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Risk-Based Framework (RBF) for a UK pan-European Supergrid

Eskandari Torbaghan, Mehran; Burrow, Michael; Hunt, Dexter; ElCheikh, Marwa

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Title: Risk-based framework (RBF) for a UK Pan-European Supergrid

Author 1 (Corresponding author)

• Given name: Mehran Family name: Eskandari Torbaghan, MSc, PhD. Research Fellow

E-Mail: M.Eskandaritorbaghan@bham.ac.uk;

Tel.: +44-74056-39382; Fax: +44-121-414-3675.

Author 2

• Given name: Michael P.N. Family name: Burrow, MA, PhD. Senior Lecturer ^a,

Author 3

• **Given name**: Dexter V.L. **Family name**: Hunt, MEng, PhD. Researcher and Lecturer in Sustainable Construction ^a,

Author 4

• Given name: Marwa Family name: Elcheikh, MSc, PhD. Senior Risk Analyst ^b

^a Department of Civil Engineering, College of Engineering and Physical Sciences, University of Birmingham, Birmingham, B15 2TT, UK

^b Crossrail, 25 Canada Square, Canary Wharf, London E14 5LQ, UK

Abstract

1

- 2 Interconnected electricity networks, or Supergrids, are considered as a possible solution to
- 3 tackle challenges associated with near and far-future supply of electricity. These include, but
- 4 are not limited to, reducing Green House Gas emissions and reliance on non-renewable fossil
- 5 fuels. Supergrids can help to tackle these challenges, for example, by providing a reliable
- 6 interconnection platform for wider application (and development) of renewable technologies.
- 7 However, there is a range of risks and uncertainties associated with selecting appropriate
- 8 interconnections. Heretofore these have been a hindrance to developing interconnections and
- 9 therefore a Risk-Based Framework (RBF) which addresses these risks and uncertainties could
- 10 encourage the wider uptake of Supergrids.
- 11 This paper presents for the first time such a robust framework. The RBF comprises of four
- stages; (1) initial screening for selecting candidate countries, (2) risk identification, (3) risk
- semi-quantification and (4) risk quantification. In stage 4 the uncertainties associated with the
- 14 identified risks are quantified using a cost-risk model under uncertainty based on a whole life
- appraisal approach. The usefulness of the approach, demonstrated using the UK as a case
- study, showed that greatest cost risks are associated with (a) regulatory framework, and (b)
- 17 changes in energy policy. The most desirable interconnection option for the UK was
- 18 identified as France.

19 **Keywords**

- 20 Interconnections; Risk assessment; Quantitative risk analysis; Trading electricity; Supergrid;
- 21 Whole Life Appraisal.

22 Abbreviations

- 23 DP Dynamic Positioning
- 24 E_e Interconnection Capacities
- 25 HVDC High-Voltage Direct Current
- 26 NPV Net Present Value
- 27 RBF Risk-Based Framework
- 28 RE Renewable Electricity
- 29 STEEP Social, Technical, Economic, Environmental and Political
- 30 PERT Program Evaluation and Review Technique
- 31 PI Profitability Index
- 32 PPPs Public Private Partnerships
- 33 P80 80th percentile
- 34 WLA Whole Life Appraisal

