Study on the value of interconnections between France and Great Britain

Report

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03/10/2017
Final Version

SAS with capital €107,332.60
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NAF Code 5829C

Executive Summary

Electrical interconnections between countries make it possible to exploit the complementarities of energy systems, to facilitate the integration of intermittent renewable production and to provide mutual assistance at the European level for the security of the electricity supply in each country. Today, **thirteen[1] interconnection projects between the United Kingdom of Great Britain and Northern Ireland (hereinafter the United Kingdom) and its European neighbours are being studied or are under construction, five of which connect Great Britain to France**.

The purpose of this study is **to assess the value of an interconnection project between France and Great Britain** in a context made uncertain by the withdrawal of the United Kingdom from the European Union (Brexit). Uncertainties linked to the future evolution of the composition of electricity generation mixes in the various European countries are added to the **economic, energy and trade implications of Brexit**. The withdrawal of the United Kingdom from the European Union leads to a new situation. The composition of the UK energy mix, costs of interconnection projects and trade arrangements - particularly **rules for the functioning of electricity markets** - are all factors that can be impacted. In this context, this study considered several possible Brexit scenarios to **compare the cost of an interconnection project between France and Great Britain to the benefits it could generate**. The selected scenarios are constructed from 2020 projections and TYDNP 2030 visions (ENTSO-E, 2016); assumptions relating to the United Kingdom are changed according to the degree of severity of Brexit's application procedures. Two alternative Brexit contexts are considered: **a "Soft" Brexit and a "Hard" Brexit**, with each of these corresponding to different levels of coordination between the United Kingdom and the European Union in the electricity sector. **In the context of a Hard Brexit**, it is assumed that the United Kingdom is equipped with higher production capacities to ensure its security of supply independently and that **the electricity markets of the United Kingdom and continental Europe are decoupled**.

For each of these scenarios, and for each of ENTSO-E's 2020 and 2030 visions that they include, simulations, with an hourly time resolution and over 10 climatic years, of the management of generation, storage and transmission of electricity on the ENTSO-E perimeter, are carried out using the Artelys Crystal Super Grid software. With the exception of France-Great Britain, all interconnection capacities between the ENTSO-E countries are set at the values defined by the TYNDP 2016[2]. Between France and Great Britain, each calculation was carried out twice, with an interconnection level of 4 GW in one instance and 5.4 GW in the other instance[3]. Comparing of the results of these simulations made

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[1] Source: http://tyndp.entsoe.eu/documents/TYNDP2016_Projects%20data.xlsx as well as on the project sheets published by ENTSO-E on the TYNDP 2016 - http://tyndp.entsoe.eu/reference/#downloads

[2] With the exception of the UK-Ireland interconnection assumed to be 1 GW in 2030, corresponding to the commissioning of the GreenLink project, which has been approved by Ofgem.

[3] These 4 GW correspond to IFA (operational, 2 GW), IFA2 (approved by CRE, 1 GW) and ElecLink (approved by CRE, 1 GW). The additional 1.4 GW correspond to the expected installed capacity of FAB Link, an interconnection

it possible to evaluate the benefits obtained by such a reinforcement of the interconnection capacity between France and the United Kingdom, and led to the following observations:

- *From 2020 to 2030, the value of an interconnection project between France and Great Britain will gradually decrease.* This decrease can be observed in all scenarios: in the adapted TYNDP 2016, and in the case of either a Soft Brexit or a Hard Brexit. By 2020, an interconnection project between France and Great Britain would generate an average net surplus[4] over all scenarios of €68 million/GW/year, but by 2030, due to changes in the energy mix, interconnection capacities and lower exports from France to Great Britain, this net surplus would be reduced from 25% to 40% depending on the scenario.
- *Brexit reduces the value of the interconnections between France and Great Britain, and much more markedly within in the context of a Hard Brexit.* Indeed, the hypotheses made for the United Kingdom in a Soft Brexit with a 11% lower renewable generation capacity than in the 2030 scenario without Brexit (and thus a reduction in export opportunities) and a 4% lower level of electricity demand than in the 2030 scenario without Brexit (and thus a reduction in the import needs) decrease the value of interconnections by about 10%. This decrease is much more significant and exceeds 30% in the context of a Hard Brexit, in particular because electricity markets are assumed to be decoupled, which prevents an optimal use of the interconnection.
- *The distribution of surpluses[5] linked to a new interconnection is not symmetrical between the United Kingdom and the rest of Europe. The surplus for the United Kingdom alone accounts for 70% to 80% of the total collective surplus in 2030 and 100% in 2020.* Consequently, the gross surplus generated by the interconnection for the ENTSO-E zone outside the United Kingdom would be low in 2030, and nil in 2020. Nevertheless, it is important to note that although this value is low for continental Europe, it is far from being zero for each of its countries. The gain for France is significant in many scenarios. Contrarily, other countries are seeing their import opportunities drop to the benefit of Great Britain.
- *The interest of an interconnection project between France and Great Britain, as measured by its net present value, varies significantly according to the terms of Brexit*. The NPV (Net Present Value) of a reference project (in terms of cost) is very clearly negative in the context of a Hard Brexit at €-129 million/GW, whereas it is €77 million/GW for a Soft Brexit.
- *If we assume that a Hard Brexit is as likely to occur as a Soft Brexit, the expected NPVof a project will be greater if the investment decision is postponed by two years*. A decision taken today will be without information on the future Brexit context, while a two-year postponement will make it possible to know the Brexit context and make investment decisions accordingly.

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project between France and Great Britain, to which the European Commission has attributed the status of a project of common interest (PCI).

[4] Net of additional incremental costs generated by additional losses on interconnections, without taking into account investment costs.

[5] This gross surplus corresponds to the gross welfare increase, without taking into account the additional costs associated with the losses. Assuming that 50% the additional losses are allocated to the United Kingdom, the latter is allocated 80% to 90% of the net surplus for additional interconnection.

It seems preferable to wait to know the Brexit context before deciding on financing projects, unless it is considered that a Hard Brexit has at most one chance in five of occurring.

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Artelys is a company specialising in optimisation, modelling and decision support. Artelys is a leading consultancy company in optimisation and techno-economic analysis of energy systems and has carried out hundreds of studies and software development projects in the energy sector. Artelys has developed a software suite, Artelys Crystal, dedicated to the economic optimisation of management and investments in energy systems.

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Frontier Economics Limited (Europe) is a consulting firm in economics experienced in applying the principles of the economy of regulation and competition to various problems. We work in the energy sector in more than 50 countries at all levels of the value chain. We also work with various players in Europe on the impact of Brexit on their business.

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1 Introduction

1.1 Background

1.1.1 France – Great Britain interconnection at present

At present, Britain has 4 GW of interconnection capacity with its neighbours: 2 GW with France (IFA), 1 GW with the Netherlands (BritNed) and 1 GW with the Single Electricity Market (Moyle and East-West). The high price differentials between the UK and continental markets, illustrated in Figure 1, reflect a potential complementarity between these systems (generation fleet, level and demand dynamics). New interconnection projects could be worth it as long as the benefits in terms of surplus match the investment costs.

