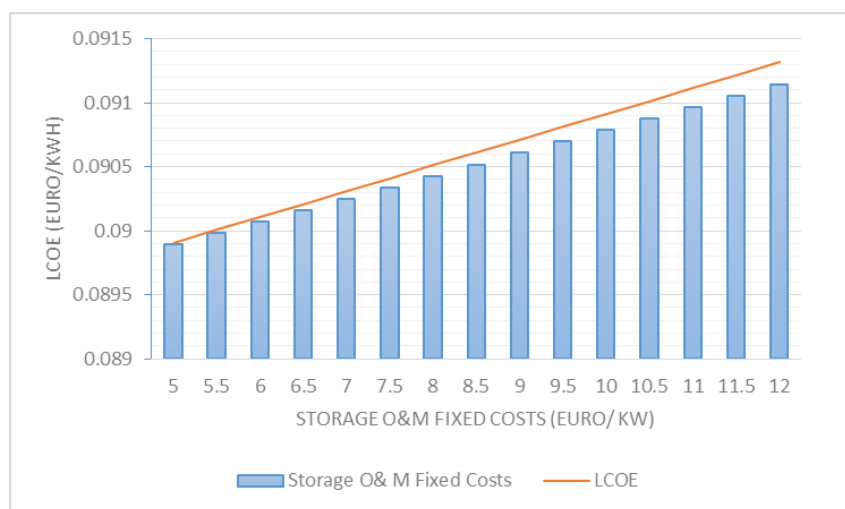


Figure 23: LCOE correlation with the Storage O&M Fixed Cost

In line with the sensitivity analysis conducted and presented under Figure 24, it is evident that even a change of 41% of the parameter doesn't impact with more than 1% the LCOE values.

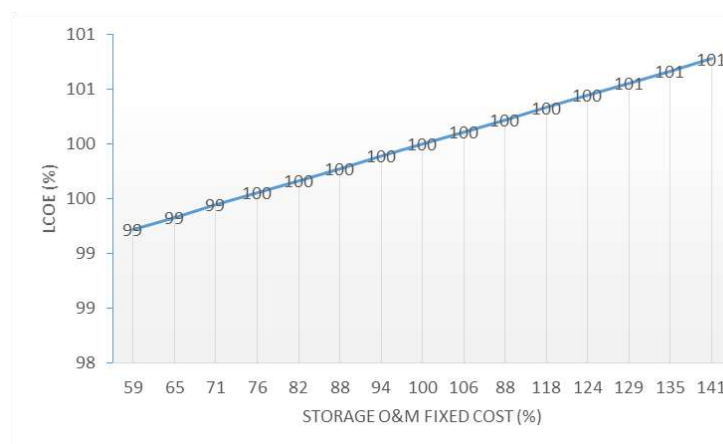


Figure 24: LCOE Sensitivity Analysis with the Storage O&M Fixed Cost

Considering the negligible impact on the LCOE, it is expected, as in the previous case, that the NPV is negative and that there is no value of the storage O&M fixed costs, for which the NPV breaks even.

#### 4.3.5 Impact of the Capacity Factor

The next parameter whose correlation with LCOE is studied, is the capacity factor. It is rather expected it will have a considerable impact on the PV and storage system's LCOE.

Table 12: Correlation with the Capacity Factor

| PV Investment Cost (€/kW) | PV Storage Cost (€/kWh) | PV O&M fixed costs (€/kW) | Storage O&M fixed costs (€/kW) | Capacity Factor (%)                    | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|---------------------------|-------------------------|---------------------------|--------------------------------|----------------------------------------|-------------------|---------------------------|----------------------------|
| 900                       | 550                     | 14.5                      | 8.5                            | Increase of 1%€ in the range of 13-27% | 7.5               | 0.05                      | 0.025                      |

The previous assumption is validated from the results presented under Figure 25, as for a range of the CF between 13-27%, the LCOE receives values between 0.1203 and 0.0727 €/kWh.

This means that in line with the sensitivity analysis presented under Figure 26, a change of 35% in the parameter leads to an almost equal (33%) change in the LCOE for values below the base (CF of 20%). As the capacity factor improves above the base value, its impact on the LCOE is still highly considerable, but at a lower rate (20% reduction in the LCOE for a 35% increase of the CF).

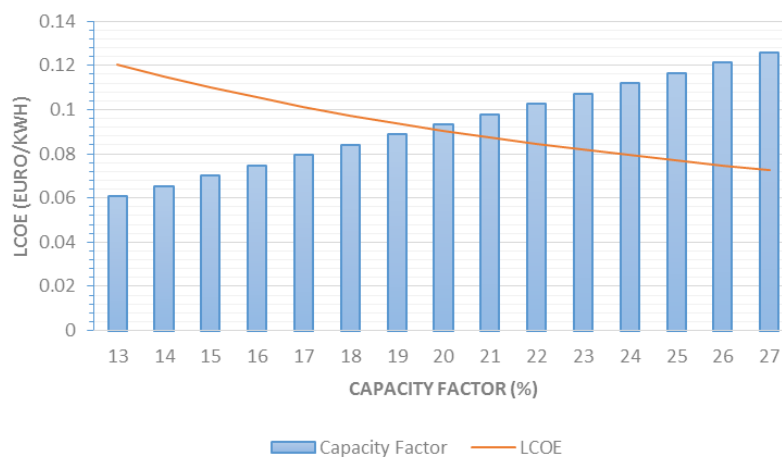


Figure 25: LCOE correlation with the Capacity Factor

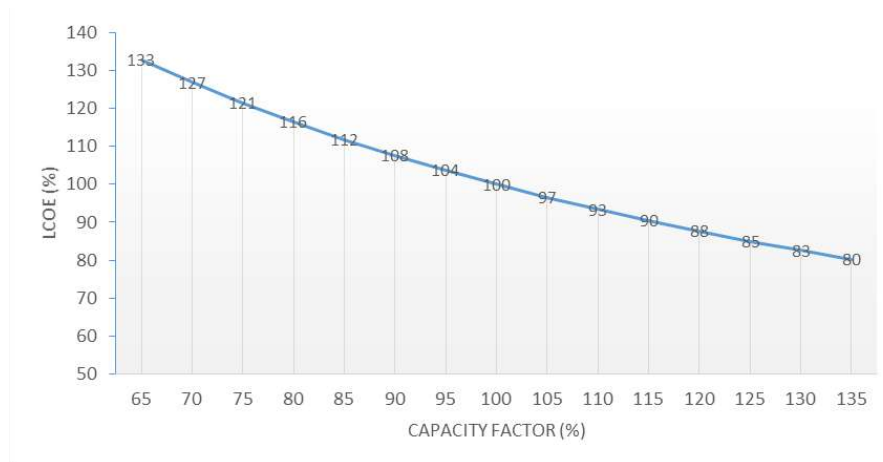


Figure 26: LCOE Sensitivity Analysis with the Capacity Factor

The NPV's break even value for the CF is 47% for market values of 103% (48% for a market value of 100%), thus demonstrating positive values for capacity factors over this number. Considering that the capacity factor is a parameter affected highly from the solar irradiation, the solar multiple, as well as the storage, 47% is already considered to be at the high end, or even exceed the capacity factor that can be achieved for PV systems with storage. Thus, any change in the CF is not considered to trigger a positive NPV, while the different market values considered have no impact on the NPV.

#### 4.3.6 Impact of the Discount Rate

The last parameter whose impact on the LCOE is studied is the discount rate. As mentioned in the literature survey, although lower values of the discount rate are available for the implementation of PV projects, the discount rate offered to companies implementing projects in EU is higher, especially if the combination of a mature technology with a developing one such as storage, is considered. The data utilized for the calculation of the LCOE related to this parameter are presented in Table 13.

Table 13: Correlation with the Discount Rate

| PV Investment Cost (€/kW) | PV Storage Cost (€/kWh) | PV O&M fixed costs (€/kW) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%)                      | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|---------------------------|-------------------------|---------------------------|--------------------------------|---------------------|----------------------------------------|---------------------------|----------------------------|
| 900                       | 550                     | 14.5                      | 8.5                            | 20                  | Increase of 0.1%€ in the range of 6-9% | 0.05                      | 0.025                      |

As evident from Figure 27, for a discount rate between 6-9%, the LCOE receives values in the range of 0.082 – 0.010 €/kWh. This means that following the linear relationship between the two parameters, a change of 20% in the discount rate leads to almost 10% variation of the LCOE, in line with the sensitivity analysis conducted and presented under Figure 28.