1. Introduction

- 2 Renewable energy is seen as a viable means of helping to tackle the global challenges of
- 3 climate change whilst meeting a significant part of global energy demands (MacKay, 2009;
- 4 Jacobson and Delucchi, 2011; WWF, 2011; DNV, 2014). However, in order to realise the full
- 5 potential of these geographically dispersed and intermittent renewable energy supply
- 6 resources it is necessary to provide a means of connection. An interconnected electricity
- 7 network, utilising high capacity long transmission lines, is technologically feasible and can be
- 8 economically competitive (Chatzivasileiadis et al., 2013; DNV, 2014). Such a system, known
- 9 as Supergrid, is currently being developed in Europe, and will be capable of transmitting
- power from renewable sources using a High Voltage Direct Current (HVDC) grid across the
- 11 European continent and beyond.
- 12 Interconnections through this Supergrid are expected to provide a solution to many of the
- 13 challenges associated with renewables. These include, for example, their intermittency,
- variability and cyclic nature (Chatzivasileiadis et al., 2013; Elliott, 2013; Edmunds et al.,
- 15 2014; Pöyry, 2016). In addition a Supergrid can improve security of energy supply issues
- through provisioning of multiple supply pathways that connect countries across different time
- zones with different (yet complimentary) electricity generating profiles, consumption
- demands and patterns (Van Hertem and Ghandhari, 2010; Hirschhausen, 2012; Torriti, 2014;
- 19 Pöyry, 2016).
- However, there are a number of social and political barriers for the implementation of a
- 21 Supergrid (Jacobson and Delucchi, 2011; Tobiasson and Jamasb, 2016). Not least, the
- decision-making process required for their implementation is often a protracted procedure.
- For example, lengthy negotiations between France and Spain were initiated in 1980 but the
- 24 interconnection only started operating 35 years later (Tobiasson and Jamasb, 2016). Part of
- 25 the reason is related to uncertainties associated with: changes in energy policy within
- 26 countries concerned; availability of spare electricity; security of supply issues; comparatively
- 27 lengthy construction periods and unsubstantiated predicted life-times for the physical
- interconnections (Great Britain Parliament, 2011a; Pöyry, 2016).
- 29 A crucial early-stage decision regarding the development of interconnections is identifying
- 30 the most appropriate country(ies) and region(s) with which to make an interconnection(s). A
- 31 proven means of facilitating similar decisions in other industries is through utilising an

- 1 appropriate risk assessment process that enables early-stage risk identification, better
- 2 understanding, and mitigation for potential impacts before they occur (Flyvbjerg et al., 2003;
- 3 Read and Rizkalla, 2015). Within this context a common language and shared understanding
- 4 between all engaging countries can help resolve disputes and shape common priorities
- 5 (Tobiasson and Jamasb, 2016). However, such a Risk-Based Framework (RBF) to facilitate
- 6 decision-makers is yet to be developed to encourage the uptake of Supergrids.
- 7 To address this, the goals of this paper are to describe a robust RBF for selecting the most
- 8 appropriate country(ies) with which to make grid interconnections and to describe its use via
- 9 a case study. Even though the need for such an RBF has been identified, this paper presents
- 10 for the first time the development, application and components of the RBF and is therefore a
- major contribution to the existing literature (Great Britain Parliament, 2011b; Great Britain
- 12 Parliament, 2011a; Pöyry, 2016; Tobiasson and Jamasb, 2016).
- 13 The RBF includes the identification, assessment, and quantification of uncertainties and
- whole life cost risks associated with electricity interconnections. Lifetime uncertainties and
- risks are incorporated, for the first time, within the newly developed risk cost-risk model
- under uncertainty. Therein, a quantitative risk analysis technique is utilised to compare
- candidate countries by incorporating the likelihood of the occurrence of identified risks and
- uncertainties together with their impacts associated with the construction and maintenance of
- 19 interconnections. Lack of sufficient data can be one of the main reasons for not adopting a
- 20 robust RBF. This paper shows how expert opinion can be utilised to fulfil such a shortfall.
- 21 The successful implementation of the RBF in this paper, described through a case study, it is
- 22 anticipated will encourage the development of interconnections and thereby maximise the
- 23 utilisation of global renewable energy resources.
- 24 The major findings of the research described here are:
- 25 The proposed RBF provides a rigorous means of quantifying risks and uncertainties
- associated with making energy interconnections. Data scarcity can be successfully addressed
- 27 using a robust process which incorporates expert opinion.
- 28 The greatest cost risks for the UK are associated with (a) regulatory framework, and (b)
- 29 changes in energy policy. The most desirable interconnection option for the UK is with
- 30 France.