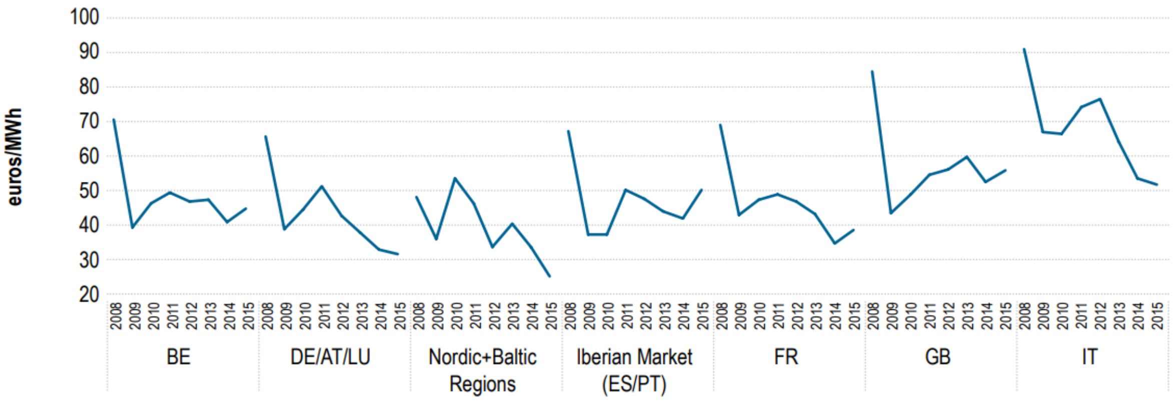

Figure 1 - Evolution of annual averages of day-ahead market prices for different European market areas (source: ACER, Market Monitoring 2015)

A number of new projects have already been approved by the UK regulator (Ofgem), notably under the "Cap & Floor" incentive mechanism, which has been set up to ensure a greater risk-sharing between project developers and public authorities (see Figure 2).

The increase in interconnection capacity is part of the National Infrastructure Commission's recommendations to the UK Government (National Infrastructure Commission, 2016) and has also been incorporated into the National Grid prospective scenario hypotheses and BEIS projections. The latter forecasts an interconnection level of around 20 GW by 2030 (UK Department for Business, Energy and Industrial Strategy (BEIS), 2017).

Cap & Floor Window 1

- NSL (Norway, 1.4 GW)
- FAB Link (France, 1.4 GW)
- IFA2 (France, 1 GW)
- Viking Link (Denmark, 1 GW)
- Greenlink (Ireland, 500 MW)

Cap & Floor Window 2

- GridLink (France, 1.4 GW)
- NorthConnect (Norway, 1.4 GW)
- NeuConnect (Germany, 1.4 GW)

Figure 2 - Interconnection projects declared as eligible for the Cap & Floor mechanism by Ofgem

The ElecLink project (France, 1 GW) obtained a partial derogation from CRE and Ofgem to the usual regulatory obligations (in particular those relating to the organisation of third party access to the network, i.e. Article 32 of the European Directive 2009/72/EC) and will not be subject to the "Cap & Floor" regulation. It will collect the entire revenue generated[6]. It is likely that the developers of the Aquind project (France, 2 GW) are also seeking such an exemption.

Among the projects linking France and Great Britain, IFA2 has already been approved by the CRE, but the FAB Link, GridLink and Aquind projects have not yet been evaluated by its services. As can be seen from the above, at least three requests for evaluation from project developers could reach CRE in the coming months and years (at least the FAB Link, Grid Link and Aquind projects).

1.1.2 Issue studied

In order to examine the different projects, their respective impacts in terms of collective surplus must be analysed. Given the operational lifetime of electricity interconnectors, the assessment of surpluses must take into account various possible developments of the European electricity system. These scenarios may reflect energy or climate policy elements (priority investments in renewable sectors, removal of certain thermal technologies, etc.), economic conditions, which, in particular, influence the level of demand, and dissemination of new technologies, uses and practices (electric vehicles, heat pumps, active demand management).

In this respect, Brexit[7] is one of the sources of uncertainty that must be considered carefully when assessing projects connecting Great Britain to continental Europe. The withdrawal of the United Kingdom[8] from the European Union, voted by the British public in a referendum on 23 June 2016, could have profound effects on the evolution of the British energy sector and on the modalities governing energy exchanges, assistance during periods of tension on the networks and coordination of investments in infrastructure, such as interconnections.

Moreover, Brexit has a temporality that differs from the other medium- and long-term uncertainties: the negotiations now under way between the United Kingdom and the other Member States of the

[6] Beyond a certain income level, an profit-sharing mechanism has been set up with other network users.
[7] Procedure for the withdrawal of the United Kingdom from the European Union.
[8] United Kingdom of Great Britain and Northern Ireland (hereinafter the United Kingdom).

European Union will result in an agreement which, as of March 2019, the date of the withdrawal of the United Kingdom from the European Union, will govern relations between the United Kingdom and the EU27. Also, a number of uncertainties are expected to vanish in the next two years. It is therefore legitimate to question the appropriateness of waiting until uncertainties are removed before deciding on public support for new infrastructure.

1.2 Objectives

The purpose of this study is to understand the economic implications related to increasing the capacity of electricity interconnectors between France and the United Kingdom. This analysis is carried out taking into account the uncertainties, particularly those generated by Brexit, on the evolution of the electricity generation mix and its various cost items.

The aim is to evaluate the profitability of interconnection projects over their entire lifespan, taking into account different scenarios from commissioning to end-of-life. Indeed, if the benefits associated with a project exist in a given situation, for example close to the current context, they may decrease on a medium-term horizon, for which the energy context will have evolved[9].

1.3 Modelling tool: Artelys Crystal Super Grid

Calculations on which the analysis is based were performed using the Artelys Crystal Super Grid software. Developed and distributed by Artelys, this tool is dedicated to the realisation of cost-benefit analyses of energy systems and in particular to the evaluation of the economic interest of interconnection projects.

The tool consists of a graphical interface used to create the models and to analyse the results and a calculation engine implementing advanced optimisation algorithms to optimise the generation dispatch with an hourly time resolution in all the European countries for multiple climatic scenarios. The model takes into account a large number of technical and economic parameters including dynamic stock management, fuel costs, CO_2 and dynamic constraints of thermal generation fleets (ramps, start-up costs, etc.).

Furthermore, *Artelys Crystal Super Grid* has an investment planning module, which was used in this study. Figure 3 illustrates how the software works.

[9] For example, a country can now take advantage of large imports of electricity from low-cost baseload production from neighbouring countries to meet its demand without using its own more expensive mid-merit or peak production capacity. However, if demand decreases in the coming years, and its own baseload production capacity increases while the available baseload production of its neighbours tends to decline, gains from interconnection can gradually decrease.

Figure 3 - Overview of the Artelys Crystal Super Grid tool

1.4 Methodology

The gross profit created by an additional interconnection between France and the United Kingdom is assessed in a context close to today's projected to 2020 and in more distant 2030 contexts using the assumptions of the ENTSO-E TYNDP 2016[10] projections and visions (ENTSO-E, 2016) for the evolution of the European energy mix.

The method adopted follows the ENTSO-E *Guideline* for the cost-benefit analysis of network development projects (ENTSO-E, 2015), usually used[11] for the assessment of interconnection projects. For the two time horizons considered and for each of the scenarios (projection 2020 and visions 2030) of the TYNDP 2016, optimised dispatch[12] and annual[13] electricity flows[14] in all the ENTSO-E countries (Figure 4)[15] are simulated with *Artelys Crystal Super Grid* with an hourly time resolution in two situations: with and without an additional interconnection between France and the United

[10] As explained in details in the appendix to paragraph 7.8.1., the way in which Brexit is taken into account for the evolution of the UK energy mix is described in section 2.
[11] Many studies are taking a similar approach, for example: CRE, 2016; European Commission, Artelys, May 2016; European Commission, Artelys, April 2016.
[12] The flexibility of the thermal generating units is finely represented and takes account of technical parameters and constraints such as start-up costs; more details are given in paragraph 7.8.2.
[13] Electricity trade flows between countries are explicitly simulated using a standard NTC (Net Transfer Capacity) model, which represents maximum exchange capacities.
[14] Optimised dispatch is simulated, for each vision and each horizon, over ten climatic years, which are characterised by distinct solar and wind production generation profiles and demands.
[15] More precisely 34 of the 36 countries currently in ENTSO-E are explicitly modelled; the two countries that are not represented are Iceland (not interconnected) and Albania (due to the lack of data from ENTSO-E to calibrate the models).

Kingdom. The difference in *collective surplus - or socio-economic welfare*[16] - between these two situations corresponds to the gross profit attributable to the interconnection project.

This gross profit minus the cost associated with the increment of losses on the interconnection studied[17] is then compared to the project's annuity in order to compute an average net benefit for the two considered time horizons. The net profit is computed for the entire ENTSO-E perimeter and also broken down by zones in order to capture, in particular, the share of this net benefit captured by the United Kingdom. The net present value of the project over its lifetime is also computed.