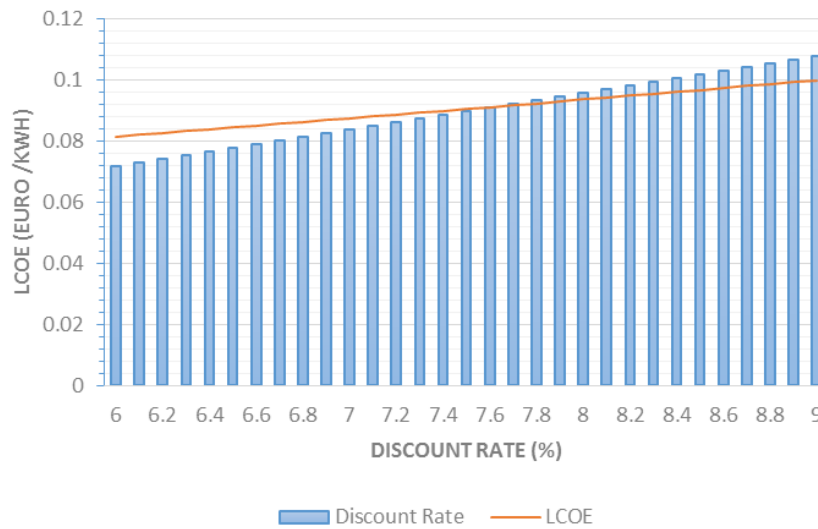


Figure 27: LCOE correlation with the Discount Rate



Figure 28: LCOE Sensitivity Analysis with the Discount Rate

This correlation between the two parameters is not strong enough in order to lead to positive NPV values, in line with the conducted calculations.

The NPV has been also calculated negative for an average cost of ancillary services at 0.025€/kWh and a wholesale market price ranging between 0.04-0.06€/kWh. More specifically, the NPV is positive for wholesale electricity prices higher than 0.1185 €/kWh and a market value of 103%, while if a market value of 100% is considered, the wholesale electricity price is 0.1188 €/kWh.

Considering the price in the wholesale electricity market constant at 0.05 €/kWh and a market value of 103%, the revenues from the ancillary services provided utilizing the electricity from storage, need to reach at least 0.1845€/kWh, in order for the NPV to be marginally positive. For a market value of 100%, the ancillary services' price for which the NPV breaks even is calculated to be

0.19€/kWh. From the above, it is clear that the low number of storage hours (two hours) used as dispatchable electricity, cannot improve the financial feasibility of the hybrid system (PV with storage), regardless of the market value of the electricity produced (100 or 103%).

## 4.4 Offshore Wind with Storage assessment results

The calculation of the LCOE for the data presented under Table 3, as well as Section 4.1, was realised, accompanied by the conduction of a sensitivity analysis for all engaged parameters. Also, the impact on the NPV, besides the LCOE, has been examined for all studied parameters.

The analysis presented below is based on two (2) hours of storage, in line with the assumptions under Section 4.1 and the analysis conducted for PVs with storage. The cumulative results for four (4) hours of storage are presented under Section 4.5 and the comparative analysis conducted.

### 4.4.1 Impact of the Offshore Wind Investment Cost

The correlation results of LCOE for offshore wind with its investment cost are presented in the following figures, based on the values in Table 14. This cost, as in the case of PVs, has not embedded the storage investment related cost, which is considered a different parameter in this study.

Table 14: Correlation with Offshore Wind Investment Cost

| Wind Investment Cost (€/kW)                   | Wind Storage Cost (€/kWh) | Wind O&M fixed costs (€/kW) | Wind O&M variable costs (€/kWh) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------------------------|---------------------------|-----------------------------|---------------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| Increase of 100€ in the range of 3,100-5,100€ | 550                       | 102.5                       | 0.015                           | 8.5                            | 47.5                | 7.5               | 0.05                      | 0.025                      |

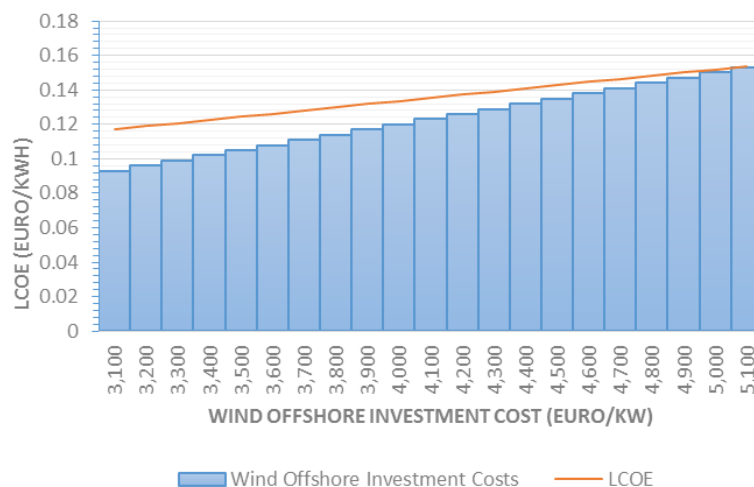


Figure 29: LCOE correlation with the Wind Offshore Investment Cost

For the offshore wind investment costs between 3,100 and 5,100 €/kW, the LCOE ranges between 0.1171 and 0.1538 €/kWh. These results are in line with IRENA (2018) and IRENA (2019), which refer to a global weighted LCOE of 12.6 eurocents /kWh in 2016, which fell to 10.7 eurocents /kWh in 2018, considering that they include also an investment cost for storage.

Based on the above, it seems that although the cost of wind offshore projects is a significant parameter for the LCOE, as someone would expect, it nevertheless doesn't affect more than 14% the LCOE value, for a change of 24% in its values (see the sensitivity analysis in Figure 30).

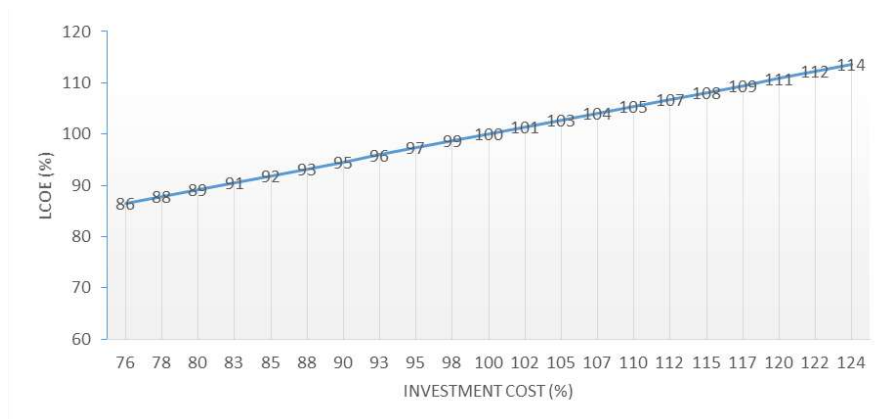


Figure 30: LCOE sensitivity analysis with the Wind Offshore Investment Cost

The calculation results of the NPV value demonstrate that the investment is not economically attractive for any values, while the investment cost's break-even point cannot be identified.

#### 4.4.2 Impact of the Storage Investment Cost

Having examined the impact of the offshore wind investment per se, the next parameter to be studied in line with Table 15 data is the storage investment cost, which is also contributing to the CAPEX of the overall investment.

Table 15: Correlation with Wind Storage Cost

| Wind Investment Cost (€/kW) | Wind Storage Cost (€/kWh)                | Wind O&M fixed costs (€/kW) | Wind O&M variable costs (€/kWh) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------|------------------------------------------|-----------------------------|---------------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 4,100                       | Increase of 50€ in the range of 200-900€ | 102.5                       | 0.015                           | 8.5                            | 47.5                | 7.5               | 0.05                      | 0.025                      |

The LCOE of the electricity produced by a wind offshore unit that includes a storage component, calculated for a storage cost between 200 – 900 €/kWh ranges between 0.1191-0.1518 €/kWh; is thus again considered rather rational compared to the reference values of the weighted global LCOE

average, since they don't include a storage investment cost, while the discount rates used are significantly lower.

As presented also in the sensitivity analysis under Figure 32, the storage cost although high, has a much lower impact on the LCOE compared to the investment cost for the offshore wind facility itself. Almost 64% variation of the storage's value has to take place in order to impact on the LCOE by approximately 12%, while an almost equal impact (12%) is achieved for a variation of 22% of the offshore wind investment cost.