1 2. Literature review: Risk assessment and its implication for

interconnections

- 3 Methodologies for addressing and dealing with risk and uncertainties have been utilised for
- 4 over 40 years. For example, Salter (1973) described a probabilistic forecasting methodology
- 5 in which stochastic data and subjective probability estimates were used to achieve a
- 6 probabilistically stated forecast of the USA's electricity consumption in the year 2000. Since
- 7 then, similar analyses have been used to allocate probabilities to uncertainties regarding
- 8 future energy supply/demand and the impact of climate change on energy supply among
- 9 other things (see for example Song et al. (2013), Maleki et al. (2016), Kearns et al. (2012)
- 10 and Hamlet et al. (2010)).
- 11 The literature is less well developed with respect to the risks and uncertainties of
- 12 interconnections. Whilst economists such as Parail (2010) have introduced probabilistic
- methodologies to address economic uncertainty associated with electricity trading by way of
- 14 interconnections, this work was not extended to uncertainties associated with the social,
- technical, environmental and political aspect of developing and operating interconnections. A
- recent study by Pöyry (2016) explores the costs and benefits of potential interconnections for
- 17 the UK and describes some of the associated risks but without any further analysis.
- 18 Understanding the construction and maintenance risks of an interconnection requires
- 19 comprehending their causes, likelihoods and consequences of occurrence to adopt appropriate
- 20 mitigation measures. In conventional risk assessment these are typically considered as part of
- a framework which consists of three main processes, namely (BSI, 2010; Jutte, 2012; Bozek
- 22 *et al.*, 2015):
- 23 1. risk identification;
- 24 2. semi-quantification; and
- 25 3. quantification.
- 26 Risk identification is the process of finding, recognising and recording risks whilst semi-
- 27 quantification and quantification stages are to do with determining the consequences and
- 28 likelihood of occurrence for identified risk events (BSI, 2010; Pritchard, 2014). Quantitative
- 29 analysis is used to apportion values to consequences and their probabilities and thereby
- provide a quantified level of risk (BSI, 2010; Pawar et al., 2013; Pritchard, 2014).

- 1 In the case of interconnections, the identified risks are directly related to, or influenced by,
- 2 project complexity, construction time (up to 10 years for some seabed interconnections),
- 3 duration of asset use (40 years or more), and the involvement of various industries and
- 4 stakeholders (Chatzivasileiadis et al., 2013). Allied to these, an interconnection project is
- 5 notoriously risky because (at least) two countries, each with their own local priorities,
- 6 conditions and policies, are involved.
- 7 A major challenge of carrying out risk assessment within this field, which can significantly
- 8 reduce the cost of projects, is obtaining reliable information (IRG, 2013). This includes
- 9 identifying a range of risks and thereafter assessing their likelihood of occurrence and
- 10 ultimately impact. This is not straightforward when interconnection construction projects are
- essentially one-off enterprises (Eskandari Torbaghan et al., 2015). In such cases knowledge
- obtained from a diverse range of experts in the field, who are well versed in terms of
- experience, judgement and application including rules-of-thumb can be usefully utilised
- 14 (Dikmen et al., 2007; Yildiz et al., 2014). Such an approach has been used in the research
- described in this paper.

16 3. Methodological Approach

- 17 The developed RBF consists of 4 principal stages, summarised in Figure 1, and described
- 18 below.

19 20

3.1 Stage 1: Initial screening

- 21 The screening stage was used to identify suitable and unsuitable candidate countries for
- 22 interconnection. The procedure took into account the distance between countries in addition
- 23 to Political, Economic, Environmental and Social factors. The outcome of this stage is shown
- 24 for the UK case study application in Section 4.1.

2526

3.2 Stage 2: Risk identification

- 27 This stage identifies the risks (and associated circumstances) that might affect the availability
- and security of interconnections and of trading electricity (BSI, 2010). The risks were
- 29 identified from a review of the literature which was subsequently used to inform (and extract)

- 1 expert opinion through questionnaires and one-to-one interviews. The outcome of this stage
- 2 is shown for the UK case study application in Section 4.2.

3 3.3 Stage 3: Risk Semi-quantification

- 4 Risk semi-quantification allows identified risks to be determined according to the common
- 5 definition of risk; impacts multiplied by probabilities of occurrence, for each risk in each
- 6 country (Chapman and Ward, 2004; BSI, 2010). Calculated exposures for all identified risks
- 7 are then combined to determine an overall risk level for each country.