The rest of this report is divided into four parts: Section 2 describes the assumptions and rationale to model Brexit in 2020 and 2030 scenarios; Section 3 sets out the economic gains related to an additional interconnection between France and Great Britain; Section 4 analyses the profitability of projects by comparing these gains to project costs; and Section 5 presents the impact of the additional interconnection on flows between France and Great Britain and more generally on all European countries.

Figure 4 - Representation of the European power system in Artelys Crystal Super Grid

[16] An economic indicator usually used to assess the benefits of a project for the community as a whole. A more precise definition of this indicator is provided in the appendix to paragraph 7.3.
[17] The cost of these losses are taken from CRE, 2016.

2 Impact of Brexit on the UK energy mix and presentation of scenarios

2.1 British background

Since the announcement of a possible withdrawal from the United Kingdom of the European Union and Euratom, the potential consequences, notably for the energy sector, have been the subject of controversy. Some of the potential impacts of Brexit, as well as the extent to which they were taken into account in the development of scenarios 2020 and 2030, are described below.

- **Economic growth** - The UK's economic growth rate is likely to be affected by Brexit. In line with most work carried out on the potential consequences of Brexit, this study considers a lower growth of electricity demand in the Brexit scenarios.
- **European coordination** - A number of EU-defined targets are set at the Union level, including targets for the share of demand to be met by technologies using renewable energy sources at the 2030 horizon. Mechanisms are in place (including tenders open to neighbouring countries) in order to exploit the sites with the best conditions first. Therefore, it is assumed here that the wind turbine deployment in highly coordinated scenarios is reduced in the UK for the Brexit scenarios.
- **Access to markets** - The coupling of electricity markets between the UK and continental Europe could be impacted by Brexit. Such an assumption is considered here only in the case of a particularly Hard Brexit[18].
- **Security of supply** - The withdrawal of the United Kingdom from the European Union will likely result in a change in the arrangements for assistance between countries during periods of high tension on the networks. In scenarios reflecting this hypothesis, the electricity generation capacity is dimensioned in such a way that the UK can meet its demand - notably peak demand - without resorting to interconnections.

Many other potential consequences of Brexit are considered in the literature, but are not included in this study because they are identified as less likely, or far from consensus, when the focus here is on structuring changes aiming to draw up contrasting scenarios: impact on the CO_2 price (withdrawal of the EU ETS mechanism, modification of the Carbon Price Support), delay in the application of the announced exit from coal in 2025, impact on investments in new nuclear power plants, etc. The impact of the new exchange rate between the pound sterling and other European currencies is not considered here. Indeed, the exchange rate should only very marginally affect the bids made by British producers on the electricity markets, and thus the electricity dispatch at the European level.

[18] This makes it possible to assess the impact of market decoupling on the value of interconnections.

2.2 General principle: impact of a Soft or a Hard Brexit on the TYNDP scenarios

This study focuses on a scenario-based vision of the 2020 and 2030 horizons (Figure 5). Two alternatives are envisaged for 2020, reflecting different degrees of rigor in the application of Brexit, which may be "Soft" (context in which certain conditions of trade with the UE27 are maintained) or "Hard" (total independence of the United Kingdom from Europe and its constraints). Twelve possibilities are considered for 2030, a more remote and more uncertain horizon.

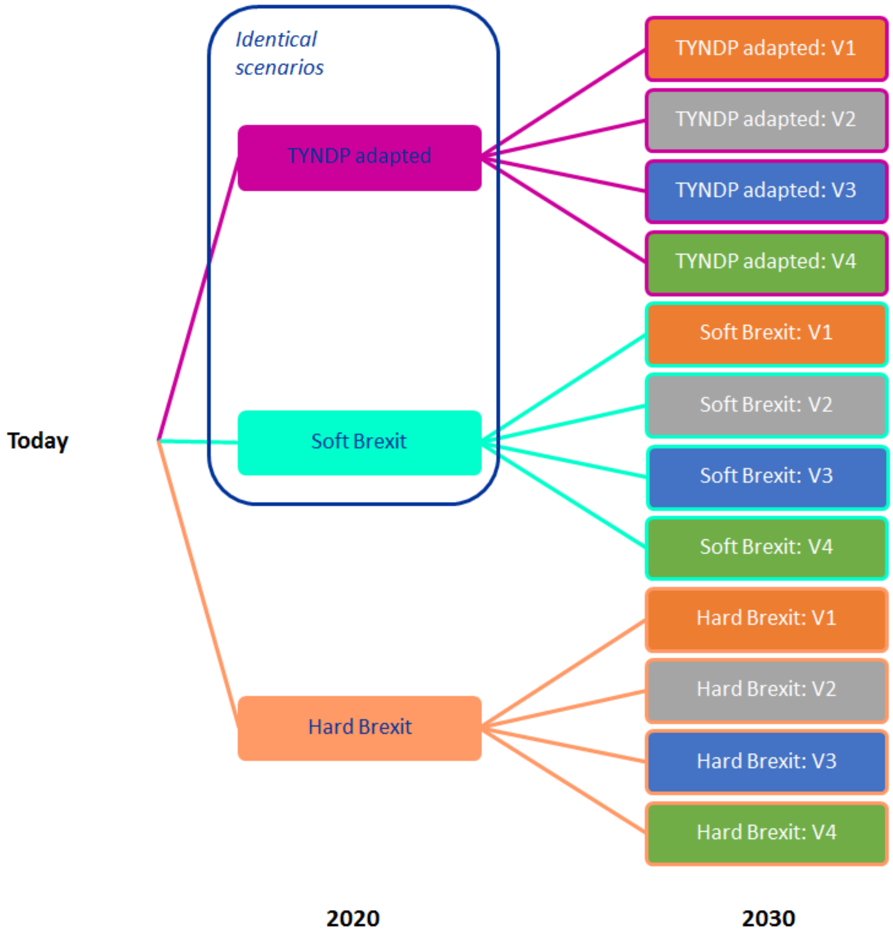

Figure 5 - Scenarios considered in the study

More specifically, three sets of scenarios are analysed, each including a projection to 2020, corresponding to the "Expected Progress" scenario of the TYNDP 2016, and four possible scenarios for 2030, corresponding to the four 2030 visions of the TYNDP (ENTSO-E, 2016).

Note: Two of the three 2020 scenarios will be assumed to be identical, which is why only two alternatives are considered in 2020, as explained in Figure 5 above.

The assumptions used to describe the different possible degrees of Brexit within the ENTSO-E Visions are shown Figure 6 and described below:

- The "Adapted TYNDP" scenarios, which do not take Brexit into account and serve essentially as a point of comparison: it is more precisely an update[19], for the United Kingdom, of the TYNDP assumptions[20]. The following adjustments were made to build these scenarios:
  - Annual demand of the United Kingdom not exceeding 366 TWh in 2030 (notably for Vision 4);
  - Solar capacity in the United Kingdom increased to 12.8 GW in 2020 and to at least 14.7 GW in 2030;
  - Wind turbine capacity in the United Kingdom sitting between 28.6 GW and 47.3 GW in 2030;
  - Interconnection between the United Kingdom and Ireland reaching 1 GW in 2030.
- The "Soft Brexit" scenarios, for which a smaller increase in electricity demand in the United Kingdom is assumed for the years to come (demand is virtually stable between today and 2030), which results in a 4% decrease of the 2030 projections for renewable (RES) and gas production capacities. In addition, it is assumed that the UK's renewable energy capacities evolve independently of any EU coordination policy[21].
- In the context of a "Hard Brexit" for which the reductions in demand and RES are even more marked than previously[22] and for which a decoupling of the electricity markets between the United Kingdom and Europe is also assumed[23]. Gas production capacity rise to represent the assumed capability of the United Kingdom to ensure its security of supply without relying on interconnectors.

