European University Institute

ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES

EUI WORKING PAPERS

RSCAS 2017/53
Robert Schuman Centre for Advanced Studies
Florence School of Regulation

Assessment of Cost-Benefit Analysis for offshore electricity infrastructure development

Pradyumna C Bhagwat, Tim Schittekatte, Nico Keyaerts and Leonardo Meeus

European University Institute
Robert Schuman Centre for Advanced Studies
Florence School of Regulation

Assessment of Cost-Benefit Analysis for offshore electricity infrastructure development

Pradyumna C Bhagwat, Tim Schittekatte, Nico Keyaerts and
Leonardo Meeus

EUI Working Paper **RSCAS** 2017/53

ISSN 1028-3625

Printed in Italy, October 2017
European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy
www.eui.eu/RSCAS/Publications/
www.eui.eu
cadmus.eui.eu

Robert Schuman Centre for Advanced Studies

The Robert Schuman Centre for Advanced Studies (RSCAS), created in 1992 and directed by Professor Brigid Laffan, aims to develop inter-disciplinary and comparative research and to promote work on the major issues facing the process of integration and European society.

The Centre is home to a large post-doctoral programme and hosts major research programmes and projects, and a range of working groups and *ad hoc* initiatives. The research agenda is organised around a set of core themes and is continuously evolving, reflecting the changing agenda of European integration and the expanding membership of the European Union.

Details of the research of the Centre can be found on:
http://www.eui.eu/RSCAS/Research/

Research publications take the form of Working Papers, Policy Papers, Policy Briefs, Distinguished Lectures, Research Project Reports and Books.

Most of these are also available on the RSCAS website:
http://www.eui.eu/RSCAS/Publications/

Florence School of Regulation

The Florence School of Regulation (FSR) is a partnership between the Robert Schuman Centre for Advanced Studies (RSCAS) at the European University Institute (EUI), the Council of the European Energy Regulators (CEER) and the Independent Regulators Group (IRG). Moreover, as part of the EUI, the FSR works closely with the European Commission.

The objectives of the FSR are to promote informed discussions on key policy issues, through workshops and seminars, to provide state-of-the-art training for practitioners (from European Commission, National Regulators and private companies), to produce analytical and empirical researches about regulated sectors, to network, and to exchange documents and ideas.

At present, its scope is focused on the regulation of Energy (electricity and gas markets), Communications & Media, and Transport.

This series of working papers aims at disseminating the work of scholars and practitioners on current regulatory issues.

For further information
Florence School of Regulation
Robert Schuman Centre for Advanced Studies
European University Institute
Casale, Via Boccaccio, 121
I-50133 Florence, Italy
Tel: +39 055 4685 878
E-mail: FSR.Secretariat@eui.eu
Web: http://fsr.eui.eu/

The research leading to this publication is part of a project that has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714 - PROMOTION. This paper reflects only reflects the author’s view and the EU is not liable for any use made of the information in this report.

Abstract

The application of cost-benefit analysis (CBA) for offshore electricity infrastructure projects with a pan-European impact is discussed. An analytical framework for the evaluation of CBA methodologies is presented. The framework is then applied to assess the CBAs of three offshore infrastructure projects (EWIC, COBRAcable and ISLES). Overall, the CBAs assessed already comply with several dimensions of the analytical framework. However, based on this assessment it is found that scope for improvement in quality exists in three areas namely, in considering project interactions, in dealing with uncertainty and in making the results between CBAs comparable by ensuring full monetisation. Furthermore, the research also confirms the view that a common harmonised CBA methodology is essential for selection of PCIs.

Keywords

Cost-benefit analysis, offshore infrastructure, electricity transmission, transmission expansion planning.

1. Introduction*

The use of CBA for guiding investments in electricity transmission is relatively new. Therefore, the research on this topic has been limited. De Nooij, (2011) discussed the CBA of two case studies namely NorNed and EWIC to study investment decisions in interconnectors. In conclusion, the authors found that there is scope for improvement in the CBA and provide recommendations. In this paper, we extend the academic research on this subject by analysing in detail the use of a CBA in the planning of three offshore transmission interconnector projects namely, EWIC, COBRAcable and ISLES. The cases were chosen due to their differing characteristic as described in 0. We also present an analytical framework utilised for the assessment of these case studies.

Cost-Benefit Analysis (CBA) is a well-established decision support instrument (Courtney et al., 2013) that finds its roots in 'welfare economics' (Griffin, 1998). CBA has been used to guide investment decisions in various sectors, including the energy sector. It can be utilised either to assess whether the benefit of a project or policy, outweighs its cost or to compare alternative projects on an equal footing (Mishan and Quah, 2007; Pearce, 1971). In the context of electricity infrastructure projects such as interconnectors, the results from the CBA are valuable in the process of making cross-border cost allocation (CBCA) decisions as well.

The European Union too has acknowledged the importance of using common decision support tool for infrastructure investments. This is evident from the TEN-E regulation (European Parliament, 2013), which makes it mandatory for project developers to conduct a CBA to be eligible for European Union financing as projects of common interest (PCIs). PCIs are projects that are expected to lead to a pan-European welfare increase. While earlier projects have been evaluated using ad hoc methods, the projects which applied for the 2015 PCI list[1] were assessed applying the ENTSO-E CBA methodology[2]. The coordinated application of a cost-benefit analysis (CBA) to select and facilitate those energy infrastructure projects that bring forth the largest net welfare gain for Europe has been a significant step forward (L. Meeus et al., 2013a). In our earlier work, we focused on the common methodology, where it was argued that the common methodology require further improvement to provide a high level of comparability between projects. In this research, we now shift the focus on to analysing actual projects.

The research aims to provide recommendations on enabling robust CBAs for offshore infrastructure investment decision making. Offshore transmission infrastructure projects have been selected for the analysis of CBA methods because the development of a robust offshore electricity grid infrastructure is critical for effectively integrating renewable energy sources into the system. The importance of offshore grids has been highlighted in the literature by Cole et al., (2014) De Decker and Woyte, (2013); Decker et al., (2011); Green and Vasilakos, (2011) Konstantelos et al., (2017) amongst others. Offshore wind generation is indeed expected to play a major role in enabling the EU to meet its greenhouse gas (GHG) reduction and renewable energy target in the near and long-term future (European Commission, 2015). The recent offshore wind tenders in Germany which had a minimum price of 0.00 €/kWh (BMWi, 2017) provide a clear insight into the viability of this technology.