8

- 9 The process includes mapping identified risks associated with activities to build and maintain
- 10 interconnections. To measure the level of risk herein expert opinion is used to estimate the
- 11 range of potential consequences that might arise from an event, situation or circumstance,
- 12 (e.g. a power cut) and their associated probability of occurrence. Integer rating scales for
- impact and probability informed by expert opinion are used to produce a semi-quantified *risk*
- 14 evaluation. The outcome of this stage is shown for the case study in Section 4.2.

15

16

3.4 Stage 4: Risk Quantification

- 17 Risk Quantification develops a measure of the cost of risks and uncertainties associated with
- a project, the so called project cost risk, using a combination of whole life appraisal (3.4.1)
- 19 and risk modelling (3.4.2), to identify the most appropriate country for making an
- 20 interconnection (Levander et al., 2009; Flanagan, 2015). Project cost risk being primarily
- 21 caused by one (or both) of the following factors:
- 22 1. Uncertainties associated with future revenues and costs;
- 23 2. Risks related to the construction and operational phases (which ultimately have impacts on
- both future revenue and cost steams)

- 26 The least risky country with which to make an interconnection is that with the minimum, so
- 27 determined, cost risk.
- 28 3.4.1. Developing a cost model through Whole Life Appraisal (WLA)
- 29 WLA is an economic tool which can be used to make an informed choice between various
- 30 competing options (in this case for comparing candidate countries for interconnection).

- 1 The requirements of the WLA for task at hand are (Flanagan and Jewell, 2008):
- 2 1. Identification of an overall useful life (i.e. whole life) for the interconnections
- 3 2. Collection of costs and revenues associated with constructing, utilising and
- 4 maintaining an interconnection
- 3. Consideration only of those costs and revenues which have a direct impact on the 5
- 6 project itself. Thereby excluding for example employment generated through the
- 7 construction of interconnections.
- 4. Consideration of time on the value of investment, this includes; 8
- 9 a. The impact of inflation
- 10 b. The opportunity cost of capital (i.e. by utilising a discount rate).

12

- The Net Present Value (NPV) methodology was chosen as the most appropriate tool to
- 13 implement the WLA.
- 14 3.4.2 Developing a Cost-Risk Model
- 15 Risks and uncertainties were accommodated in the RBF as follows:
- 16 1. Uncertainty with future cost estimation(s) identified by the literature together with a panel
- 17 of experts
- 18 2. Construction and operational risks identified from the literature and further informed by an
- 19 expert panel.

20

11

21 The cost risk model so developed is given in Equation 1.

$$22 \qquad \widehat{NPV} = \widehat{C}_I + \sum_{i=1}^{T} \frac{\widehat{c_{0i}} - \widehat{R_{Ai}}}{(1+\hat{r})^i} \tag{1}$$

- 23 Where:
- 24 \hat{C}_I = Investment cost risk (£) (see Equation 2)
- \hat{C}_{O} = Annual operational cost (£) (see Equation 3) 25
- $\widehat{R_A}$ = Annual revenue (£) (Equation 4) 26
- (^) signifies uncertainty (i.e. risks) 27

28
$$\hat{C}_I = \hat{C}_C + \hat{C}_{CT} - S + \sum_{j=1}^{N} (I_j \times P_j)$$
 (2)

1 Where:

2

- \hat{C}_C = Cable cost (£) [uncertainties associated with cable cost such as inflation rate and
- 4 currency exchange rate],
- 5 \hat{C}_{CT} = Converter station cost (£) [i.e. High Voltage DC (HVDC) cables and DC-AC
- 6 convertor stations; an HVDC connection within an AC system requires two converter
- 7 stations]
- S =savings equal to the equivalent cost of generating electricity [i.e. the savings accruing
- 9 from supplying electricity from other countries compared to the average cost of various
- electricity generation technologies for the recipient country
- I_i and P_i = impact and probability (respectively) of N identified construction risks, j

12

13
$$\hat{C}_O = \hat{C}_M + \hat{C}_L + \hat{C}_{RE} + \sum_{n=1}^K (I_n \times P_n)$$
 (3)

- 14 Where
- \hat{C}_{M} = Annual maintenance cost,
- \hat{C}_L = Annual cost of losing power due to heating of the line
- $\hat{C}_{RE} = \text{Cost of imported RE}.$
- In and P_n = Impact and probability of K identified operational risks

$$\widehat{R_A} = \widehat{R_{A1}} \times \widehat{r_{RG}}$$

$$21$$
(4)