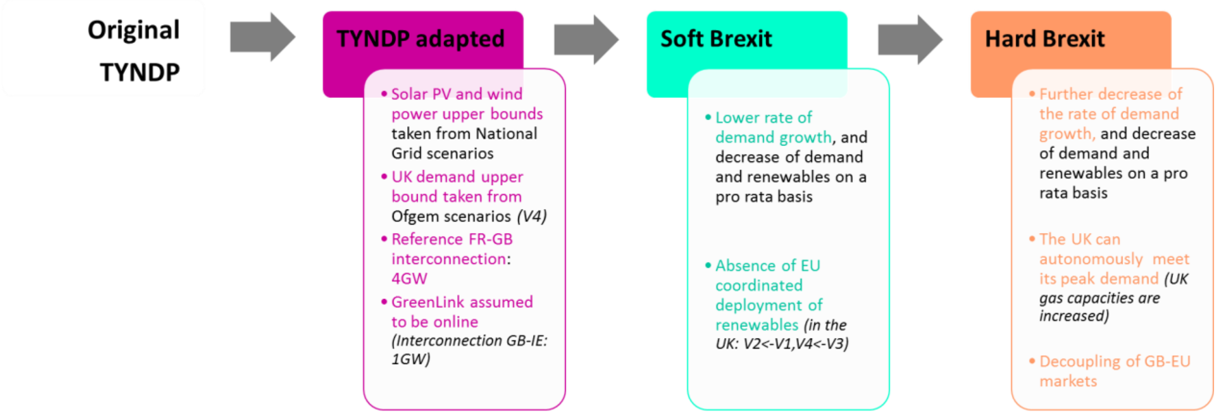

Figure 6 - Brexit representation assumptions

[19] The ENTSO-E 2016 assumptions were mostly made in 2014. The methods used to update these assumptions are detailed in appendix 7.8.
[20] The TYNDP data have also been enriched, as specified in appendix 7.8.
[21] In particular, this implies that, under the Brexit scenarios, the UK's renewable energy capacities for Visions 2 and 4 correspond to those of Visions 1 and 3, respectively.
[22] 6% decrease of 2030 renewable electricity generation capacities (and absence of European coordination).
[23] The modelling adopted to represent the decoupling of markets is described in appendix 7.5.

2.3 Detailed presentation of scenarios

Figure 7 presents the annual production by technology in the various scenarios for the whole modelled perimeter[24]. ENTSO-E's Visions 1 and 2 (Slowest Progress and Constrained Progress, respectively) assume little change in the mix between 2020 and 2030 on a European scale, with the exception of an increase in renewable energies. They differ from each other by a higher gas production capacity for the first Vision, due to greater electricity demand, and by the assumed level of coordination of renewable technologies deployment among EU countries. Visions 3 and 4 (National Green Transition and European Green Revolution, respectively) are characterised by a significant increase in renewable energies and gas capacities (which become more profitable than coal ones due to the carbon price assumption), and a decrease in nuclear, coal and lignite capacities (which are all the more pronounced in Vision 4).

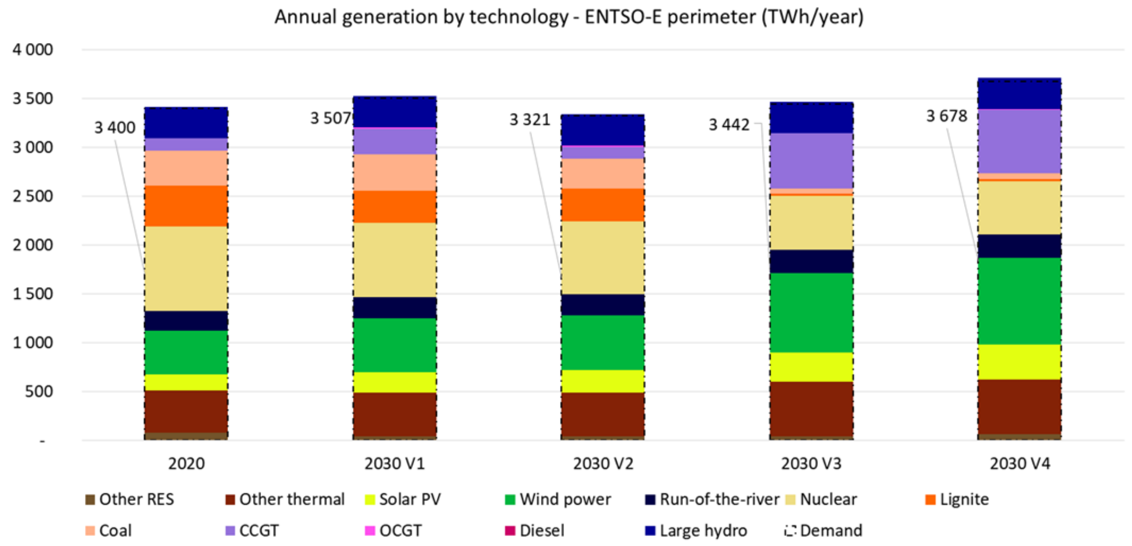

Figure 7 - Production by technology on the ENTSO-E perimeter in the various scenarios

Figure 8 presents the generation by technology in the United Kingdom in the considered scenarios (for a situation where no new interconnection project has been added, i.e. with 4 GW of interconnection between France and Great Britain). In the Brexit scenarios corresponding to Visions 1 and 3, in particular in the Hard Brexit scenario, demand for local gas production is found to decrease (in purple and pink in the figures).

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[24] For this graph, the assumptions made for the United Kingdom are those corresponding to the "adapted" TYNDP.