* The authors would like to thank the PROMOTioN consortium and the European Commission for their support. The authors would like to thank **Guy Henley** and **Andrew Johnson** from Carbon Trust for their input on the ISLES case study. We would also like to thank **Diyun Huang** from KULeuven for her support and input during the development of this research. We thank TenneT for their constructive feedback on this research.

[1] The list is available here: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0089&from=EN

[2] The regulation mandated ENTSO-E for Electricity and ENTSOG for Gas to create a common methodology for assessing these projects. (ENTSO-E, 2016, 2015; ENTSOG, 2015). The methodologies also underwent a European Commission approval process.

Notwithstanding the focus on three offshore transmission cases, the insights and recommendations extend to all cross-border transmission infrastructure projects. It is important that thorough evaluation of every project be conducted before any decision regarding its execution is made as a limited budget for such investments is allocated. This makes a study of CBA extremely relevant from the perspective of academic research as well as practice.

This paper is structured as follows. In0, we present an analytical framework for the evaluation of CBA methodologies. Subsequently, this framework is applied to analyse three case studies in Section 0. Finally, conclusions are provided in Section 0.

2. Analytical Framework

In this section, the analytical framework for evaluating CBA methodologies is presented. We apply the theoretical framework initially introduced by L. Meeus et al., (2013b). This framework has been discussed and refined at several occasions, including FSR & BNetzA EU Energy Law & Policy Forum, Florence, 19 October 2012. The Future of Energy Infrastructure Development in Europe at IIEA, Dublin, 22 February 2013. ENTSOG meeting, Brussels, 9 July 2013. FSR Webinar 30 April 2013. Executive Seminar Getting European electricity infrastructure financed, Florence, 8 March 2013. Workshop on Cost-Benefit Analysis in the Assessment of Energy Infrastructure Projects, Florence, 22 March 2013. The EU's Second Cross-Regional Group Meeting of 29 September 2014. FSR Policy Workshop on 24 October 2015. FSR-BNetzA Forum of 6 February 2015. Horizon 2020 BRIDGE meeting of 15 September 2015. Various Horizon 2020 PROMOTioN Meetings 2016-2017.

The ten dimensions of implementation of a cost-benefit analysis are divided based on three aspects: input, the calculation, and the output of a CBA.

2.1 Input of cost-benefit analysis

On the input side of cost-benefit analysis, there are three implementation issues: 1) considering project interaction, 2) organising the data gathering process and 3) provision of disaggregated cost numbers.

2.1.1 Considering project interaction

In network systems like the electricity and gas systems in Europe, the actual value of an infrastructure project must be assessed considering the interaction of the project with the current and future system. By doing so, potential positive or negative synergies with other proposed projects can be found. Positive synergies mean that the economic value of the combined projects exceeds the stand-alone values of the projects, while for negative synergies or competing projects the value of these projects diminishes when they are combined.

2.1.2 Data gathering process

All assessments rely on forecasted data of demand, supply, fuel prices, conversion factors, etc. Considering that the conventional time horizon for the assessment of infrastructure investment is twenty years or more, there can be different views on the forecasted numbers. To the extent that each project uses their own forecasts of non-project-specific data as input into the cost-benefit analysis, comparing projects becomes impossible.

2.1.3 Disaggregated reporting of cost data

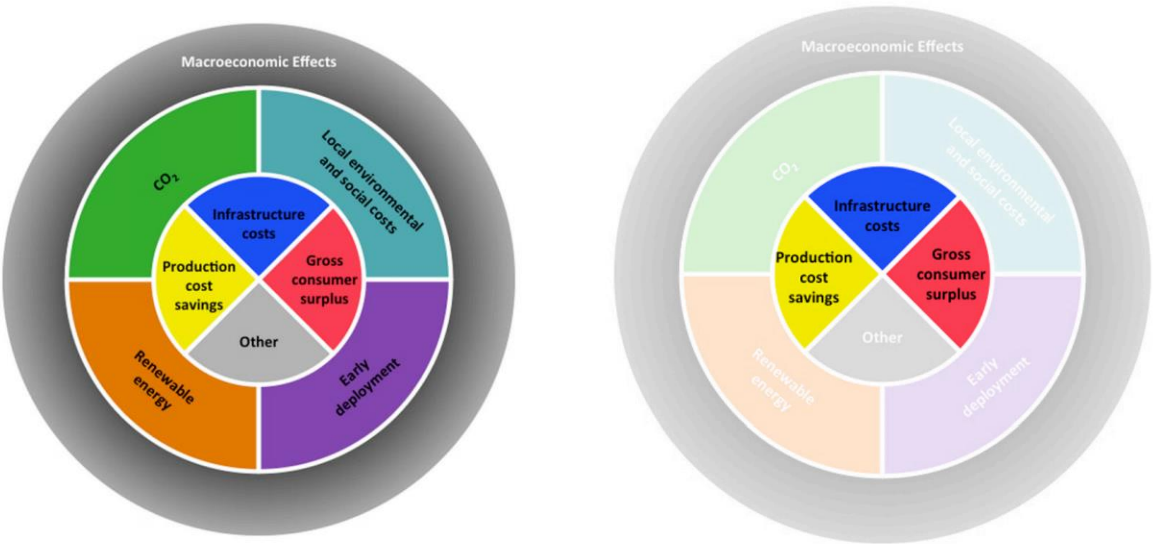
Besides the common data, the input to the cost-benefit analysis includes the costs of implementing the specific project. These costs should be reported in a disaggregated format to allow benchmarking of the cost components, with respect for the confidentiality of commercially valuable information.[3] Disaggregated reporting of costs makes it a lot easier to detect discrepancies between the cost drivers of different projects. Also, instead of providing a point estimate per cost component, the provision of a cost range, especially for immature projects can be considered as a good practice.

2.2 Calculations of cost-benefit analysis

2.2.1 Using a common list of effects

It is important to use a common list of effects to assess projects on the same footing. A comprehensive list of possible effects consists of firstly, the impacts within and beyond the power system. These impacts are infrastructure costs consisting of capex and opex. Production cost saving from the efficient use of ancillary and balancing services and efficient dispatching. Change in Gross consumer surplus or willingness to pay arising from consumption volume change**.** Other benefits that may arise from investment in electricity infrastructure investment. Secondly, externalities defined by a change in CO_2 emissions due to re-dispatching of power plants. Reduction in spilling of renewable energy. Local environmental and social costs due to the impact of the new infrastructure on the surrounding areas. Early deployment benefits arising from an increase in knowledge about particular types of technology or project as well as the risk of sunk investment due to premature technologies. Thirdly, Macroeconomic effects such as job creation and impact of economic growth need to be considered. Figure 1 (left) provides an illustrative overview of the comprehensive list of effects.