- Where
- \hat{R}_{A1} = Revenue in the first year (i.e. 2030)
- \hat{r}_{RG} = Annual revenue growth rate
- 25 Within Equation 1, cost uncertainties were represented as a range of possible cost values (i.e.
- 26 impacts) with an associated likelihood of occurrence. The costs and their probabilities were
- 27 determined from the literature and via consultation with the pool of experts and were
- 28 modelled using statistical distributions, to accommodate the range of expert estimated values.
- \hat{R}_{A1} in Equation 4 is determined by the likely supply capacity (i.e. surplus energy availability)
- of the interconnection (E_e) and was determined using a RE availability model [for more
- information see Eskandari Torbaghan et al. (2014)]. The RE model is related to:

- 1 i) the ability of the host country to sell spare renewable energy to the recipient
- 2 country (after meeting its domestic demand);
- 3 ii) CO₂ related cost savings (e.g. through reduced carbon credit payments).
- 4 Construction and operational risks were quantified by three point-estimates, derived from
- 5 three defined scenarios; worst, most-likely and best case scenarios.
- 6 Triangular and binomial distributions were used to model all cost uncertainties, risks and
- 7 their likelihood (probability) respectively, except for the growth rate for which a normal
- 8 distribution was used.

4. Application of RBF to the UK

- 10 The RBF developed in Section 3.0 is demonstrated here via a case study which identifies the
- 11 most appropriate country (in terms of the minimum cost risk) for the UK with which to make
- 12 an interconnection.

9

13 **4.1 Stage 1: Initial screening**

- 14 Nine feasible candidate countries (Belgium, Denmark, France, Germany, Ireland,
- Netherlands, Norway, Spain and Sweden) were identified by an initial screening exercise for
- making interconnections with the UK (Eskandari Torbaghan *et al.*, 2015).

4.2 Stage 2 and 3: Risk identification and Semi-quantification

- An initial extensive literature review, augmented by canvassing the opinion of a group of
- 19 experts, through a series of structured interviews, identified 18 construction and 8
- 20 maintenance risks (Table 1) which could impact costs. In brief the process involved 20
- 21 experts, representing eight different European countries, with specialist skills and knowledge
- in electricity generation and distribution participated in the research.
- 23 The risks were subsequently semi-quantified, as described above and using a risk matrix
- 24 (Figure 2) where the probability and cost impact values were determined by consulting with
- 25 the panel of experts.

26 4.3 Stage 4: Risk Quantification

- 27 Within the risk quantification stage the probabilities and impacts of the identified
- 28 construction and operational risks on the costs and benefits of an interconnection with the UK

- were evaluated using the cost risk model incorporating the NPV method as described above.
- 2 The NPV for each interconnection was calculated according to Equation 1 for an assumed 40
- 3 year period of operation. Construction and operational costs adopted for the study are shown
- 4 in Tables 2 and 3. For the purposes of the risk quantification the triangular probability
- 5 distributions were determined by using within the Monte Carlo Simulation (MCS) the
- 6 minimum, maximum and most likely values obtained from the literature. N.B. The value of
- 7 S, Equation 2, is assumed to be £1400/kW, based on studies by Mott MacDonald (2011),
- 8 Kannan (2009) and Parsons Brinckerhoff (2011).
- 9 For the purposes of the case study values of 80th percentile (P80) E_e were used (Table 4) for
- 10 the countries considered (i.e. the result of simulations for E_e shows that 80% of them
- produced values equal to or smaller than the value shown in the Table 4). Using these values
- of E_e the revenues were calculated by considering i) the revenue from selling the UK's spare
- RE to the candidate country and ii) value of CO₂ emission cost savings (i.e. saving the cost of
- 14 CO₂ emission taxation from generating electricity rather than importing it).
- 15 As an example, the revenue component for Norway is presented in Table 5 which shows the
- minimum, most likely and maximum availability of RE.
- 17 The uncertainty associated with estimating revenue growth (i.e. Equation 4) is based on an
- analysis by Nooij (2012) of the Norway-Netherland (NorNed) interconnection and assumes
- an annual 2 % growth rate with a standard deviation of 1 %.
- 20 The discount rate used was an after-tax rate of interest that is expected to be earned on
- 21 investments over the stated period. In this analysis a value of 9% was assumed for all
- 22 countries based on work by Nooij (2011) for the NorNed interconnection. For the purpose of
- 23 this case study the discount rate was not considered to be uncertain.
- 24 The distribution of Norway revenue growth rate is shown as an example in Figure 3, from
- 25 which it may be seen that there is a 5 % likelihood of achieving a growth rate of less than
- 26 0.355% and a 5 % likelihood of achieving one over 3.645 %. This highlights the chance of an
- 27 overestimation or underestimation of growth estimation for an interconnection project.
- 28 Therefore any decision regarding building a new interconnection should be informed by this
- 29 uncertainty and whether it is tolerable.
- 30 In order to ensure a sufficiently accurate output 10,000 MCS iterations were undertaken to
- 31 generate a frequency distribution of possible NPVs for each interconnection. Following risk