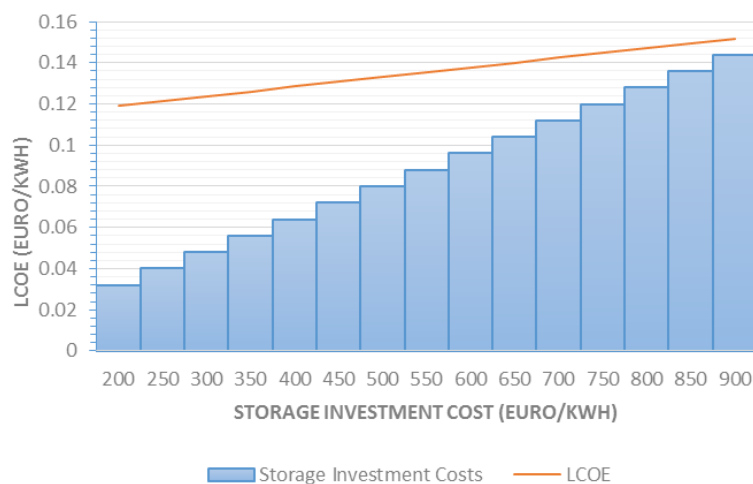


Figure 31: LCOE correlation with the Storage Investment Cost

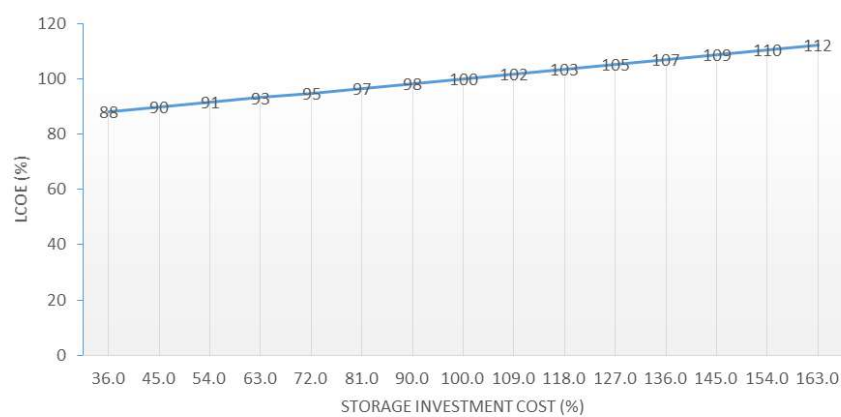


Figure 32: LCOE sensitivity analysis with the Storage Investment Cost

Considering the above mentioned figures from the sensitivity analyses conducted, as well as the results presented in the following sections, it is evident that the calculated LCOE of the offshore wind produced electricity is rather significantly affected by five parameters, namely investment cost, storage investment cost, capacity factor, discount rate, and O&M offshore wind variable costs. This means that there are more than one parameters significantly affecting the LCOE, and that the

sole impact of only one parameter on the NPV will be rather difficult to render it positive, when the rest of the parameters are kept at their average values. As a result, the NPV's calculation for the storage investment cost returns negative results in this case as well, regardless of the market value considered (100% or 103%). Of course, this doesn't mean that there are no offshore wind projects implemented, combined with storage, that would result in a positive financial evaluation, as these projects may have achieved values closer to the more optimistic end of the selected ranges for each parameter. It rather demonstrates the trend for each technological option, considering that average values in line with the available literature have been considered for all parameters.

#### 4.4.3 Impact of the Offshore Wind O&M Fixed Costs

Next parameter under study is the O&M Fixed Cost related only to the offshore wind component, in line with the values of Table 16, as the O&M fixed cost for storage is examined separately.

Table 16: Correlation with Offshore Wind O&M fixed Cost

| Wind Investment Cost (€/kW) | Wind Storage Cost (€/kWh) | Wind O&M fixed costs (€/kW)            | Wind O&M variable costs (€/kWh) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------|---------------------------|----------------------------------------|---------------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 4,100                       | 550                       | Increase of 5€ in the range of 75-130€ | 0.015                           | 8.5                            | 47.5                | 7.5               | 0.05                      | 0.025                      |

The impact of fixed O&M costs for the offshore wind farm on the LCOE, is not negligible, as someone would expect in line with the CSP and PV technologies. The calculated LCOE ranges between 0.1298 and 0.139 €/kWh, or in line with the sensitivity analysis conducted and presented under Figure 34, demonstrates a variation by slightly over 4% for a parameter variation up to 27%.

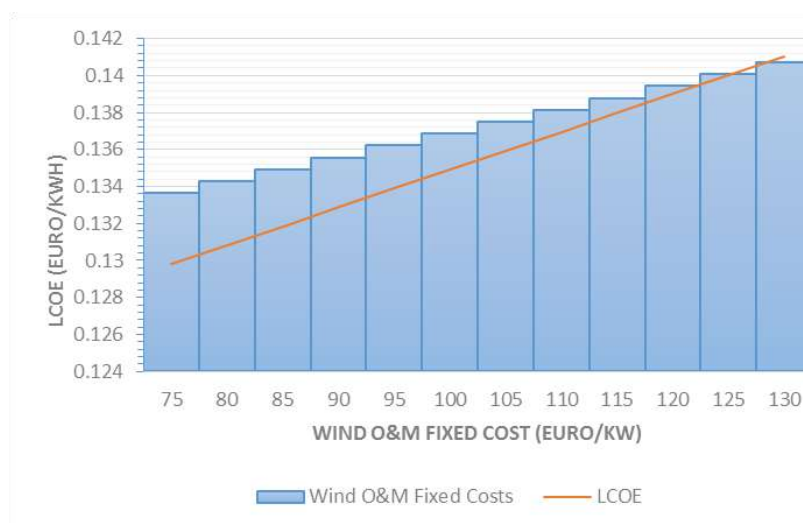


Figure 33: LCOE correlation with the Wind O&M Fixed Cost

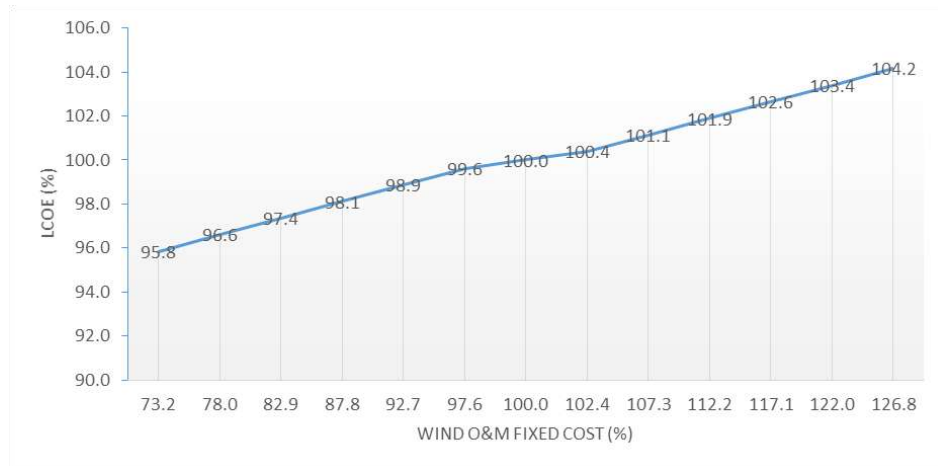


Figure 34: LCOE sensitivity analysis with the Wind O&M Fixed Cost

As expected, the NPV for the Table 16 parameters' values is not financially feasible.

#### 4.4.4 Impact of the Offshore Wind O&M Variable Cost

Having checked the correlation between LCOE and O&M Fixed Costs for offshore wind, the impact of O&M variable cost for the same system is next in line. Data from Table 17 is used for the calculations.

Table 17: Correlation with Offshore Wind O&M Variable Cost

| Wind Investment Cost (€/kW) | Wind Storage Cost (€/kWh) | Wind O&M fixed costs (€/kW) | Wind O&M variable costs (€/kWh)               | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------|---------------------------|-----------------------------|-----------------------------------------------|--------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 4,100                       | 550                       | 102.5                       | Increase of 0.001€ in the range of 0.01-0.02€ | 8.5                            | 47.5                | 7.5               | 0.05                      | 0.025                      |

The variable cost's impact on the LCOE is not negligible as someone would expect. For prices of 0.01-0.02 €/kWh, the LCOE ranges from 0.1312 to 0.1397 €/kWh, thus deviating by approximately 3% for a change of up to 33% of the studied parameter.