Figure 1: Comprehensive list of effects (left) and Reduced list (right).



Source: (L. Meeus et al., 2013b)

However, rather than trying to be comprehensive for all projects, the CBA should focus on a reduced list of effects that are relevant for all projects. Some benefits might be relevant only in specific cases, and some benefits might be double counted. The use of a reduced list of effect would aid in reducing

[3] It is not argued that this information should be publicly disclosed, but the officials (e.g. NRA representatives, MS representatives and other relevant stakeholders) evaluating the PCI application should have an insight in the costs on a more disaggregated level.

the complexity of the CBA. While not reducing and harmonising the list of effects renders it difficult to compare the outcome of a CBA for different projects.

A two-step scrutiny process could be utilised for identifying relevant effects. Firstly, effects from externalities that are already wholly or partly internalised in the effects within the power system can be identified (e.g. renewable energy has been internalised in production cost saving). Secondly, effects that are likely to be similar across all projects thus unlikely to affect the overall ranking could be omitted. An example is the *other market benefits* that are relatively similar across projects and very small. Figure 1 (right) indicates the three essential effects that the CBA would be required to consider in the analysis.

2.2.2 Disregarding distributional concerns

The implementation of an electricity and market design project is likely to affect the distribution of welfare among the economic agents. However, distributional concerns are best treated outside of the cost-benefit analysis through redistributive measures such as taxes or compensation mechanisms. The objective of the CBA assessment is to perform a purely economic analysis to find out if a project is overall welfare enhancing.

2.2.3 Explicit algorithms for calculating the net benefit

The model used to monetise the social welfare, which is made up of the production cost savings and the gross consumer surplus needs to be explicitly stated to build trust in the output of the cost-benefit analysis. The explicit statement of the algorithms informs the users of the CBA about the model imperfections and thus contributes to a transparent assessment of the projects.

Furthermore, in projects where such imperfections are significant, explicit stating of assumptions would enable correction of imperfections with additional analysis. An example of the need for such corrections would be that of a model in which generation investments are set exogenously. If the CBA results indicated that specific project might have a significant impact on the price in a particular zone, the model assumption regarding generation investment would require refinement for that zone.

2.2.4 Common discount factor

It is necessary to correct the time-value of those benefits that are in the far future, compared to those that are captured immediately. This raises the question what discount factor to use: a high number attaches more value to immediate benefits, whereas a low number is relatively more favourable for future benefits.

Whatever the exact number, it is recommended to use the same social discount factor for the economic assessment of all projects.[4] That approach allows discovering the best projects regardless of local risk conditions, which for most concerned projects are likely to be similar as they would obtain the PCI (quality) label. For the financial analysis, however, it is important to use a project-specific financial discount factor.

2.2.5 Dealing with uncertainty

While conducting a CBA, uncertainty is inevitable as various assumptions are necessary for the creation of the scenarios to be assessed. A robust approach towards addressing these uncertainties is

[4] Private discount rates might be systematically higher than the social rate of discount (see e.g. Solow, (1974)

necessary to ensure a thorough CBA. Thus, uncertainty in the baselines as in market and cost parameters should be addressed to obtain a robust analysis.

Uncertainties can be addressed with the use of methods such as sensitivity analysis, Multi-scenario analysis or using a stochastic analysis. It should be noted that all three are complementary to each other and ideally a combination of the three methods could provide the best results in terms of addressing uncertainty.

2.3 Output of cost-benefit analysis

On the output side of cost-benefit analysis, there are two implementation issues: 1) disaggregated reporting of benefits, 2) making the final assessment of the projects.

2.3.1 Disaggregated reporting of benefits

Even though the overall pan-European benefit of the project is the most important decision variable, the disaggregated reporting of benefits regarding their regional distribution and the specific benefits of a project provide additional insights. The reporting of regional benefits is of particular importance considering the value of the CBA output to also support decisions regarding cost allocation, exceptional regulatory incentives or financial assistance.

2.3.2 Final assessment of the projects

The usefulness of performing a CBA analysis is two-fold, firstly the estimated net benefit indicates if it is worth executing a project and secondly this result also allows different projects to be compared with each other and as such to select the projects to be prioritised. Therefore, it is important that the final assessment provided such that projects are comparable. Such a result could be achieved by the application of full monetisation of net benefit.

3. Case Studies

In this section, the analytical framework discussed in Section 2 is applied to assess the CBAs of three offshore infrastructure projects namely, EWIC, COBRAcable and ISLES. This section is based on research presented in Bhagwat et al., (2017) and is structured as follows. A brief introduction of the three projects that are under consideration in this paper is presented in Section 3.1, 3.2, 3.3 The chapter concludes with a comparative analysis of the three cases to assess areas for improvement, in Section 3.5.

The three projects under consideration, all received European public funding but differ in maturity and topology. The EWIC project was commissioned in 2012 and was built as a point-to-point interconnector, mainly to increase the security of supply and to allow for more integration of renewables in Ireland. The COBRAcable is expected to be in operation in 2019 connecting Denmark and the Netherlands. For now, there are no concrete plans to attach offshore wind generation or other offshore cables to this project, but there is the possibility to do so in the future. The ISLES project is a combined solution, proposing the construction of a meshed network connecting Scotland and Ireland, while also allowing the integration of offshore generation. The project is still in the study phase. The three projects chosen enable us to present an analysis that consists of a point-to-point case (EWIC), a point-to-point project with an option to integrate other projects (COBRACable) and a (future) integrated project (ISLES).

It should also be noted, that while researching for suitable case studies, it was observed that CBA documents only for a few projects were readily and explicitly available for scrutiny. Thus, the scope of this study was constrained by this limitation.

3.1 Case I: East-West Interconnector (EWIC)

In July 2006, the Irish government requested the Commission for Energy Regulation ("CER") to arrange a competition for the construction of an East-West Interconnector (EWIC) to Britain. It is a point-to-point project. The main reason for the construction of the EWIC was to ensure adequate supply in Ireland after ESB Power Generation announced in 2007 its intention to withdraw approximately 1,300 MW of capacity by 2010 (Eirgrid, 2006). Furthermore, building this interconnector would reduce curtailment of wind energy. The EWIC can be classified as a shore-to-shore interconnector, neither offshore generation nor other offshore cables are connected. EWIC has been designated a "Project of European Interest" and was included in the EU Trans-European Network Energy (TEN-E) Priority Interconnection Plan, which can be regarded as one of the predecessors of the PCI program.