- analysis guidelines for the case study, the 80 percentile NPV (P80 NPV) was the chosen
- 2 statistic with which to compare the possible interconnections (IRG, 2013; Oracle, 2009).

3 **5. Results**

4 5.1 Single point estimations - NPV (risks excluded)

- 5 Table 6 shows the NPVs, calculated using the most likely values, when excluding identified
- 6 risks for each country concerned. The chance(s) of achieving an NPV equal to or greater (i.e.
- 7 closer to zero) than the NPV's shown was calculated by running MCS. It can be seen that of
- 8 the 9 candidate countries, only 5 have negative NPVs (i.e. the benefits are greater than the
- 9 costs). An NPV score for the Netherlands could not be calculated as the projected 'spare' RE
- was not sufficient to consider an interconnection for this country (see Eskandari Torbaghan et
- al., 2014). In contrast France was found to have the highest NPV (with a 70% probability of
- achieving it), whilst Spain had the lowest (with only a 53% probability of achieving it).
- 13 When considering NPV (with risks excluded) the results suggest that France is the
- preferential country for the UK to make an interconnection with whilst Spain is the least
- preferred. Some of the reasoning for this is related to the proximity of France to the UK
- resulting in low construction costs (Table 6). In addition the interconnection capacity
- between the two countries is projected to be high (i.e. 4000 MW), because of France's high
- projected spare RE, and the price of exported electricity is low. Conversely the comparatively
- 19 large distance (Table 6) and expanse of ocean between Spain and the UK is a major factor in
- a connection between the two resulting in highest investment costs (£2.6b) and a relatively
- 21 low NPV.
- 22 The probabilities of achieving (as a minimum requirement) these initial NPV estimates are
- 23 relatively low, for all countries. This demonstrates the uncertainties inherent in using a
- single-point cost estimation to appraise an interconnection project. This is one of the main
- 25 reasons behind existing protracted decision-making processes.

5.2 NPV (risks included)

- 27 The P80 NPVs values when including identified risks and uncertainties associated with cost
- and revenue estimations for the 9 candidate countries are presented in Table 7. When
- comparing Tables 7 and 6 it can be seen that the hierarchy has remained relatively unchanged
- 30 with the exception that Ireland is now placed above Denmark. P80 NPVs have however

- worsened (i.e. NPV values are higher), not least for interconnection(s) between the UK and
- 2 France and UK and Germany (increasing by 30% and 25% respectively).
- 3 The higher position of Ireland with respect to Denmark is because of the lower risks impacts
- 4 associated with an interconnection between Ireland and the UK, than between the UK and
- 5 Denmark. The lower risks of a UK Ireland interconnection are also to do with the
- 6 comparatively short distance between Ireland and the UK, and broadly similar energy and
- 7 distributing systems (physically and politically). Accordingly, an interconnection between
- 8 Ireland and the UK was found to have low risk scores associated with identified electricity
- 9 price and energy policy related risks.