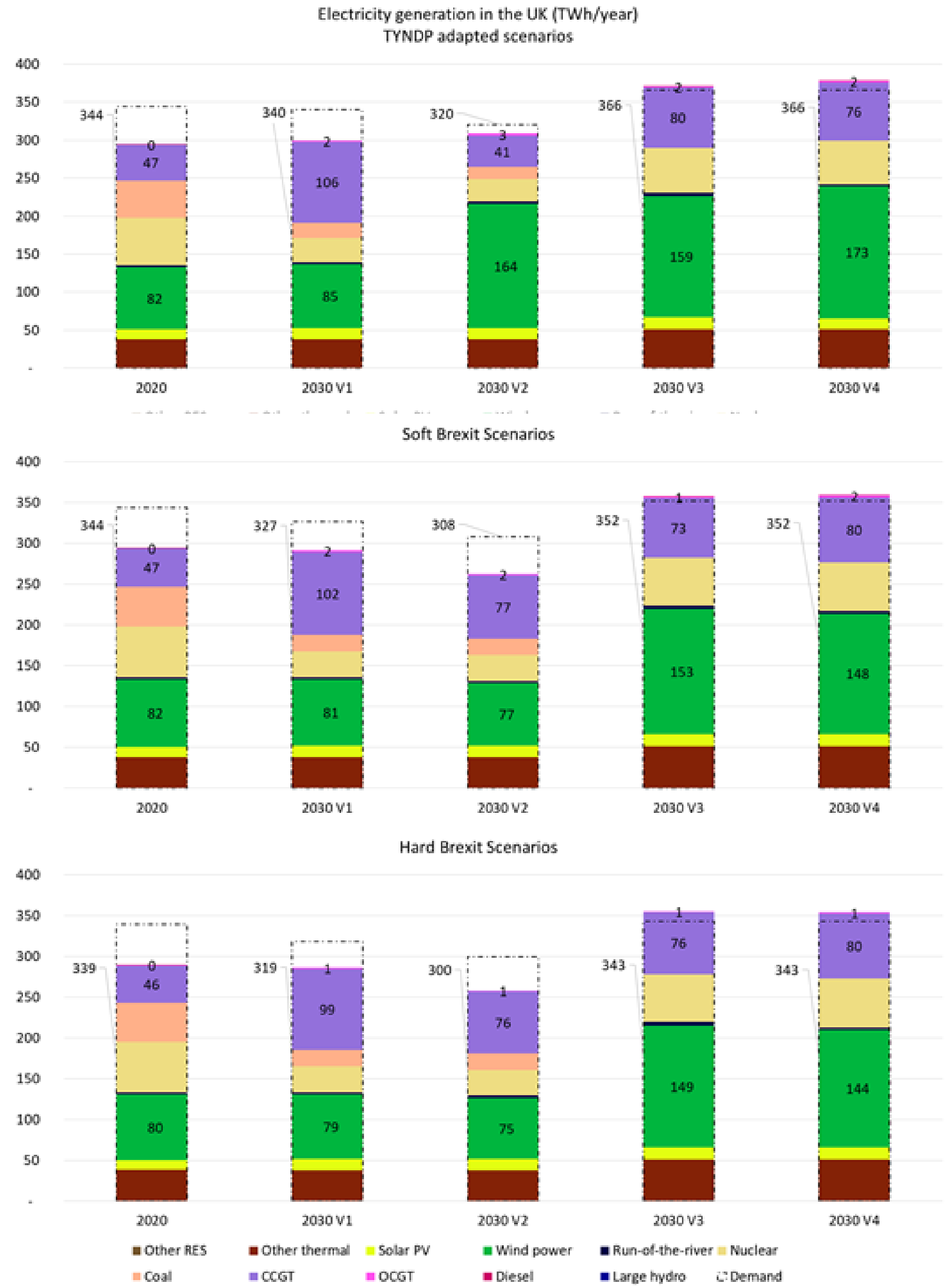

Figure 8 - Annual production by technology in the United Kingdom in the various scenarios

Comments:

1. *For Visions 1 and 3, the decrease in domestic gas production in the UK in 2030 (by comparing the TYNDP adapted scenarios to the Brexit scenarios) coincides with a decline in Britain's net imports in the Brexit scenarios, as illustrated in Figure 9.*
2. *This phenomenon is not observed in Visions 2 and 4, for which a sharp decline in the renewable capacity in the Brexit scenarios is offset by the increase in gas production and imports.*

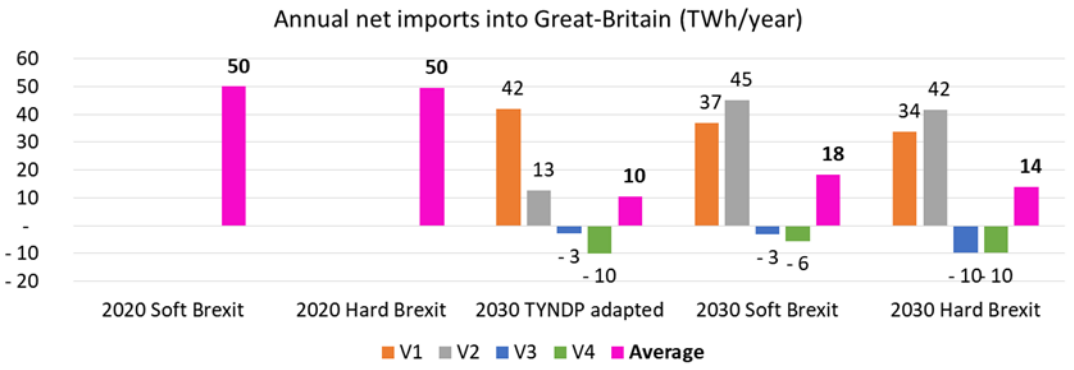

Figure 9 - Annual net imports into Great Britain in the various scenarios

Figure 10 illustrates the demand-supply equilibrium in Great Britain in 2030 over a winter week for two of the adapted TYNDP scenarios (Vision 1 above, Vision 3 below). In Vision 3, Great Britain reduces the solicitation of its OCGT gas units as it benefits from higher installed wind capacities than in Vision 1.

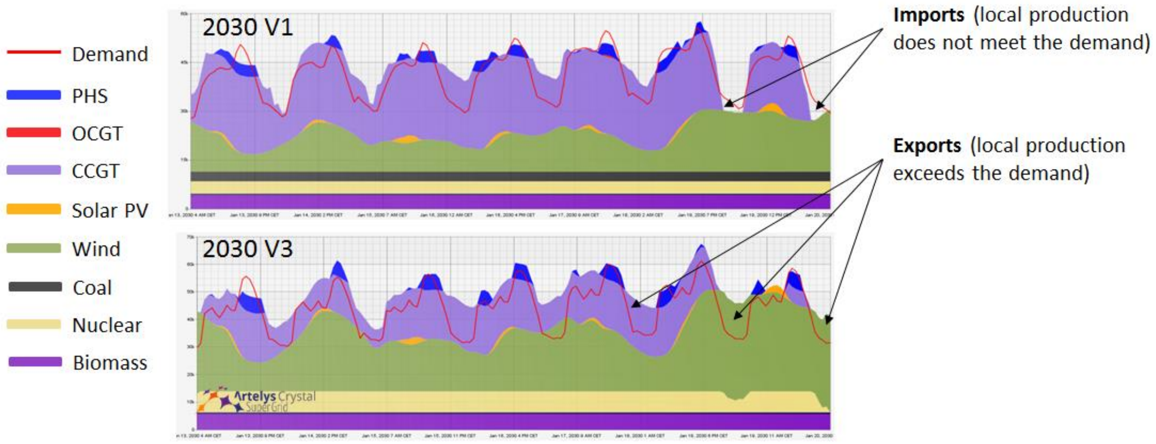

Figure 10 - Comparison of the demand-supply equilibrium in Great Britain in 2030 in Visions 1 and 3 of the adapted TYNDP over a winter week (demand profiles are different because ENTSO-E assumes different structures of the demand and its management for each of the Visions)

3 Value of interconnection projects between France and Great Britain

3.1 Reduction of the value of projects in 2030, especially in the context of a Hard Brexit

Figure 11 presents the gross welfare increase (per GW) at the ENTSO-E level as a consequence of the commissioning of a 1.4 GW interconnection project.

There is an overall decline in interconnection gains in the Brexit scenarios (in 2020 and 2030), and in particular in the Hard Brexit scenarios. Indeed, the Brexit scenarios are characterised by a decline in demand in the United Kingdom, which tends to reduce the need for imports, and by a reduction in investments in renewable energy, which can reduce export opportunities. These phenomena are all especially significant in the Hard Brexit scenarios, for which it was assumed that the markets were decoupled, preventing an optimal use of interconnections.

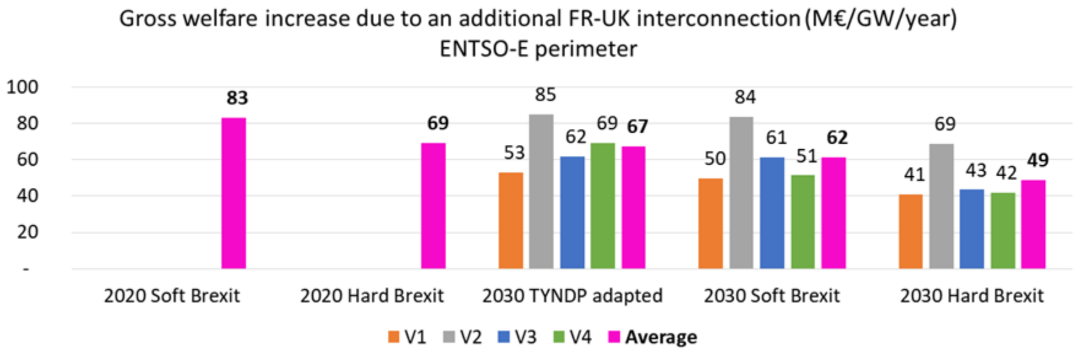

Figure 11 - Gross welfare increase (excluding additional costs related to additional power losses) on the ENTSO-E perimeter due to the installation of a 1.4 GW interconnection project between France and Great Britain

One can notice that the value of the interconnection for Vision 2 decreases more moderately in the context of a Soft Brexit; this is explained by a significant increase of imports of Great Britain in this scenario (Figure 9).

Finally, projects lose 25% to 30% of their value from 2020 to 2030 (for Soft Brexit and Hard Brexit scenarios, respectively). This is due to the evolution of energy mixes (in particular to a drop in export opportunities from France to Great Britain) and to the assumed increase of 10% in the global European Union interconnection[25] levels by 2030.