This analysis of the EWIC case is based on EirGrid, (2008). It should be noted that in 2008 no standard CBA methodology was in place. Thus, project promoters used 'ad hoc' CBA methods to apply for inclusion in the EU Trans-European Network Energy (TEN-E) Priority Interconnection Plan.

3.2 Case II: COBRACable

COBRAcable is a planned (operational by 2019) 700MW subsea interconnector between Denmark and Netherlands. The ownership of this subsea cable is shared between the Dutch TSO TenneT and the Danish TSO Energienet.dk. It is a point-to-point project with the option of integrating other projects. This project is motivated by four long-term objectives: 1) To facilitate the transport of renewable energy. 2) To form a crucial part of a strong, interconnected European electricity grid. 3) To enhance the security of supply in the Northwest European electricity market. 4) To enhance the level playing field in the internal European electricity market. The COBRAcable has acquired the Project of Common Interest (PCI) status; it was listed both on the 2013as on the 2015 PCI list.

The evaluation of the COBRACable is based on TenneT, (2013). In 2013, the ENTSO-E CBA 1.0 methodology was not yet approved by the European Commission and as such could be considered as an 'ad hoc' CBA.

3.3 Case III: Irish-Scottish Links on Energy Study (ISLES)

The Irish-Scottish Links on Energy Study (ISLES) is a proposed tripartite collaboration between Ireland, Northern Ireland, and Scotland. Thus, allowing for a pathway to reduced electricity prices and relieving constraints on the Irish grid. It aims to enable the development of market to market interconnected grid networks to enhance the integration of renewable energy between the countries. The ISLES project represents a combined solution (integrated project). Firstly, it integrates the significant offshore renewable generation. Secondly, it connects the GB and Irish electricity markets.

The analysis is based on two documents: 1) The 2012 analysis included a partial cost-benefit analysis within the *Economic and Business Case Report*. 2) the ISLES II documentation in 2015, Specifically, the *Business Plan* and the *Network Regulation and Market Alignment Study*.

3.4 Analysis

3.4.1 Considering project interaction

In the EWIC analysis, the two interconnectors in operation at the time on the island of Ireland: Moyle (subsea) Interconnector (450MW), and the North-South (onshore) Interconnector (330 MW)[5] have been acknowledged. Additionally, two proposed electricity interconnectors, another North-South (onshore) Interconnector and a second East-West interconnector linking Ireland with the GB network in Wales are mentioned. However, the CBA is solely focused on the EWIC interconnector and does not consider the positive or adverse effect of the development of any other interconnector projects on its business case.

Since COBRAcable is the first planned interconnector linking Netherlands and Denmark and no other interconnection is planned, the cost and benefit calculation of COBRA is not clustered with other new investment projects. Even if there were other new investment projects, there would most likely be no argument for clustering, because the projects would probably be competitive.

One reference grid or baseline is applied for the calculations of socioeconomic value. This reference is based on data from the Danish, Dutch and German TSOs. Data for the other countries is based on information compiled by Energinet.dk from ENTSO-E's regional groups, national plans from different countries and bilateral studies. It appears that a thorough analysis was done to assess the future interconnection capacities. However, a sensitivity analysis of the CBA results to construction (or not) of probable future projects was not conducted.

The analysis of the ISLES case does not explore the interaction of the ISLES PCI with other proposed PCIs. Neither is the interaction with the development of independent projects such as 'Greenwire'[6] explicitly examined. Instead, they focus is on the interaction between different sub-ISLES configurations. Ideally, in the first step, different ISLES configurations could be examined to determine the configuration with the greatest welfare benefits. After that this configuration should be then cross-examined against the wider EU PCIs.

Within the 2012 report, Limited comparison (monetised) is available between project clusters (i.e. north and south) and against the discrete UK Round 3 wind farms outside of the ISLES zone. Importantly, the analysis does not appear to value welfare benefits against the UK, Irish SEM or wider EU markets, i.e. evolution of these markets with and without ISLES, nor does it appear to consider other projects of common interest (PCIs) within scenarios.

The 2015 analysis improves upon this aspect, in that it is more explicit in its approach and applies two scenarios –(All) ISLES and No ISLES.[7] Also, it separately lays out ten offshore wind projects across Northern and Southern ISLES zones within an illustrative scenario.[8] For each of these, it seeks to see the effect on GB and Irish markets with and without ISLES but does not consider pan-European interaction. It suggests the impact of coordinated generation is more important for the northern cluster

---

5 The North-South interconnector later became part of the internal circuits of the new Single Electricity Market in Ireland.

6 The Greenwire project has since evolved into the Greenlink interconnector project. For more information on the development of the Greenwire and Greenlink project see Dutton, (2016). 'The politics of cross-border electricity market interconnection: the UK, Ireland and Greenlink'. The 2015 counterfactual 'No ISLES' does make reference to a 'new standalone 500MW interconnector between GB and Ireland which would match the Greenlink characteristics, but it is not mentioned by name.

7 In the (all) ISLES scenario both the development of the Northern and Southern clusters are assumed, however the benefits of both cluster is reported separately.

8 Note: the analysis makes separate references to 10 and 12 offshore wind projects within the illustrative scenario.

and benefits are likely to accrue for the Irish SEM. The overall configuration explored in ISLES I is similar to ISLES II, with some minor modifications.[9]

3.4.2 Data gathering process

The data used in the EWIC analysis is sourced from EirGrid and the GB TSO National Grid's public reports. These are well respected and transparent sources. In the absence of a TYNDP[10], use of data from the national TSOs, as a second-best option, seems to be a valid choice. It should be added that annual data was utilised for the calculation and only data from Ireland and the GB was sourced. Overall, the data used is insufficient both in granularity and geographical scope.

The calculations in the COBRACable analysis are based on the *Yearly Economic Update 2013* (Energinet.dk, 2013). The reference scenario is set up by TenneT NL, TenneT DE, and Energinet.dk. Data has come from bilateral studies of TenneT and Energinet as well as ENTSO-E. The 2011 International Energy Agency fuel price estimates are used in the reference scenario.