10

- Figure 4 shows the 80 percentile NPVs of the candidate countries. The bars on the figure
- represent the range of possible NPVs between the 5 and 95 percentile values. For instance the
- 13 range of NPVs for France is -£31 to £3 billion (Figure 5). Spain and Germany have the
- 14 greatest range of NPVs of approximately £50 billion between their 5 percentile NPVs and
- 15 their 95 percentile NPVs reveals the high level of uncertainties associated with those two
- 16 countries. The large range of possible NPVs for Spain and Germany respectively
- demonstrates the high level of uncertainty associated with the two countries and is in part to
- do with the large distance between the countries and the UK. Supplementary material in form
- of an Excel file is provided in Appendix A.

20

21

5.3 Profitability Index (PI)

- 22 For the case study, the Profitability index (PI) was calculated to take into account the possible
- capital limitation for developing a new interconnection (since more costly projects are likely
- to have larger NPVs).
- 25 The profitability index was defined as:

$$PI = \frac{NPV_{[P80]}}{C}$$
(5)

- Where (units in italics):
- 28 $NPV_{IP801} = 80$ percentile NPV (£)

- 1 C_I = Investment cost (£)
- 2 The calculated PIs are presented in Table 8.
- 3 Comparing Tables 6 and 8 it can be seen that the hierarchy has remained relatively
- 4 unchanged with the exception that Germany is fifth (moving from second place in Table 6).
- 5 This is due to the added consideration of the high investment cost (£1.717 billion) associated
- 6 with the interconnection between the UK and Germany caused by the comparatively large
- 7 distance between the two countries (Table 6).
- 8 The PI index for the France is the highest amongst the 9 candidate countries considered and
- 9 shows that the interconnection could generate £12 for every pound invested.

5.4 Sensitivity analysis

- In order to test the robustness of this approach, a sensitivity analyses was conducted to
- 12 identify parameters that most influenced calculated NPVs, and therefore those which will
- 13 require additional scrutiny.
- 14 The sensitivity analyses revealed the 1st Year Revenue and the Cost of Imported RE to be the
- most dominant contributors to the calculated NPVs for all candidate countries. This is due to
- the fact that yearly revenues are highly dependent on first year revenue and are a function of
- 17 the growth rate. The cost of imported RE is one of the main components of the cost model
- with direct impact on the calculated NPVs. The other relative influences of the other 8
- parameters on NPV vary according to the country considered, but they are related to the cost
- 20 of maintenance and growth rate. An example for France in the form of a Tornado graph is
- shown in Figure 6.
- 22 Management efforts such as the development and adaptation of revenue and cost models
- 23 which include various risks and uncertainties could be utilised to ensure that the 1st Year
- 24 Revenue and the Cost of Imported RE will not jeopardise the viability of an interconnection.

25

6. Concluding Discussion

- 2 The literature review presented within this paper set the context for the need for a Risk-Based
- 3 Framework to identify the least risky region or country with which to make an electricity
- 4 interconnection. As such this paper set forward a robust methodological process by which
- 5 this could be developed. The underpinning methodology consisted of:
- 6 (1) an initial screening process to identify countries to be excluded from further analysis,
- 7 (2) a risk identification process, utilising expert opinion, to identify uncertainties associated
- 8 with both building interconnections and importing electricity,
- 9 (3) a risk semi-quantification stage which consisted of determining consequences and
- probabilities of occurrence to define a level of risk, and
- 11 (4) a risk quantification stage to forecast the risk contingencies for capital expenditure and
- 12 operational excellence.
- Once developed and in order to demonstrate the methodology fully, the RBF was applied to
- 14 the UK as an example case study. After initial screening in Stage 1 the case study considered
- 9 potential candidate countries and after final processing in Stage 4 it was shown that the
- 16 country with the highest NPV_[P80] was France. Therefore France was identified as the best
- 17 countries for the UK to make interconnections with, when considering NPV, PI and the
- associated probabilities. Additionally France was shown to be the preferred option as an
- 19 interconnection between the UK and France has a relatively low capital cost forecast, a lower
- 20 risk in general and there is relatively large availability of RE. The findings for France are
- 21 consistent with the past and current UK policy as the UK's first interconnection to be built
- 22 was with France and there are on-going discussions about building a second. An
- 23 interconnection with Germany has also been recognised in this paper as potentially attractive,
- 24 although with high capital costs. Indeed Germany has already been recognised as a potential
- option by the UK government, albeit without any apparent numerical evidence. Whilst the
- 26 cost-risks associated with the large distance between German and the UK are relatively high,
- 27 these are offset by Germany's very large projected supply of RE. Spain is ranked as the least
- 28 preferred country mainly because of the large distance between it and the UK which result in
- 29 relatively high capital costs and associated risks.