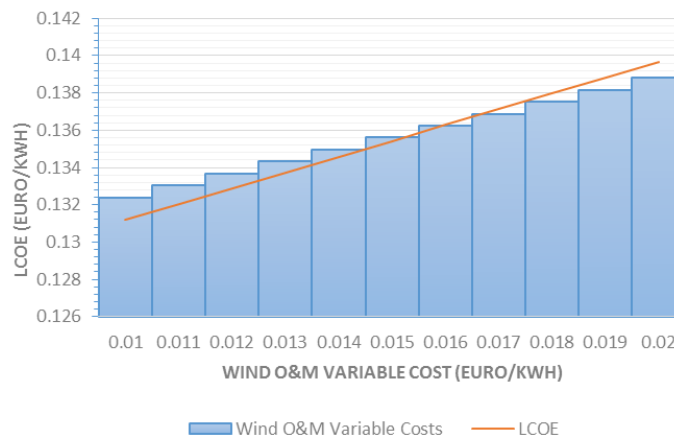


Figure 35: LCOE correlation with the Wind O&M Variable Cost

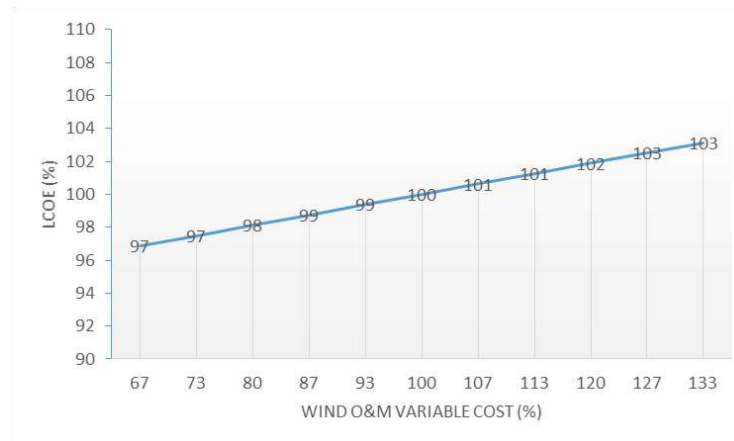


Figure 36: LCOE sensitivity analysis with the Wind O&M Variable Cost

The calculation of the NPV also received negative results.

#### 4.4.5 Impact of the Storage O&M Fixed Cost

The relevant O&M fixed costs for storage and their impact on the LCOE of the electricity produced by the offshore wind farm are calculated in line with Table 18 data.

Table 18: Correlation with Storage O&M Fixed Cost

| Wind Investment Cost (€/kW) | Wind Storage Cost (€/kWh) | Wind O&M fixed costs (€/kW) | Wind O&M variable costs (€/kWh) | Storage O&M fixed costs (€/kW)          | Capacity Factor (%) | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------|---------------------------|-----------------------------|---------------------------------|-----------------------------------------|---------------------|-------------------|---------------------------|----------------------------|
| 4,100                       | 550                       | 102.5                       | 0.015                           | Increase of 0.5€ in the range of 5- 12€ | 47.5                | 7.5               | 0.05                      | 0.025                      |

As demonstrated in Figure 37, the impact of this parameter on the LCOE is negligible, since LCOE receives values in the range of 0.1351-0.1358€/kWh. This is more understandable from the sensitivity analysis conducted, where a change in the parameter up to 40% doesn't return a differentiated LCOE (LCOE % values remain the same).

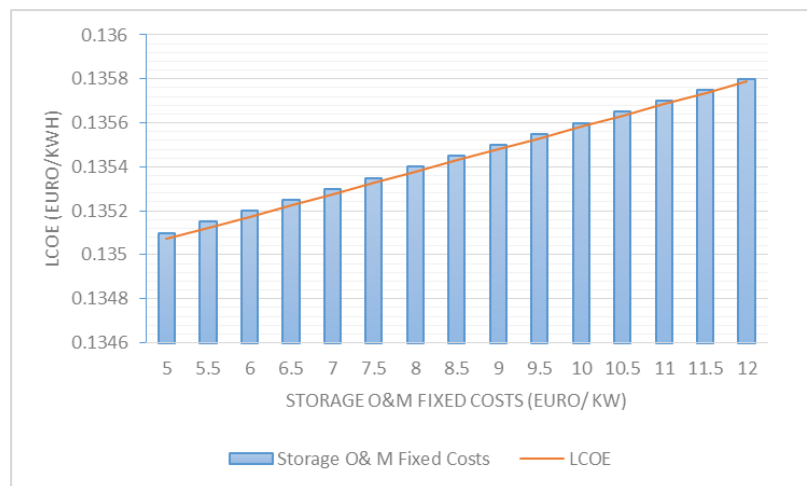


Figure 37: LCOE correlation with the Storage O&M Fixed Cost

Based on the above, of course the NPV for this parameter is calculated negative.

#### 4.4.6 Impact of the Capacity Factor

The next parameter whose correlation with the LCOE is studied is the capacity factor, which so far for the CSP and PV with storage has demonstrated to be among the most significant parameters. The LCOE calculation is conducted for the data presented in Table 19.

Table 19: Correlation with the Capacity Factor

| Wind Investment Cost (€/kW) | Wind Storage Cost (€/kWh) | Wind O&M fixed costs (€/kW) | Wind O&M variable costs (€/kWh) | Storage O&M fixed costs (€/kW) | Capacity Factor (%)                   | Discount rate (%) | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------|---------------------------|-----------------------------|---------------------------------|--------------------------------|---------------------------------------|-------------------|---------------------------|----------------------------|
| 4,100                       | 550                       | 102.5                       | 0.015                           | 8.5                            | Increase of 1% in the range of 40-55% | 7.5               | 0.05                      | 0.025                      |

In this case, the same assumption is validated, as for a range of the CF between 40-55%, the LCOE receives values starting from as high as 15.41 eurocents/kWh, and reaching even 12.12 eurocents/kWh.

This conclusion is even more clearly depicted under the sensitivity analysis conducted and presented under Figure 39, where a 16% change in the parameter's value leads to an almost equal variation

(14%) of the LCOE price for a CF value between 40-47.5%. The correlation remains almost equally strong, for CF values between 47.5-55%, where the reduction of the LCOE is approximately 11% for a variation of 16%.

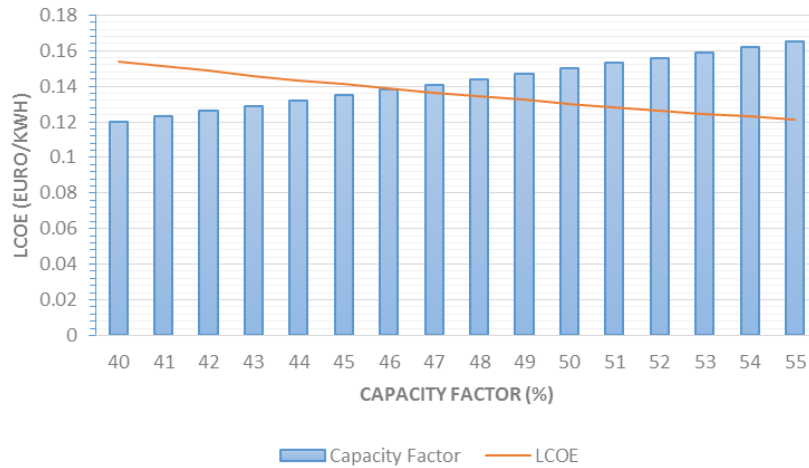


Figure 38: LCOE correlation with the Capacity Factor

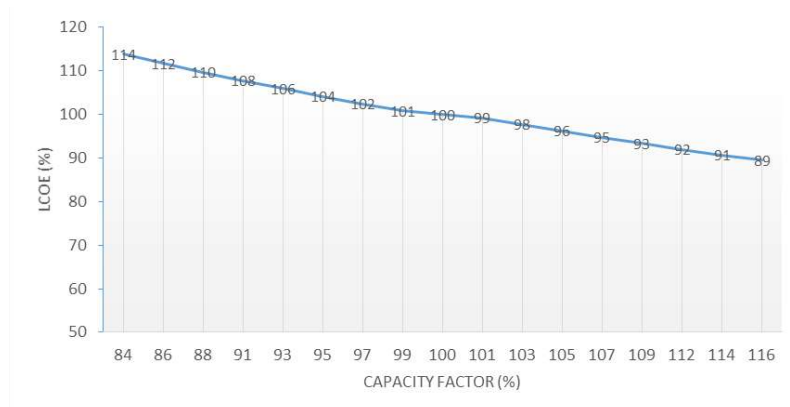


Figure 39: LCOE sensitivity analysis with the Capacity Factor

The calculation of the NPV for the values of Table 19 is again negative for any market values considered, despite this strong dependence of the LCOE price on the CF. The reasoning behind this phenomenon has been described in previous sections where negative values of the NPV were also experienced. This has to do on one hand with the fact that many parameters significantly affect the LCOE, while on the other hand, that the average values of the parameters utilized in the analysis are higher than those of potentially implemented wind offshore projects with storage with positive NPV.

#### 4.4.7 Impact of the Discount Rate

The last parameter examined is the discount rate, according to the data provided under Table 20.

Table 20: Correlation with the Discount Rate

| Wind Investment Cost (€/kW) | Wind Storage Cost (€/kWh) | Wind O&M fixed costs (€/kW) | Wind O&M variable costs (€/kWh) | Storage O&M fixed costs (€/kW) | Capacity Factor (%) | Discount rate (%)                     | Electricity Price (€/kWh) | Ancillary Services (€/kWh) |
|-----------------------------|---------------------------|-----------------------------|---------------------------------|--------------------------------|---------------------|---------------------------------------|---------------------------|----------------------------|
| 4,100                       | 550                       | 102.5                       | 0.015                           | 8.5                            | 47.5                | Increase of 0.1% in the range of 6-9% | 0.05                      | 0.025                      |

As in the previous technologies examined, this as well affects rather significantly the LCOE values, that range between 0.1233 and 0.1482 €/kWh, thus a change of 9% over the base value, for a change in the parameter of 20%, as depicted in Figure 41.