Note: As discussed in more detail in Section 4, this decline makes the NPV (Net Present Value) of projects and the associated option value highly dependent on their date of commissioning[26].

[25] Interconnection levels are provided in appendix 7.8.
[26] The longer a project takes before being commissioned, the less favourable the context will be for this project.

3.2 Interconnection projects that are beneficial to the UK

Figure 12 illustrates the geographical decomposition of the gross welfare increase due to an additional interconnection between France and Great Britain in 2020.

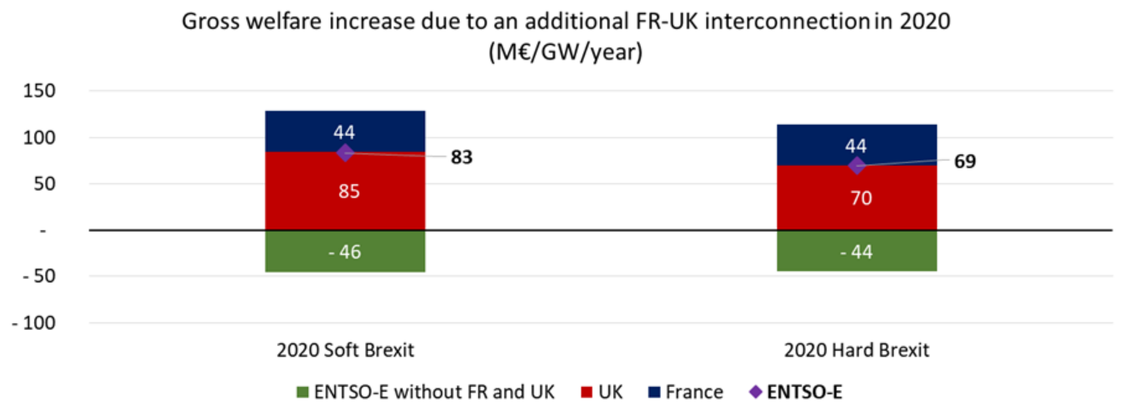

Figure 12 – Gross welfare increase (excluding additional costs related to additional power losses) due to the installation of a 1.4 GW interconnection project between France and Great Britain, calculated on different geographical perimeters in 2020

It shows that gross gains at the ENTSO-E level are of the same magnitude as those at the UK level, i.e. ENTSO-E excluding the United Kingdom[27] does not generally benefit from this additional interconnection. This is due to the fact that if certain countries such as France can benefit from it, others, characterised by a positive net import balance, suffer losses.

Indeed, on average over the 2020 scenarios, the additional interconnection between France and Great Britain results in increased net imports of Great Britain by 10% (from 50 to 55 TWh/year), so that some imports can no longer benefit other countries - known as "net importers" - such as Italy whose net imports are found to decrease by 1 TWh/year. These net importing countries must therefore generate more power using their local mid-merit units to offset the decrease of low cost imports (nuclear or renewable). This has the effect of increasing their marginal costs (from around €0.2 to 0.3/MWh on average[28] for Italy for example) and reducing their consumer surplus[29]. In addition, the decline in trade flows between net importing countries and their neighbours[30] impacts their congestion revenues (the impact on the volume exchanged being predominant compared to the impact on price differentials).

[27] EU27 to which Bosnia, Montenegro, Norway, Serbia and Switzerland have been added.
[28] The same order of magnitude is found whether computing the average market prices or the average market prices weighted by the hourly demand.
[29] The precise definition of the methods of calculation of the various surpluses (producer surplus, consumer surplus, congestion rents) is presented in appendix 7.3.
[30] As well as a price differential that can be reduced, as is the case between France and Italy.

This explains a decrease in the overall surplus of the net importing countries[31], as illustrated in a schematic and simplified way in Figure 13.

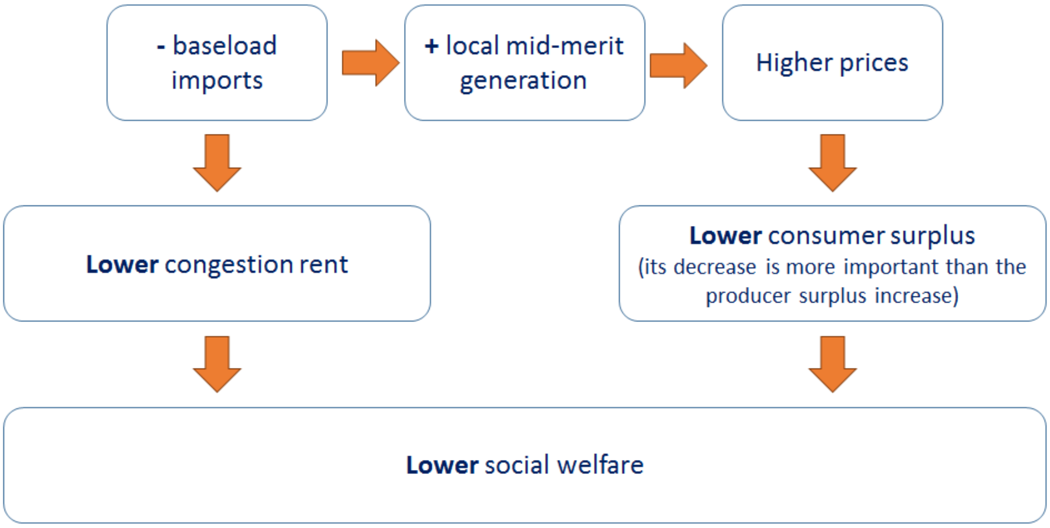

Figure 13 - Simplified diagram illustrating the impact of the reduction of import opportunities on the surplus of net importing countries

Figure 14 presents the gross welfare increase due to an additional interconnection between France and Great Britain[32] on the ENTSO-E perimeter and on the perimeter of the United Kingdom alone by 2030. It shows that without the United Kingdom, Europe receives only 20% to 30% of the gross surpluses generated by an additional interconnection between France and Great Britain by 2030.

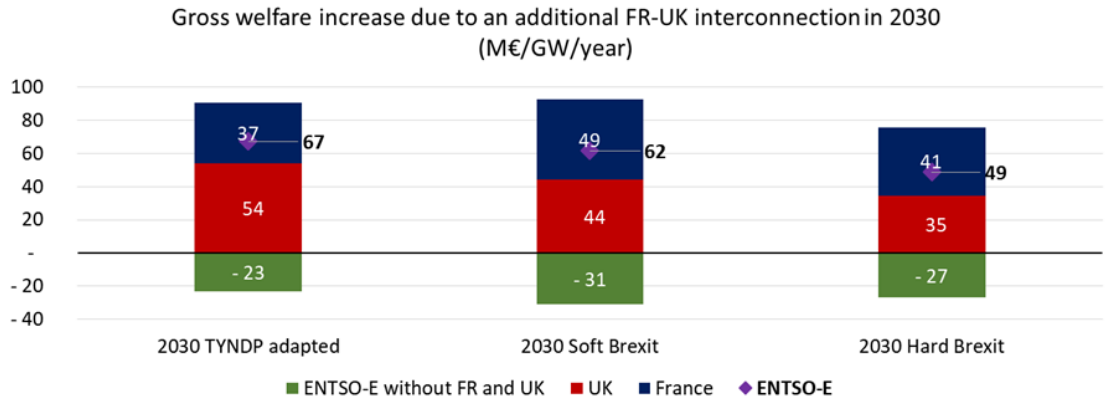

Figure 14 – Gross welfare increase (excluding additional costs related to additional losses) due to the installation of a 1.4 GW interconnection project between France and Great Britain, calculated on different geographical perimeters in 2030

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[31] Even if the surplus of their producers increases, as these countries are net importers, the increase of their marginal costs reduces their consumer surplus by an amount that is larger than their producer surplus increase.
[32] For the sake of the readability of the graph, the surpluses have been averaged (without weighting) on the different 2030 visions of the ENTSO-E.