- 1 The results of the sensitivity analysis emphasises the importance of interconnection revenue
- 2 estimation, and in particular the component of the benefit associated with selling spare RE, as
- 3 it was found to have the highest impact on the distribution of NPVs. The estimation of the
- 4 accrued benefits of selling electricity has a high level of uncertainty as the analysis considers
- 5 RE availability and price over a 40 year time horizon. This aspect was addressed by
- 6 generating and including various plausible energy scenarios to estimate RE availability
- 7 reported. Future development of a modified and updated energy scenario projection model
- 8 for the involved countries is desirable.
- 9 As far as the risk quantification process is concerned, a whole life appraisal (WLA) approach
- 10 has been shown to work effectively when utilised within an MCS. The developed RBF has
- demonstrated the inherent need for such an approach and highlighted the benefits that can be
- reaped in terms of informed decision-making. The developed methodology can be used to
- encourage building new interconnections and can be used by any country, public or private
- organisation. This becomes readily apparent when it is being used to identify the highest and
- 15 lowest NPVs, as an indicator for whole life economic benefit associated with construction
- and operation.
- 17 The RBF should be considered as a precursor within any risk analysis project and should be
- applied occur in the initial stages of any interconnection works.
- 19 One significant barrier to be overcome when adopting the proposed RBF is the availability of
- 20 appropriate data for risk identification and for estimating the associated risk impacts and
- 21 probabilities. A well-tried method of tackling this issue, as used in this paper, is to make use
- of expert opinion. The results of the analysis obtained however will ultimately depend upon
- 23 the range and quality of the experts considered. Moreover it is important, where possible,
- 24 when using experts' opinion to mitigate any possible bias. To this end, in this study a pool of
- 25 20 experts was drawn from across Europe, from both industry and academia, their opinions
- were recorded via targeted questionnaires and in-depth one-to-one interviews. This produced
- 27 a well-balanced response making use of knowledge from experts who are well versed in
- 28 terms of experience in electricity generation and distribution. However it is recognised also
- 29 that the process of consultation could be improved further to help avoid any unintentional
- 30 bias by involvement of a wider range of experts and other interview techniques, such as brain
- 31 storming sessions, risk review meetings during workshops and/or Delphi technique(s).

- 1 Where possible the preliminary results should be verified against historical data in order to
- 2 consider the relative weights (i.e. importance to stakeholder groups) of the identified risks
- 3 (rather than identical weightages as considered here), allowing for more weighting to be
- 4 placed against key identified risks.
- 5 In general, a fundamental impediment that acts as a significant barrier for the development of
- 6 interconnections is changing government energy policy. Interviews with experts revealed that
- 7 this is a major reason for the current protracted procedures for governmental approvals and
- 8 can be avoided (in part) through improved engagement with the private sectors. This can be
- 9 achieved through mechanisms such as public private partnerships (PPPs) in order to facilitate
- both the procedure and by providing knowhow to help reduce some of the risks that occur
- when considering the public (or private sector) alone. The procedure developed herein can
- also help with this process by identifying the causes of significant risks (e.g. the pressure of
- public opinion) leading to appropriate mitigation measures (e.g. raising public awareness).
- 14 The current trend for developing renewables can also help address the second major
- uncertainty found in this research, which related to the availability of tradable renewable
- electricity. This is also related to and affected by energy policy. Engagement of the private
- sector could also help here and may enhance the development of interconnections to provide
- a larger market for renewables.
- 19 The proposed RBF should also be utilised to model interdependencies and consequential
- 20 impact of risks associated with construction and operational phases. Further, special attention
- should be given to develop the model to take into account highly disruptive risks (i.e. those
- 22 with low likelihood and high impact), such as catastrophic failure, terrorist attacks and
- 23 political instability of energy producing countries.

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8. References

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