In the ISLES analysis, the assumptions utilised in the 2012 model are qualitatively and quantitatively laid out, along with the key sensitivities. The rationale for the choice of assumptions is discussed as appropriate. Data was not derived from a common data set, but instead, a mix of geographically appropriate and publicly available sources was used. While the 2012 study did for the large part provide explicit assumptions, the data was acquired from a diverse set of sources, some of which were not referenced. The document suggests a comparison with other data sources was conducted and preference is given to sources where core numbers were clearly referenced (although there was no further clarity on the other sources). There was no evidence that stakeholders were given the opportunity to propose or challenge numbers. The 2015 analysis is even less clear in its data gathering process as it largely uses a proprietary model and in-house data sets (although some limited information is available in the appendix).

The choice between a common data set and locally appropriate data presents a trade-off between comparability and accuracy. For projects similar to ISLES, where the exercise is theoretical, and developers are notably absent, common data sets would be highly beneficial. Consultants could then apply regional data sets to tailor analysis to specific items (e.g. prices for construction and operation).

3.4.3 Disaggregated reporting of cost data

In the EWIC analysis, the estimated infrastructure costs are reported in a disaggregated manner and on a component basis. The construction costs are split up into costs for the converter stations, land cables (HVDC) and marine cables (HVDC). The total capital costs are broken down into land acquisition costs, project development costs, interest during construction, reinstatement/disturbance costs, and contingency costs. No cost ranges are provided, but point estimates are given per cost component.

In the COBRACable analysis, the estimated investment cost of the COBRAcable is segmented into the following components: COBRA automation, COBRA land cable, COBRA sea cable, COBRA DC converter, COBRA civil works, COBRA licensing, COBRA project cost, CAR and contingency PM. The uncertainty of total cost is reported with two probability intervals. However, point estimates based on the experience, and indicators from TenneT and Energinet for the cost per component. These costs are calculated on an annual basis from 2014 to 2019 when the project is expected to be built.

---

9 The 2015 document states that in coordination with the ISLES steering committee a wind farm in the west area of the Northern ISLES zone was removed from the analysis when compared to ISLES I.

10 The first TYNDP was published for the period 2010-2020 in 2009 (Buijs et al., 2011).

In the ISLES analysis, the level of disaggregation throughout the 2012 analysis is mixed. Key inputs are provided and referenced. Some aspects are presented in granular detail, but not all (for instance CAPEX is provided as a gross sum, and not broken down into the sub-components). The 2015 analysis was less systematic in its provision of cost data as compared to the 2012 analysis. However, some aspects were improved such as within ISLES I a single unit generation cost (£/MW) was applied to all ISLES generation sites, while in the ISLES II analysis these were tailored to water depth and distance to shore. In most cases, single data costs are provided, i.e. a range of possible costs / future costs are not provided.

3.4.4 Using a common list of effects

In the EWIC analysis, the main benefits listed are an enhancement of the security of supply, promotion of further competition in the electricity market, and environmental benefits – greater wind penetration by facilitating wind power exports and reduction of wind curtailment, reduced need for carrying reserve and reduction of carbon credit payments.

In the COBRACable analysis, the main quantified benefit indicators used are: the value of environmental sensibility, technical resilience, flexibility, non-curtailed RES, reduced CO2 emissions, increased the security of supply, socioeconomic value and auction revenues. On the cost side, reduced congestion rents, losses, operational expenditure and investment cost are listed.

The benefits of COBRAcable concerning CO2 reduction and system overload reduction as an indicator for system integration of renewable energy in Germany, Netherlands, and Denmark is presented. The effect on the security of supply is assessed qualitatively. The preliminary TYNDP 2014 results for the reduction of losses as well as technical resilience and system flexibility are also used in the CBA.

In the ISLES analysis, both studies go beyond the suggested reduced list of effects making comparability of the key issues difficult. The 2012 analysis examines several areas beyond the suggested reduced list described in Section 0.

Also, the analysis delves deeper into the level of renewable subsidies required; transmission pricing; interconnection (including - spinning reserve, system security, restrictions, pricing); network optimisation; the impact of network availability; financing and bankability; and comparison with alternatives.

The 2015 analysis is more aligned to a reduced list of effects. For example, it correctly omits analysis on jobs and supply chain benefits, seabed leasing revenue, and tax benefits. However, it still covers a wide number of areas by applying analysis on network cost savings to generation from connecting to multiple use networks; increased network reliability; access to low cost European funding; project risk; commercial value of increased capacity between Irish and British markets; and wider impacts (including average wholesale electricity prices, displaced cost of fossil fuel generation, CO_2 emissions, reduced number of starts for fossil fuel generation; capture prices).

3.4.5 Disregard distributional concerns

In the EWIC analysis, the expected benefit of 1% for the consumers due to a decrease in wholesale electricity prices has been presented. The benefit/loss for producers because of the market coupling with the GB market is not mentioned. However, in the final assessment, the estimated reduction in market costs for the consumers is not considered.

Similarly, in the COBRACable analysis, an overall economic assessment is conducted, but the distributional concerns are disregarded. It should be noted that the consumer and producer surplus are aggregated and reported as socio-economic welfare while the congestion revenues are reported separately.

In the ISLES analysis, the 2012 and 2015 analyses both include some level of distributional concerns, i.e. they highlight the economic benefits between countries and/or between consumers and producers. Indeed, it explicitly states that "the quantitative analysis is used to explore the distribution of costs and benefits of several types of coordination." However, no different weights are given to benefits or costs for certain countries or agents which can be regarded as best practice.

3.4.6 Explicit algorithms for calculating the net benefit

In the EWIC analysis, the assumptions made to estimate the annual benefits are clearly stated. However, the estimations do not consider a market model, combined with a network model of sufficient granularity. As a consequence, the (potentially significant) benefit from more efficient trade because of market coupling is not quantified.

In the COBRACable analysis, the presented business case is based on an analysis conducted in 2013 by Energinet. The BID-model was applied in the study by Energinet. Some of the underlying assumptions are described in the assessed document, but the algorithm is not discussed explicitly.

Model calculations were made for 2018, 2023 and 2030. The value of intervening years was investigated through linear interpolation. The annual costs and benefits after 2030 were assumed to remain unchanged concerning the values for 2030.

In the ISLES analysis, the exact calculations are not made available, neither are the models available to test the assumptions. However, both pieces of analysis are clear in approach, models applied and aspects examined.

The 2012 modelling took a multi-stage approach. First, an overview model[11] analysing financial flows was run to determine which input assumptions had the most sensitivity, and impact on outputs and rank these accordingly. These were then applied to the detailed model. The overview model was also used to explore indirect impacts initially, and a comparison of ISLES with other similar UK offshore projects was made. The analysis uses as its cost base, the spot year of 2020 (as this is deemed the earliest date when the Northern ISLES would be connected). From this point on, costs evolve according to defined inputs (e.g. fuel costs).