Note: In addition to the analysis conducted above for 2020, for 2030, the gains for an additional interconnection between France and Great Britain is unevenly distributed between the different European countries; some net exporting countries, such as France, are benefiting from such infrastructure while net importer countries are seeing their surplus being reduced.

4 Cost-benefit analysis

4.1 Preliminary remark

The investment costs of the projects mentioned are neither audited nor final. They also show strong disparities[33] and are likely to evolve. The purpose of this study being to analyse the value of interconnections, and in particular the impact of Brexit on this value (not an evaluation of the projects under consideration), the cost-benefit analysis is not executed for a particular project, but for a "reference" project, whose CAPEX of €600 million/GW is around the average of the projects' CAPEX.

The conclusions of this cost-benefit analysis are therefore not final and may evolve as the CRE carries out the detailed examination of costs when further analysing each of the projects.

4.2 2030 net revenues are not necessarily positive, depending on the Brexit context

Figure 15 shows:

- In the histograms, in violet: the net welfare increases due to an additional interconnection, from which the costs of the additional losses on this interconnection have been deducted;
- On a horizontal line, the annuity[34] corresponding to the reference interconnection project, which is envisaged to be commissioned by 2020-2030 (ENTSO-E, 2016).

There is a positive net revenue (difference between annual gains and costs) in 2020 (since the line corresponding to the annuities is below the upper limit of the two histograms of the left-hand side of the figure). By contrast, in 2030, the net revenue is close to zero in the context of a Soft Brexit and negative, by €13 million/GW/year, in the context of a Hard Brexit.

[33] The project costs are presented in appendix 7.6.

[34] This annuity corresponds to the sum of the annualised CAPEX over 25 years (taking into account the interests during construction, using a discount rate of 4.5%) and the OPEX of the project; more details on the calculation of the annuities are given in appendix 7.6.

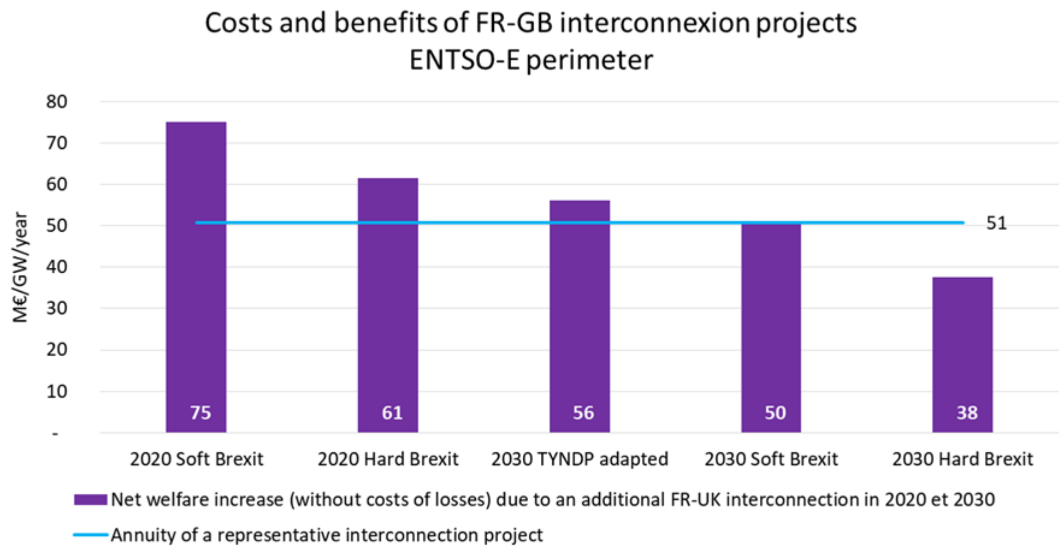

Figure 15 - Comparison between costs (in blue) and welfare increase net of losses (in purple) of an interconnection project between France and Great Britain

4.3 Net present value of an interconnection project: positive for Soft Brexit and negative for Hard Brexit

Figure 16 presents the result of the net present value (NPV) calculation[35] of the reference project[36] for the various considered scenarios. The NPV of the project is positive for the "Adapted TYNDP" and "Soft Brexit" scenarios, but it is found to become negative in the context of a Hard Brexit. Moreover, while the NPV is always positive for the United Kingdom, it is always negative for all the other countries of continental Europe.

[35] Assuming commissioning in 2022 for the "adapted" and "Soft" scenarios and in 2023 as part of a Hard Brexit. More details on how NPV are calculated are available in appendix 7.7.
[36] Paragraph 7.1 presents a sensitivity analysis to the cost of the reference project

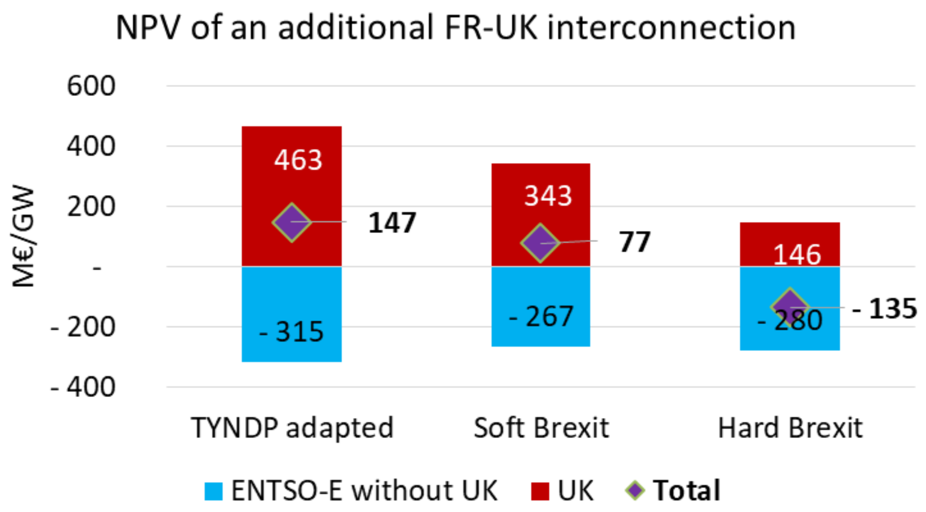

Figure 16 - NPV of an FR-GB interconnection project for the different scenarios

4.4 Option value: advantage of waiting before deciding to invest

The NPV studied in the previous paragraph were calculated assuming that the decision to invest in the project was made today, without knowing whether we would end up in the context of a Soft or a Hard Brexit in the coming years. The average of these NPVs corresponds to the expectation of the NPV *without information on the Brexit context* (as illustrated Figure 17).

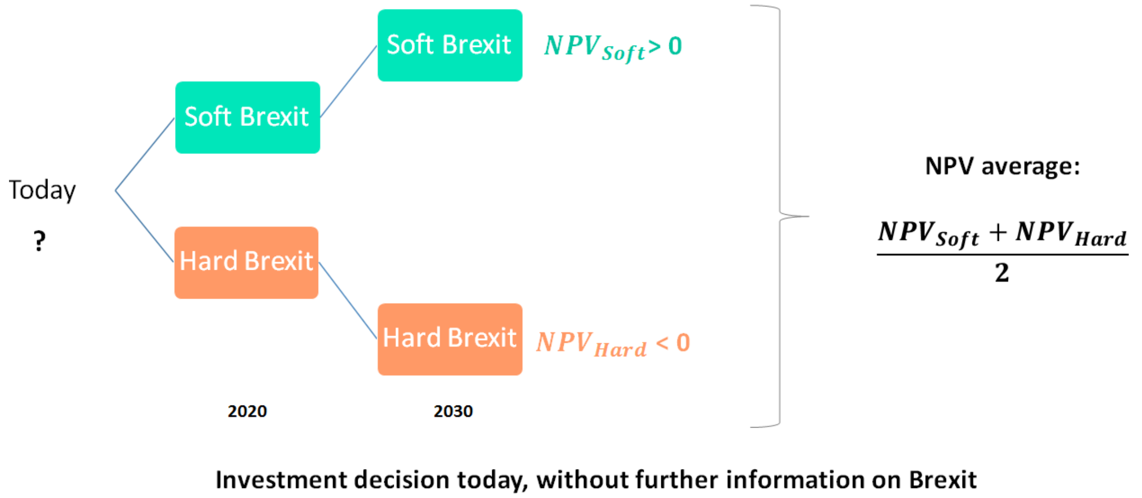

Figure 17 - Calculation of the NPV expectation without information on the Brexit context

The calculation of the NPV expectation when the decision to invest is delayed until 2020 is represented in Figure 18. The NPV of the project is negative in a context of a Hard Brexit. Therefore, if we postpone the investment decision until 2020 and a Hard Brexit materialises, the decision will be made not to invest, and the associated NPV will be zero.