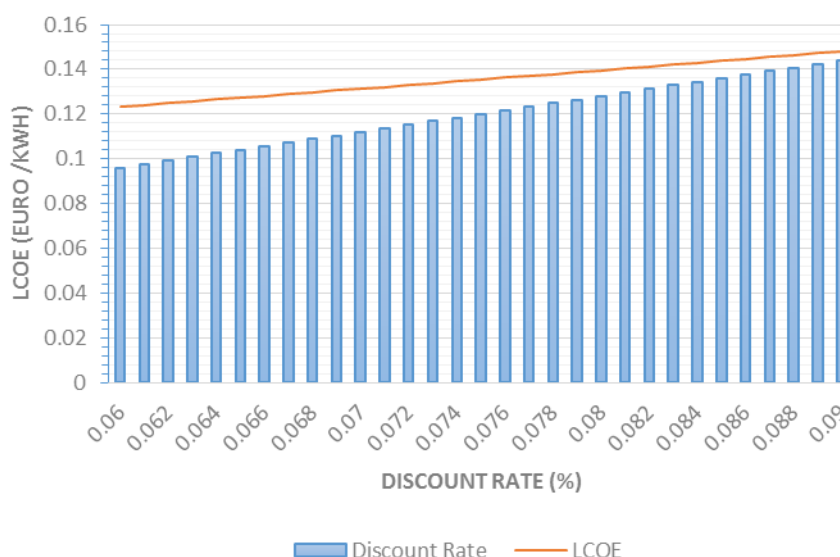
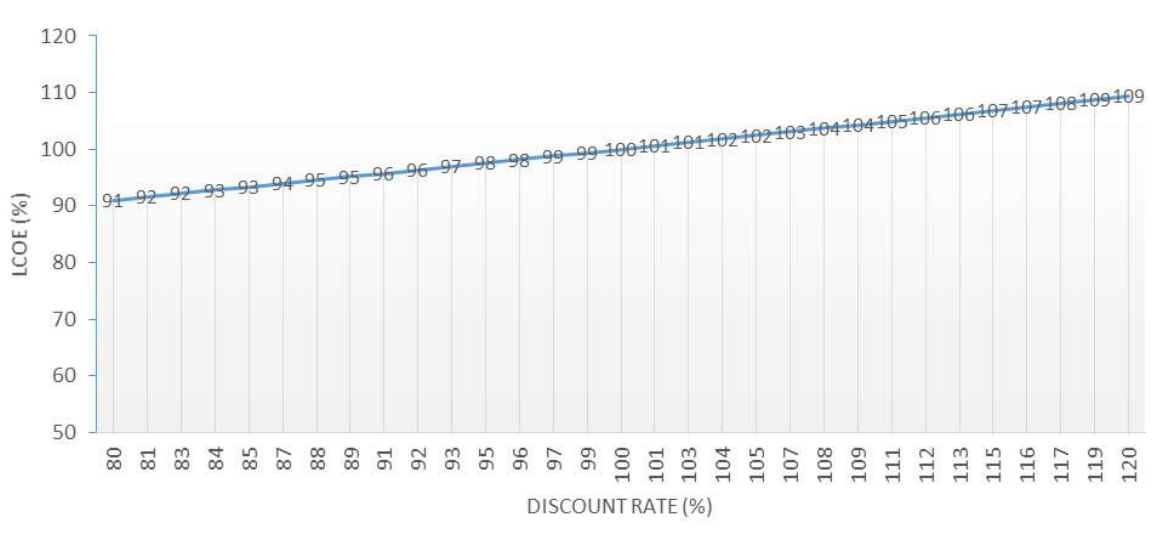


Figure 40: LCOE correlation with the Discount Rate



*Figure 41: LCOE sensitivity analysis with the Discount Rate*

The NPV for this parameter is also calculated to be negative. As mentioned above, it is assumed that due to the high correlation of LCOE with more than one parameters, optimum values need to be achieved in more than one variables in order to obtain a positive NPV.

An electricity market price of 0.1547 €/kWh is the break-even point for offshore wind values to be positive for a market value of 103% (and 0.1548€/kWh for a market value of 100%). Offshore wind is already a highly capital-intensive technology, which if combined with electrical batteries as storage, narrows even further its margins for financial sustainability. It is also evident that due to the limited dispatchability offered by the two hours of storage, the ancillary services considered cannot make a real difference, while the market value selected between 100% and 103% has negligible impact on the results.

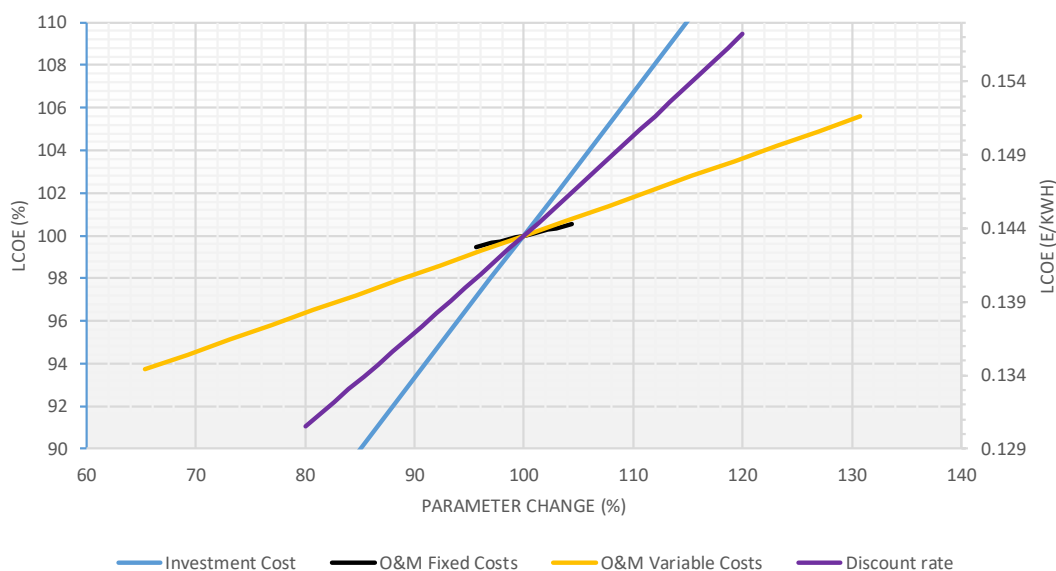
## 4.5 Results from the comparative analysis

In the previous sections, a technoeconomic assessment of each technological option, accompanied by a sensitivity analysis conducted for each parameter, is presented.

A more accurate comparative depiction of the impact each one of the studied parameters has per technology is presented in the following figures, that gather the sensitivity analysis results for each technological option.

The conclusions derived through the analysis of the parameters' impact on LCOE values for the CSP with storage technology, are validated through the comparable plotting of LCOE variation with each one of the CSP parameters studied, in line with Figure 42, namely:

- The parameter most significantly affecting the LCOE is the investment cost, that has already embedded the capacity factor influence. More specifically, a 15% change in the parameter value results in at least 10% differentiation in the LCOE price.
- The second parameter affecting the LCOE is the discount rate applied, but at a lower percentage, with a 20% change in the parameter resulting in 9% change in the LCOE.
- The behavior of O&M variable costs on the LCOE is also remarkable, as they manage to create a 6% variation of the LCOE value, even for a change in their own value by 30%.
- The O&M fixed costs have a negligible impact on the LCOE.
- Finally, the LCOE price calculated for an average value at all prices is 0.1429€/kWh.