This overview model included the impact of intermittency of renewables on system operating costs and CO_2 emissions because of the need for part loading and fast reserve requirements on conventional generation. Other aspects that were examined included: energy/demand forecasts; fuel price forecasts; dispatch models based on load duration curve; chronological models (half hourly demand and wind output data); new entry evaluation; financial overview; system security; and overall project costs and revenues. Also, a full NPV cost-benefit model was developed built around the Northern ISLES concept using discounted cash flow analysis from 2010 to 2035. This incorporates time-dependent forecasts for key input variables and captures flows of direct project revenues and costs.

The 2015 analysis aligns with the UK regulator's approach for impact assessments for proposals of the Integrated Transmission Planning Regime (ITPR), by examining where coordination is socially beneficial. The costs and benefits are the results of two models. Namely, a generation and transmission project cost model built for the CBA analysis, and Pöyry's proprietary wholesale electricity model (BID3). This analysis included relevant European countries (France, Belgium, Netherlands, Denmark, Germany, and Norway) modelling the hourly dispatch of plants to minimise costs for Europe. Specifically, spot years were modelled to assess the development and operation of ISLES (2022, 2023, 2025, 2027, 2030, and 2035). Outputs are electricity prices, generation and revenue of the plant, arbitrage revenue for interconnectors, the total cost of generation, and CO_2 emissions.

---

[11] Leaning upon, energy / demand forecasts, fuel price forecasts, a dispatch model based on load curve duration, and a chorological model – half hourly demand and wind output data.

3.4.7 Common discount factor

In the EWIC analysis, EirGrid's allowed weighted average cost of capital (WACC) of 5.63% (pre-tax real rate) and an asset depreciation period of 30 years is utilised. As there was no guideline for a common discount factor in 2008, this can be considered as an acceptable discount factor.

In the COBRACable analysis, the discount rate of 4% as recommended by ACER (ACER, 2014) is adopted for the net present value calculation of COBRA business case. Sensitivity analysis is performed with discount rate at 3.6% and 5%. The technical lifespan of 40 years is assumed to calculate the expected revenue.

In the ISLES 2012 analysis, a 2% discount rate was applied to cash flows out to 2035. This differs quite substantially with the proposed 4% discount rate, and the 3.5% discount rate mandated in the UK Treasury's Green Book (HM Treasury UK, 2011). The 2015 analysis does not provide the discount rate used; this makes a cross-comparison of results between the two ISLES analyses and with other PCIs very difficult.

3.4.8 Dealing with uncertainty

In the EWIC analysis, uncertainty in the future evolution of the system is completely disregarded. Neither a scenario analysis nor sensitivity analysis is applied.

In the COBRACable analysis, uncertainties are addressed both in the cost and benefit computation. On the cost side, sensitivity analysis is performed for the COBRA investment costs. The investment cost estimation varies between 540 million and 621 million with the expected investment cost to be 577 million.

Two previous studies were conducted for the COBRAcable. In 2010 the business case for COBRAcable was assessed by Pöyry, (2010) and in 2011 a re-assessment was done by the Brattle Group, (2011). These studies assumed two scenarios: New Stronghold and Green Revolution. The New Stronghold scenario assumes that the generation mix mainly consists of conventional generation in 2030, while the Green Revolution includes more wind and solar energy in the generation mix. The reference scenario, applied in this case study, holds the midst between New Stronghold and Green Revolution. No scenario analysis was implemented in this case study, but the result of the study by Brattle Group, (2011) is seen as a suitable reference for comparison and could be regarded as a substitute for scenario analysis.

Overall in the ISLES analysis, it unclear, how the CBA dealt with uncertainty. Both the 2012 and 2015 analysis highlights the inherent impact of uncertainty. However, they do not appear to use TYNDP scenarios to negate this. To counteract uncertainty, public references are used for items such as carbon emissions, fuel prices, and energy demand. Also, sensitivity analysis is conducted. The 2015 analysis suggests that the proprietary model features stochastic dynamic pricing of hydro dispatch to quantify the role of intermittency in the EU electricity markets and the role of flexibility. However, the extent to which this was used for the ISLES analysis is unclear.

3.4.9 Disaggregated reporting of benefits

In the EWIC Analysis, the (quantified) benefits are reported per benefit indicator but are not geographically disaggregated. More precisely, only the benefits for Ireland are reported, no benefits for Great Britain are estimated. This is not considered best practice and does not facilitate a robust CBCA process.

In the COBRACable analysis, the welfare impact is split up between producer and consumer surplus. It is reported for three countries: Netherlands, Denmark, and Germany. The benefits are quantified for each benefit indicator. The benefit indicators in each geographical area are the value of environmental sensibility, the value of technical resilience, the value of flexibility, the value of non-curtailed RES, the value of reduced CO2 emissions, the value of increased security of supply, socioeconomic value. Specifically, for Germany**,** also the reduction of re-dispatch cost is calculated.

The ISLES 2012 analysis examines the costs and benefits to the generators, owner of the offshore grid, onshore network owner, system operators, impacts upon conventional power plants, and the impact on energy users. However, regarding the country to country distribution, it only qualitatively suggests there may be a greater benefit to Ireland and Northern Ireland. It states that for England and Wales the ISLES proposition would only be attractive if the energy derived from ISLES was cheaper than that of other projects under consideration.

The ISLES 2015 analysis, specifically examines the distribution of costs and benefits that accrue to the individual projects within ISLES versus the wider benefits. Also, it examines the distribution of several metrics (e.g. capacity market revenues, arbitrage revenue, and wholesale price impact) between Ireland and Great Britain.

3.4.10 Final assessment of the projects

In the EWIC analysis, full monetisation is applied. The increase in security of supply, more precisely SoS adequacy indicator, is monetised using the ‘additional adequacy margin’ approach (ENTSO-E, 2016). As no detailed market and network model are applied the expected energy not served (EENS) is not calculated, and as such, the problem of determining a Value for Lost Load (VOLL) is omitted. Additionally, lower wind curtailment reduced the need for carrying reserves. The reduced carbon credit payments are monetised.