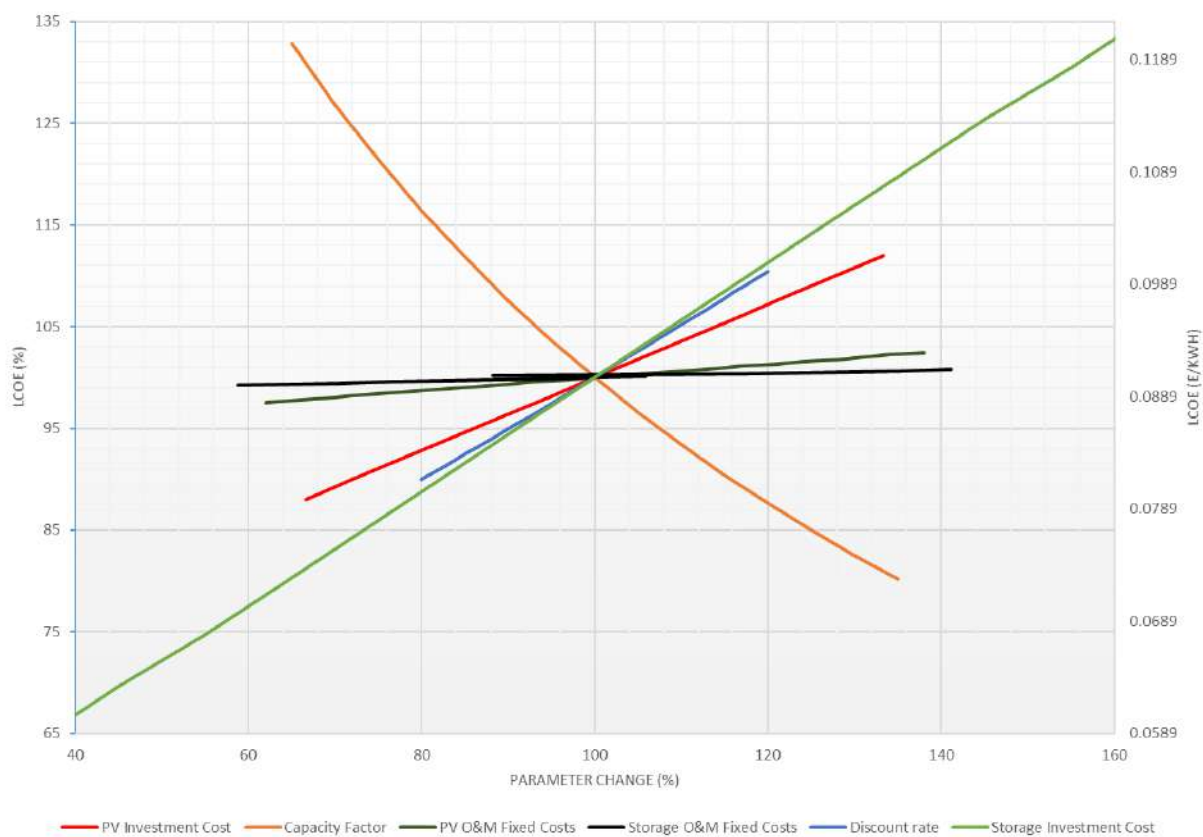


*Figure 42: LCOE sensitivity analysis with all CSP plus Storage Parameters*

As regards the PV with a storage component of two hours, in line with Figure 43, the following conclusions can be derived:

- The parameter most significantly affecting the LCOE is the Capacity Factor, as for a 35% variation, it triggers an almost equal increase of the LCOE (33%), for values below its base reference, namely CF of 20%. The reduction of the LCOE for values higher than CF 20%, e.g. 35% increase of the CF, leads to only 20% reduction of the LCOE.
- As a result, the second parameter in terms of impact on the LCOE is considered the Storage Investment Cost, which for a 35% variation in its value, results in a 20% change in the LCOE.
- The impact of the discount rate is third in line, with a 20% variation in its value triggering a 10% deviation in the LCOE values.

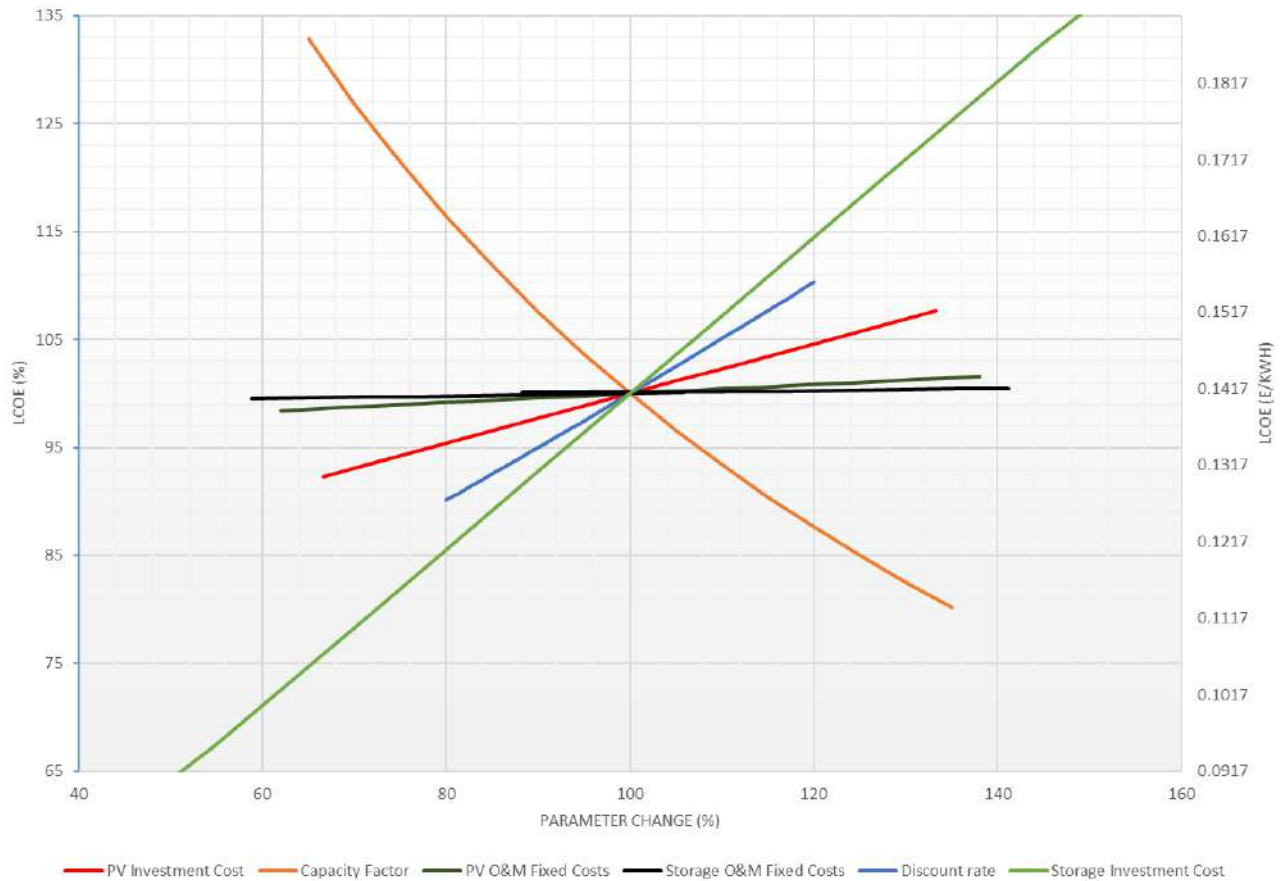
- The impact of the PV investment cost on the LCOE is closely behind the discount rate, where a variation of the LCOE by 10% is triggered by 28% change in its value. Nevertheless, these two parameters are relatively close.
- The PV O&M fixed costs fall largely behind, as their impact on LCOE is rather insignificant, although it cannot be neglected.
- The parameter least affecting the LCOE is the Storage O&M fixed costs, which is considered negligible.
- The LCOE price calculated for all parameters at their average values is 0.0906€/kWh.



*Figure 43: LCOE sensitivity analysis with all PV plus 2 hours Storage Parameters*

An alternative scenario for the PV storage component was assumed, in order to further study its impact on the LCOE. The calculations for its impact assuming four hours of storage have been conducted and presented in the following figure. The main difference is the LCOE calculated considering average values in all parameters, namely 0.1411€/kWh. As regards each parameter's impact on the LCOE, the results are similar to the above for a storage capacity of two hours, although the exact impact on the LCOE differentiates. More specifically, the ranking of the parameters' impact on the LCOE remains the same. What differentiates is the impact of the storage cost on the LCOE, where a 36% variation in its value results to 26% variation of the LCOE (instead of 20% above).

Also, the impact of the PV investment cost, still remaining in the 4<sup>th</sup> position, is reduced; a 33% change in the parameter contributes to 8% variation of the LCOE.



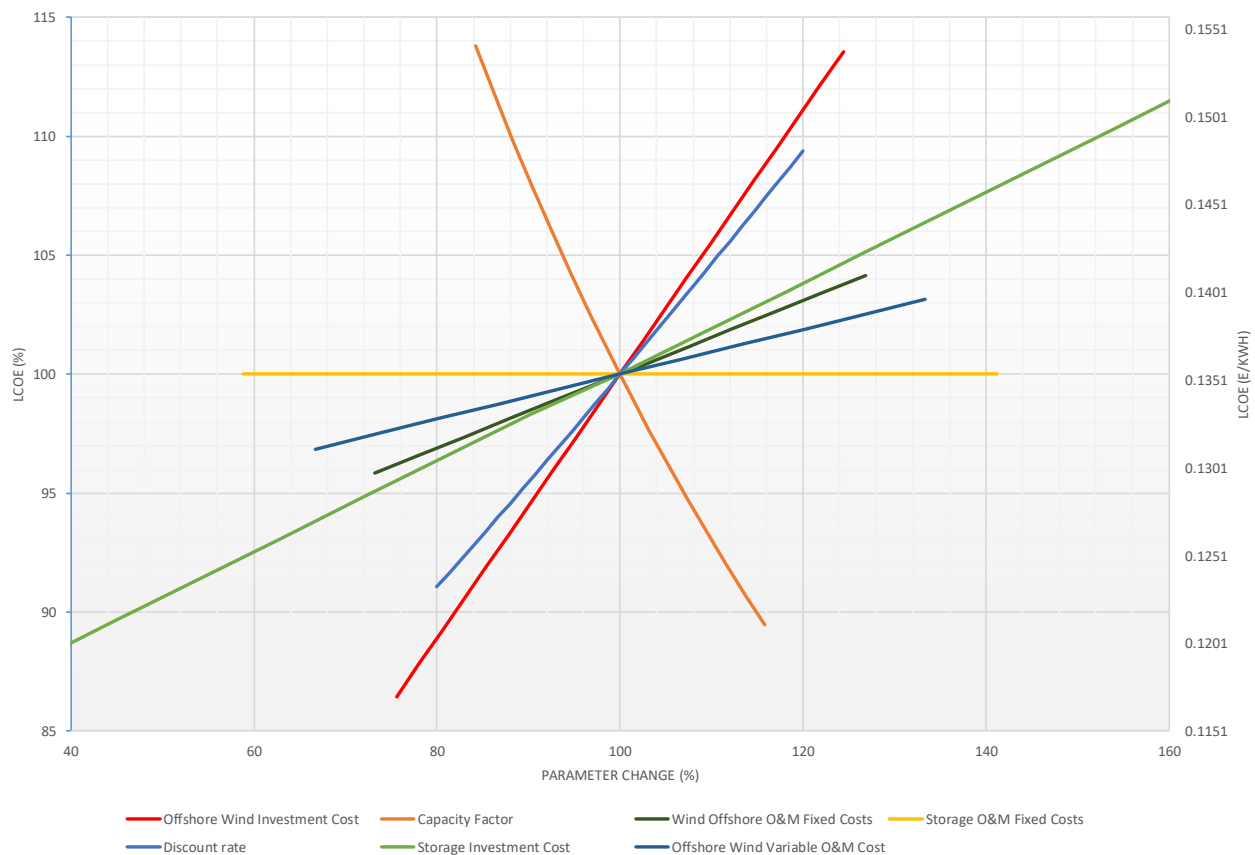
*Figure 44: LCOE sensitivity analysis with all PV plus 4 hours Storage Parameters*

The impact of the wind offshore plus storage (of two hours) related parameters is presented under Figure 45, where a more equal dependence of LCOE on more than one parameters is clearly depicted. Besides the storage O&M fixed costs which has no impact and the CF that has a strong correlation, the rest of the parameters cause a comparable deviation in the LCOE values. More specifically:

- The parameter presenting the strongest impact on the LCOE is the CF, and especially for values below its base reference, namely 47.5%.
- The wind investment cost is also largely affecting the LCOE, with a 20% change in its value resulting in approximately 11% deviation in the LCOE.
- Closely behind, in the third position is the discount rate used. The same percentage change in the parameter's value, namely 20%, leads to a 9% variation of the LCOE.
- The storage cost's impact on the LCOE is less significant than someone would expect, with only a 3% LCOE variation for a change of 20% in the parameter's value. This is probably attributed to

the storage cost scale compared to the much more capital intensive values of the initial investment cost for wind offshore.

- The O&M fixed costs for offshore wind, followed by the variable O&M costs for the same module have almost the same behavior, with an impact on LCOE lower than 3% for a 20% change in their values.
- The storage O&M fixed costs have no impact on the LCOE.
- The LCOE calculated for an average value of all parameters is 0.1354 €/kWh.

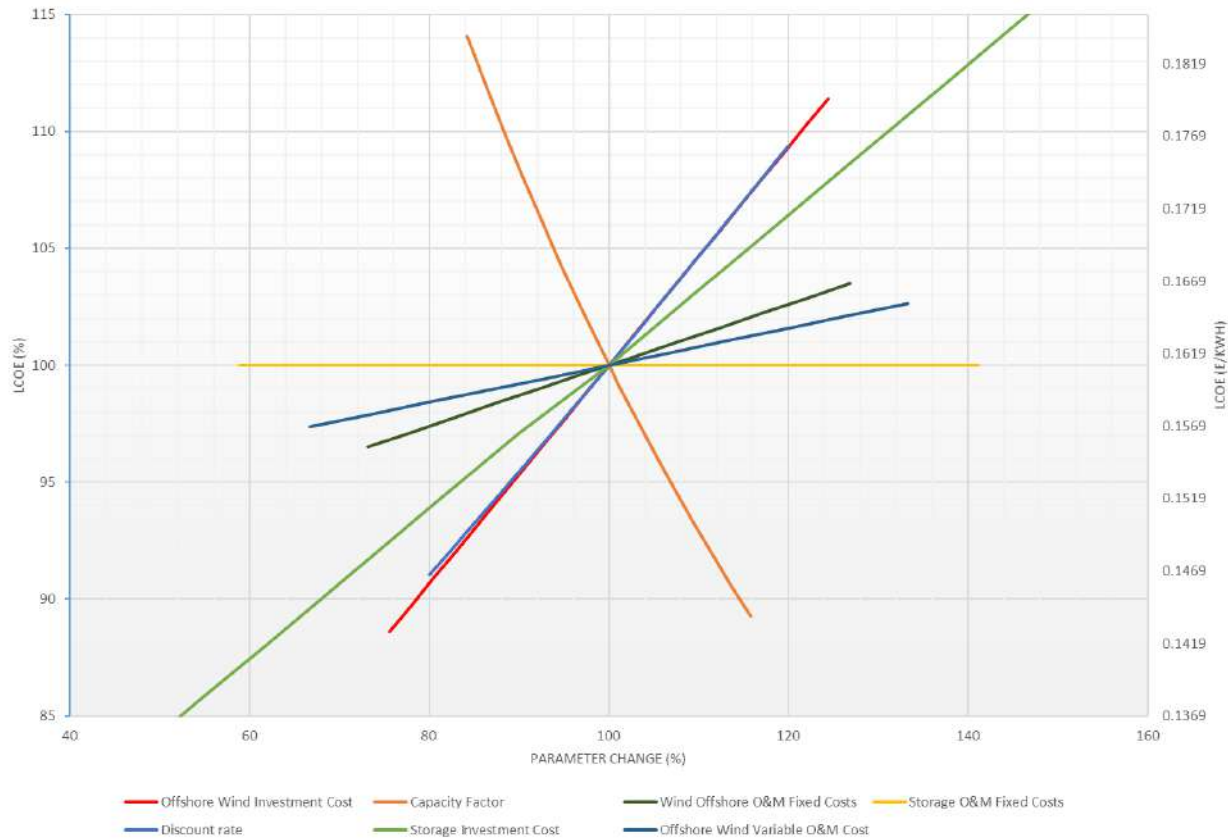


*Figure 45: LCOE sensitivity analysis for all Offshore Wind plus 2 hours Storage Parameters*

With reference to a four hours storage capacity, the situation is differentiated as follows. First of all, the calculated LCOE for an average of all parameters is 0.1611€/kWh, instead of 0.1354€/kWh described above. This means that the LCOE increase percentage for a doubling of the storage capacity (from 2 to 4 hours) is 15.6% for offshore wind, compared with PV, where the LCOE increase is 35.8%. This significant difference is attributed to the higher capital investment cost of offshore wind compared to PV; consequently, the increase of the storage cost triggers a higher percentage increase in the PVs, compared to offshore wind.

The behavior of all the parameters remains in line with the conclusions of Figure 46; namely the capacity factor is still the most important parameter, followed by offshore wind investment cost

and discount rate at the second place. Third place, reducing the overall distance from the previous parameters, goes to the storage cost. The rest remain rather the same.



*Figure 46: LCOE sensitivity analysis for all Offshore Wind plus 4 hours Storage Parameters*

Overall, for the whole range of values studied for CSP with storage, the low and high end of the values that LCOE received were between 0.1295 and 0.157€/kWh. The LCOE reference range in the PV plus storage of two hours were between 0.059 and 0.1223€/kWh, while for the same technology and four hours of storage, the values varied between 0.0917 and 0.1905 €/kWh. Considering the offshore wind plus storage of two hours, the values varied between 0.1171 and 0.1538 €/kWh, while for four hours of storage, the LCOE ranged between 0.1284 and 0.1937€/kWh. The largest range in the values attained is presented for PV plus storage of four hours, followed by offshore wind plus storage of four hours. Third place goes to PVs with two hours of storage, followed by offshore wind with the same storage hours. The lowest range in this analysis is attributed to CSP.