In the COBRACable analysis, project benefit is partially monetised. However, a final NPV value of the project is presented as the outcome of the analysis. For the security of supply, only a qualitative assessment was conducted. The argument made is that the three involved countries have supply rates of 99.99% and therefore an additional 700 MW would not significantly improve the security of supply. The CO2 emissions are reported in k-tons/year, while the reduction in overload due to RES and reduced losses is in GWh/year.

As previously highlighted these studies are formulated principally as proof of concept documents rather than full CBAs and do not present a single NPV value for the entire ISLES project. This limits comparability with other PCIs. Across both analyses, final assessment of the project is laid out based on both monetised and qualitative benefits across several areas. Ideally, these should have been separated and ranked accordingly.

In the ISLES 2012 analysis, monetised aspects include subsidy levels and potential subsidy savings, and CAPEX. Non-monetised aspects include CO_2 emissions saved, as well as considerations of network availability, lower capital costs, and interconnection benefits. A single aggregated per annum saving is provided for the southern ISLES, but it is unclear how this was built up. The 2015 analysis provides in-depth analysis, both quantitative and qualitative regarding aspects highlighted in Section 2.3.1. However, there is limited attempt to provide a single net benefit or cost number. Overall both studies highlight the strong uncertainties and limited benefit of the ISLES project. However, they do mention the benefit from coordination which could make marginal generation projects viable.

3.5 Synthesis

Table 1 gives an overview of the assessment of the case studies using the analytical framework. The dimensions which do not comply completely with the analytical framework are highlighted in yellow and the dimensions strongly disagreeing with the identified best practices are highlighted in red.

Table 1: Summary of the case studies

	EWIC (IRL-UK)	**COBRACABLE (NL-DK)**	**ISLES (SCO-IRL- N-IRL)**
INPUT(1) Considering project interaction	No project interaction is taken into account	TOOT approach is applied, and change in congestion rent of other interconnectors is calculated	No interaction with other PCI projects is included. The interaction between ISLES clusters is analysed partially.
INPUT(2) Data gathering process	Ok	Ok	No TYNDP but local data is utilised although from respected sources.
INPUT(3) Disaggregated reporting of cost data	Ok	Ok	Ok
CALCULATION(4) Using a common list of effects	Ok	Ok	Ok for the 2015 analysis. However, not the ENTSO-E CBA 1.0. The list is applied.
CALCULATION(5) Disregarding distributional concerns	Ok	Ok	Ok
CALCULATION(6) Explicit algorithms for calculating the net benefits	Explicitly stated but not detailed market and network model used	Ok, explicitly stated and detailed market and network model are used (details are not public)	Ok, explicitly stated and detailed market and network model are used
CALCULATION(7) Using a common discount factor	Ok, there was no common discount factor determined thus the allowed WACC of EirGrid was used	Ok	A very low discount factor is applied in the 2012 analysis (2%), and no value is provided in the 2015 analysis
CALCULATION(8) Dealing with uncertainty	Uncertainty is disregarded, no scenario or sensitivity analysis applied	Ok, two scenarios are applied plus sensitivity analysis by varying total cost and discount factor	Scenario and sensitivity analysis is applied, although not using the TYNDP scenarios.
OUTPUT(9) Disaggregated reporting of benefits	Only the benefits for Ireland are considered	Ok, benefits are reported disaggregated	Ok, benefits are reported disaggregated
OUTPUT(10) Final assessment of projects - monetisation	Ok, full monetisation is applied	Partial monetisation is applied, but a final NPV value of the project is underlined. Additional indicators in non-monetary metrics are mentioned more for informational purposes	Both quantitative as qualitative cost and benefit indicators are reported. No full monetisation is conducted.

Three key issues are observed regarding quality of CBA methodologies in adhering to the criterion of the framework. It can be observed that in the case studies under consideration, the compliance with the first dimension – *considering project interactions* is of critical concern. The EWIC and the ISLES analysis strongly diverge from this dimension with while the COBRACable analysis too does not fully comply. Secondly, it can be observed that the EWIC and the COBRACable analysis does not address uncertainty robustly. The third area of concern observed is the application of full monetisation for the final assessment of the projects. COBRACable and ISLES do not apply full monetisation while EWIC analysis does so. Finally, while there is significant scope for improvement in each of the CBA assessed above, one must keep in mind that these CBAs were conducted before the advent of the ENTSO-E 1.0 methodology and still adhere to several criteria of the analytical framework. This is significant, as according to the assessment of Keyaerts et al., (2016), the ENTSO-E methodology itself is not sufficiently robust to adhere to all the criteria completely.

Another important observation that can be drawn while comparing the three cases studied in this analysis is the heterogeneity in the methodologies. The methodologies utilised for conducting the CBA vary significantly indicating a lack of harmonisation between the CBA methodologies. This would have a strong negative impact on the utility of these CBA results for inter-project comparisons thus highlighting the need for a common CBA methodology. An example of such heterogeneity can be observed in the use of common discount factors. It can be observed from the discussion in section 0, each case study analysed in this research utilises a different discount factor.

4. Conclusions and Policy Implications

In this paper, application of cost-benefit analysis (CBA) for offshore electricity infrastructure projects with a pan-European impact is discussed. First, a framework for assessing CBAs is presented. The framework is then applied to evaluate the CBAs of three offshore infrastructure projects namely EWIC, COBRAcable and ISLES. The research provides two distinct insights. First being about the quality of the CBA methodologies that have been used in these case studies in adhering to the criterion of the framework. The second is insight on the level of harmonisation between the different CBA methodologies applied for assessing these projects in the absence of a common CBA methodology.

Although the EWIC and the COBRACable CBAs pre-date the ENTSO-E common CBA methodology, they adhere to several criteria of the analytical framework, while the ISLES CBA is less robust in comparison to the other two cases. Furthermore, we identify three areas of improvement regarding making the CBA more robust. The first area of improvement is the requirement for greater consideration of the interactions between different offshore projects that exist, are under construction or proposed. The second area identified is the need for a more robust approach towards addressing uncertainty. Finally, the third area with a scope of improvement is the application of full monetisation for ranking of the projects.

Considering that even the current ENTSO-E CBA methodology itself is not sufficiently robust to adhere to all criteria of the framework fully, the CBAs under assessed can be deemed to have performed relatively well regarding quality. However, an overall closer adherence to the different dimensions of the assessment framework would have led to a significantly more robust analysis.

However, the research indicates that there is a significant lack of harmonisation between the different CBA methodologies that have been utilised. The absences of a common methodology thus make the projects incomparable. Therefore, a common CBA methodology should be viewed as a necessity rather than as an additional bureaucratic process. This conclusion also corroborates the view of the European Commission on the need for a common CBA methodology for assessing PCIs.