This larger LCOE range for the PV plus storage is mainly attributed to the wider impact that the storage cost has on a technology with lower investment cost required compared to offshore wind and CSP. Thus, it is clear that the regulating parameter in the LCOE is the storage cost applied. Considering that in the case of CSP the overall investment cost has already integrated within it the storage cost, such impact cannot be isolated and compared with the other two technologies.

It should be noted though that these technologies cannot be considered entirely equivalent, as CSP offers full dispatchability, while the offshore wind and PV plus storage of two or four hours offer dispatchability to some extent.

Also, rather remarkable is the fact that the NPV calculation for the majority of the combinations studied returns negative values, as in all parameters examined for offshore wind plus storage, or returns marginally positive values for parameters

The only parameter for which a NPV positive value was achieved, considering the learning rates attained by the technologies, was a CSP plus storage investment cost lower than 1,995€/kW. In all other cases, e.g. CF for PV plus storage over 47%, or a storage investment cost for the PVs lower than 24 €/kWh, are considered not attainable.

As highlighted above, this doesn't mean that there are no real life projects in these technologies, where positive NPV values can be achieved; it rather means that in order for this to be realised, values closer to the lower (or higher for CF) end of all studied parameters should be attained for the project. This analysis is beyond the scope of this study, where the technological options are assessed based on their reference values, as identified in the international literature and following consultation with industrial stakeholders.

As for the wholesale electricity market price required in order for the technologies to break even, in the case of CSP plus storage with the values of the parameters studied in line with Table 1, this is at least 0.1385€/kWh. For PV plus storage of two hours (Table 2 data) the wholesale electricity prices should be higher than 0.1185 €/kWh and for four hours it should be more than triple this price, namely 0.365€/ kWh, for the technology to break-even. Finally, for wind offshore plus storage of two hours (Table 3) this should be higher than 0.1547 €/kWh, while for four hours this price skyrockets to an amount of 0.7635 €/kWh.

## 5 CONCLUSIONS

The current report has focused on identifying the lessons from existing cooperation initiatives and competing renewable dispatchable technologies. As such, the first section highlights the main lessons learned from the review of six regional initiatives that were launched in the EU, namely the North Seas Countries' Offshore Grid initiative, the Pentalateral energy forum, the Baltic Energy Market Interconnection Plan, the Desertec initiative, ENTSO-e regional groups and Electricity Regional Initiatives. Considering that some of these initiatives had an institutional form, while others were more informal, in terms of a dialogue basis, the main conclusions from the results they achieved are:

- Fostering cooperation requires the development of concrete regulatory solutions and related pilot projects.
- Underlying policy issues should also be taken into consideration; highest political commitment is of vital significance.
- Synchronisation with European networks and Commission leadership can play a significant role in facilitating regional cooperation.
- Compatibility issues are a critical parameter for the interconnection of Europe with other regions.
- Region overlaps in continental Europe can enhance the emergence of compatible solutions across regions, but involved countries should share specific infrastructural characteristics.
- Regional initiatives are the main vehicle for coordinating the practical implementation of the new European cross-border regulatory framework.

It is therefore evident that any regional initiatives to promote the use of dispatchable RES technologies such as CSP need to satisfy the majority of the above lessons learned in order to be successful.

With regards to the competitiveness of dispatchable RES technologies, three different technologies were evaluated: CSP with storage, PV with storage and offshore wind with storage. The aim of this comparative assessment was not to identify an optimum technology, as the high RES penetration scenarios for the long-term horizon, in line with the ambitious carbon neutral strategy for 2050, should comprise of a mix of different technological options, satisfying different needs. The objective was rather to identify the conditions under which the CSP can have a competitive advantage against other comparable technologies, in order to be sustained until the rest of the required conditions for its development are more favorable. To this end, PV and offshore wind combined with two different storage options (of two and four hours) were examined, in order to be assessed on a comparative basis. The conclusions derived from this assessment should be treated as revealing of a qualitative

trend, and not per se absolute values, considering that they were based on average ranges of data coming from recent studies (after 2017). The majority of these studies cover a broad range of projects implemented over the last couple of years and estimations for the future; as such, the comparison is not realised between specific projects, something that would allow a more accurate but less generic estimation of the current trends.

The conclusions derived from the analysis and the impact study of specific parameters on the overall performance of these technologies include the following:

- The Capacity Factor is the one most significantly affecting the overall LCOE in the cases of offshore wind with storage and PV with storage. The same assumption is valid for CSP with storage projects, where the storage cost is already embedded in the initial investment cost and thus closely connected with the capacity factor.
- The discount rate has a significant impact on the LCOE on all three technologies, comprising the second or third parameter in line affecting the LCOE. In technologies where the initial investment cost is higher (CSP, offshore wind plus storage), its impact is slightly more significant against PV with storage. Such a high impact is attributed to the fact that high ranges of the discount rate have been used, in line with the current situation in Europe. It should be noted that although slight differences in the discount rate among different technologies might exist, the same reference range has been assumed for comparability purposes.
- The rest of the parameters examined (variable and fixed operation and maintenance related costs) have low or negligible impact on the LCOE values.
- CSP with storage (average value of storage around 9-10 hours) has an LCOE range of approximately 0.1295 and 0.157€/kWh, with an average value of 0.1429€/kWh. On the other hand, PVs with two hours of storage demonstrate an LCOE reference range between 0.059 - 0.1223€/kWh and an average value of 0.0906€/kWh, while for the same technology and four hours of storage, the values varied between 0.0917 - 0.1905 €/kWh, with an average of 0.1411 €/kWh. Considering the offshore wind plus storage of two hours, the values varied between 0.1171 and 0.1538 €/kWh, with an average value of 0.1354€/kWh, while for four hours of storage, the LCOE ranged between 0.1284 and 0.1937€/kWh, with an average of 0.1611€/kWh.
- As a result, for low storage hours (two hours or less), PVs coupled with storage seem to be the most cost-effective option, followed by offshore wind with storage and CSP in the third place. For storage requirements of more than four hours, CSP with storage seem to be the preferable option, considering that for four hours, the PVs are marginally better than CSP, while the difference between these two technologies and offshore wind increases significantly. This conclusion is generally in line with ARENA (2018), who highlight the competitiveness of CSP with storage compared with other dispatchable RES technologies for storage over 6 hours. It should be highlighted that this deviation in the number of storage hours beyond which the CSP with

storage perform better between the two studies, highly depends on the assumptions on the technology related costs and discount rates considered.

- Considering that CSP has been treated in this study as a fully dispatchable technology, compared to the other two technologies that have been considered to offer partial dispatchability, a price of ancillary services has been assumed for the storage electricity that can be provided by these technologies. As such, the price of ancillary electricity for which the NPV of CSP projects breaks-even considering that all parameters are at their average values, is 0.1385€/kWh. For PV and offshore wind with storage, the price of ancillary services needed is 3 and 6 times more respectively.
- Since average values have been used for the study of the parameters' impact on the LCOE and NPV calculation, the fact that no positive value for the NPV has been calculated for any of the technologies assessed, doesn't mean that there are no real life projects that have managed to be financially attractive, with specificities in the values of the considered parameters. It is significant though that the investment cost for which the CSP technology breaks even is less than 2 million €/MW, which although low, is a price that can be achieved in the coming years based on the learning rates the technology is expected to achieve.
- The market value of 103% considered for all the technologies, it is not considered to support the performance of offshore wind and PV, as this price applies only to the storage electricity, which is rather low compared to the overall production. On the other hand, it slightly helps CSP technology, but its impact is not yet significant enough to cover the gap for its financial feasibility.

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## WHO WE ARE

The MUSTEC consortium consists of nine renowned institutions from six European countries and includes many of the most prolific researchers in the European energy policy community, with very long track records of research in European and nationally funded energy policy research projects. The project is coordinated by Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-CIEMAT.

| Name                                                                                       | Country | Logo                                                                                  |
|--------------------------------------------------------------------------------------------|---------|---------------------------------------------------------------------------------------|
| Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas – <b>CIEMAT</b>     | ES      |     |
| University of Piraeus Research Center – <b>UPRC</b>                                        | GR      |    |
| Eidgenössische Technische Hochschule Zürich - <b>ETH Zürich</b>                            | CH      |   |
| Technische Universität Wien - <b>TU WIEN</b>                                               | AT      |  |
| European Solar Thermal Electricity Association – <b>ESTELA</b>                             | BE      |  |
| COBRA Instalaciones y Servicios S.A – <b>COBRA</b>                                         | ES      |  |
| Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. – <b>Fraunhofer</b>   | DE      |   |
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| Fundacion Real Instituto Elcano de Estudios Internacionales y Estrategicos – <b>ELCANO</b> | ES      |  |



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