Finally, an analysis of actual cases is an excellent avenue and opportunity for reality checking regarding effectiveness of a policy or regulation. The research presented bears testament to the utility of such a case study based analysis. However, in the context of CBAs for electricity transmission infrastructures, few documents are readily and explicitly available for scrutiny. Thus, the scope of studies such as the one conducted here is constrained by this limitation. In the future, it can be recommended that publication of the CBA be made mandatory. Such a step would enable a deeper scrutiny and provide greater feedback for improvement, especially for the PCI selection process.

References

ACER, 2014. Opinion of ACER on the ENTSO-E Guideline for cost benefit analysis of grid development projects.

Bhagwat, P., Schittekatte, T., Lind, L., Keyaerts, N., Meeus, L., 2017. PROMOTioN Intermediate deliverable: economic framework for offshore grid planning. Florence.

BMWi, 2017. Bundesnetzagentur announces successful bids in first auction for offshore wind farms [WWW Document]. URL https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/EN/2017/13042017_WindSeeG.html?nn=404422 (accessed 4.20.17).

Brattle Group, 2011. COBRAcable Analysis: Estimates of profitability and the impact on TSO revenues, welfare, and competition.

Buijs, P., Bekaert, D., Cole, S., Van Hertem, D., Belmans, R., 2011. Transmission investment problems in Europe: Going beyond standard solutions. Energy Policy 39, 1794–1801. doi:10.1016/j.enpol.2011.01.012

Cole, S., Martinot, P., Rapoport, S., Papaefthymiou, G., Gori, V., 2014. Study of the benefits of a meshed offshore grid in Northern Seas region: Final Report.

Courtney, H., Lovallo, D., Clarke, C., 2013. Deciding how to decide: A tool kit for executives making high-risk strategic bets. Harv. Bus. Rev.

De Decker, J., Woyte, A., 2013. Review of the various proposals for the European offshore grid. Renew. Energy 49, 58–62. doi:10.1016/j.renene.2012.01.066

De Nooij, M., 2011. Social cost-benefit analysis of electricity interconnector investment: A critical appraisal. Energy Policy 39, 3096–3105. doi:10.1016/j.enpol.2011.02.049

Decker, J.D., Kreutzkamp, P., Joseph, P., Woyte, A., 2011. Offshore electricity grid infrastructure in Europe: a techno-economic assessment. 3E, Dena, EWEA, ForWind, IEO, NTUA, Senergy, SINTEF-OffshoreGrid Final Proj. Rep.

Dutton, J., 2016. The politics of cross-border electricity market interconnection: the UK, Ireland, and Greenlink., 1602. London.

Eirgrid, 2006. Independent TSO EirGrid Generation Adequacy Report 2007-2013.

Energinet.dk, 2013. Yearly economic update 2013 for COBRAcable.

ENTSO-E, 2016. Guideline for Cost Benefit Analysis of Grid Development Projects. Version for ACER official opinion.

ENTSO-E, 2015. ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects. FINAL- Approved by the European Commission.

ENTSOG, 2015. Energy System-Wide Cost Benefit Analysis. Approved by European Commission on 4 February 2015.

European Commission, 2015. Wind energy is crucial for the EU's renewable energy targets [WWW Document]. URL https://ec.europa.eu/energy/en/news/wind-energy-crucial-eus-renewable-energy-targets (accessed 2.15.17).

European Parliament, 2013. REGULATION (EU) No 347/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) N. European Union.

Green, R., Vasilakos, N., 2011. The economics of offshore wind. Energy Policy 39, 496–502. doi:10.1016/j.enpol.2010.10.011

Griffin, R.C., 1998. The fundamental principles of cost-benefit analysis. Water Resour. Res. 34, 2063–2071. doi:10.1029/98wr01335

HM Treasury UK, 2011. THE GREEN BOOK Appraisal and Evaluation in Central Government.

Keyaerts, N., Schittekatte, T., Meeus, L., 2016. Standing still is moving backward for the ABC of CBA. FSR Policy Brief. Florence. doi:10.2870/57918

Konstantelos, I., Pudjianto, D., Strbac, G., De Decker, J., Joseph, P., Flament, A., Kreutzkamp, P., Genoese, F., Rehfeldt, L., Wallasch, A.-K., Gerdes, G., Jafar, M., Yang, Y., Tidemand, N., Jansen, J., Nieuwenhout, F., van der Welle, A., Veum, K., 2017. Integrated North Sea grids: The costs, the benefits and their distribution between countries. Energy Policy 101, 28–41. doi:10.1016/j.enpol.2016.11.024

Meeus, L., von der Fehr, N.-H., Azevedo, I., He, X., Olmos, L., Glachant, J.M., 2013a. Cost Benefit Analysis in the Context of the Energy Infrastructure Package. Netw. Ind. Q. 15, 11–14.

Meeus, L., von der Fehr, N.H., Azevedo, I., He, X., Olmos, L., Glachant, J.M., 2013b. Cost benefit analysis in the context of the energy infrastructure package. Final report of the EU FP7 Funded Research project THINK. Florence. doi:10.2870/60065

Mishan, E.J., Quah, E., 2007. Cost-Benefit Analysis, 5th ed. Routledge, New York.

Pearce, D.W., 1971. Cost-Benefit Analysis. Macmillan Education UK, London. doi:10.1007/978-1-349-01091-2

Pöyry, 2010. Evaluation of the COBRAcable.

Solow, R.M., 1974. The Economics of Resources or the Resources of Economics, in: Classic Papers in Natural Resource Economics. Palgrave Macmillan UK, London, pp. 257–276. doi:10.1057/9780230523210_13

TenneT, 2013. Business case description of the COBRACABLE. Submitted to ACM.

Author contacts:

Pradyumna C Bhagwat, Tim Schittekatte, Nico Keyaerts

Florence School of Regulation

RSCAS, European University Institute

Il Casale, Via Boccaccio, 121

I-50133 Florence

Italy

Email: Pradyumna.Bhagwat@EUI.eu; Tim.Schittekatte@EUI.eu; Nico.Keyaerts@EUI.eu

Leonardo Meeus

Florence School of Regulation

RSCAS, European University Institute

Il Casale, Via Boccaccio, 121

I-50133 Florence, Italy

Vlerick Business School - Vlerick Energy Centre

Bolwerklaan, 21,

B-1210 Brussels, Belgium

Email: Leonardo.Meeus@EUI.eu