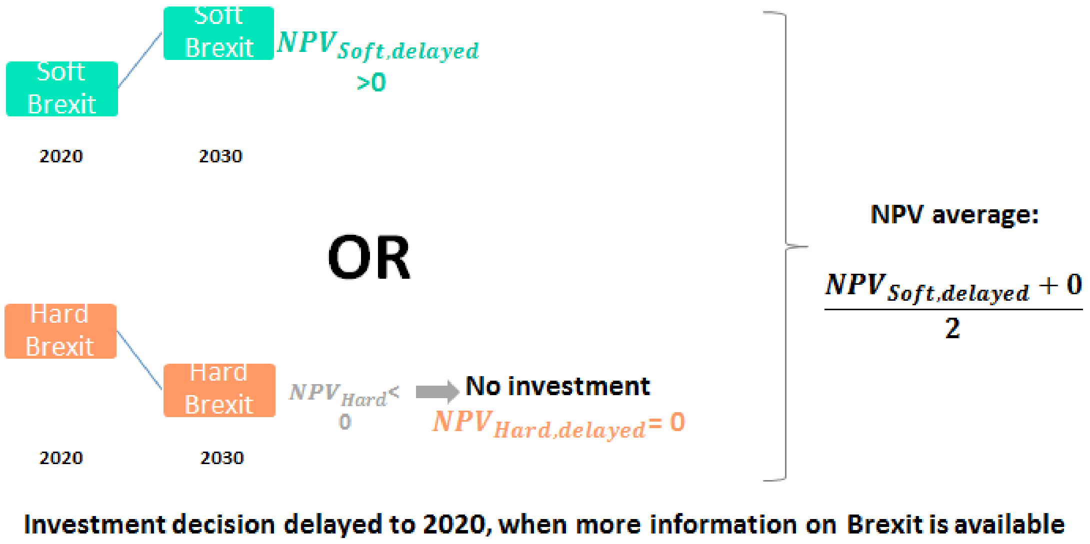

Figure 18 - Calculation of the NPV expectation when the decision is delayed until 2020

Figure 19 can be used to compare the NPV expectations without information (left side of the figure) with the expectation of the NPV in a case where we would have waited to acquire the information before making the investment decision (right side of the figure). If one delays the investment decision until the Brexit context is known, and the project is chosen to go ahead in 2020, the commissioning of the project is assumed to be delayed by two years. Such a deferral would imply a decrease of the project's NPV because, as was pointed out in subsection 3.1, it would generate a lower share of its revenues in an energy mix close to 2020 than in a context corresponding to the 2030 projections. The dotted pattern histogram of Figure 19 represents the decision not to invest in 2020 in the case of a Hard Brexit.

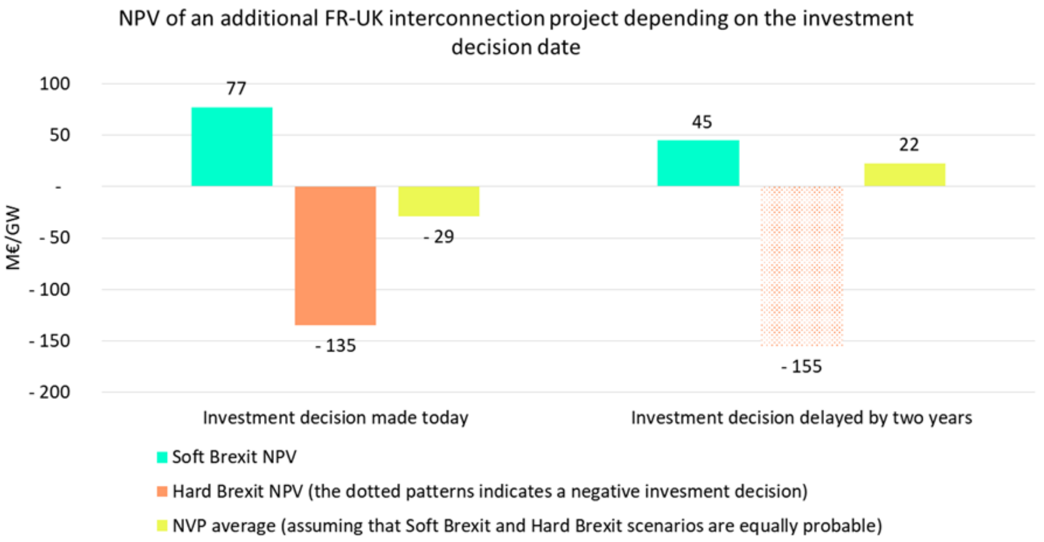

Figure 19 - NPV expectation of an FR-GB interconnection project depending on the investment decision date[37]

If the decision to invest is postponed to 2020, then the NPV expectation is found to be €22 million/GW, compared to a negative NPV expectation of €-29 million/GW if the decision is made today. Waiting for information on the Brexit context before choosing to invest would, on average, result in a gain of more than €50 million/GW.

Note: The previous estimate was made assuming that the Soft Brexit and Hard Brexit scenarios are equally probable. It should be noted, however, that the value of waiting strongly depends on the probabilities of occurrence of these scenarios. It is evaluated that if the probability of occurrence of a Hard Brexit is sufficiently low (a threshold of 19%[38] has been calculated), the project's NPV expectation will be higher if the investment decision is made today rather than in 2020[39].

4.5 Sensitivity of results to the wind turbine capacity installed in Great Britain: conservative assumptions

Figure 20 illustrates the impact of renewable energy installed capacities - in particular wind turbines - on the value of the interconnection between France and Great Britain: each dot on the graph corresponds to the gross welfare increase due to an of an additional 1 GW interconnection capacity

[37] Delaying the investment decision by two years implies that the project should be commissioned in 2024, whether it is within the context of a Soft or a Hard Brexit (i.e. a delay of only one year in the case of a Hard Brexit, for which a one-year delay with respect to the Soft Brexit scenario was already assumed). Assuming an identical commissioning date for the Soft and Hard Brexit, when delaying the investment decision, has no impact on the expectation of the NPV since the NPV in the context of a Hard Brexit is negative (and is therefore assimilated to 0 in the calculation of the expectation).

[38] This threshold strongly depends on the assumptions and models used, in particular for the representation of market decoupling.

[39] For a probability of occurrence threshold of 19% of the Hard Brexit, the NPV expectations are equal to €36 million/GW, whether investments are made today or postponed until 2020.

between the two countries for different UK wind power installed capacities. The exercise was carried out for two of the 2030 TYNDP Visions. For both visions, we can identify similar "U"-shaped curves.

- The left side of the "U" corresponds to a low installed wind capacity in Great Britain, which gives rise to a high interconnection value: in a context of moderate local production in Great Britain, import opportunities can allow to reduce the generation of local mid-merit production units.
- The right side of the "U" corresponds to a strong installed wind capacity in Great Britain, which also induces a significant interconnection value: it allows an increase in the exports of domestic wind production, which exceeds the UK demand (and to avoid curtailment); these exports make it possible to avoid generation by more expensive thermal production in the rest of Europe.
- The central part of the "U"-shaped curve (around 40 GW of installed wind power) corresponds to a situation where the baseload production in Britain (i.e. wind generation added to solar, hydro, run-of-the-river, nuclear and priority access[40]) is sufficiently close to the demand so that local thermal production units are not required to run and curtailment can be avoided[41].

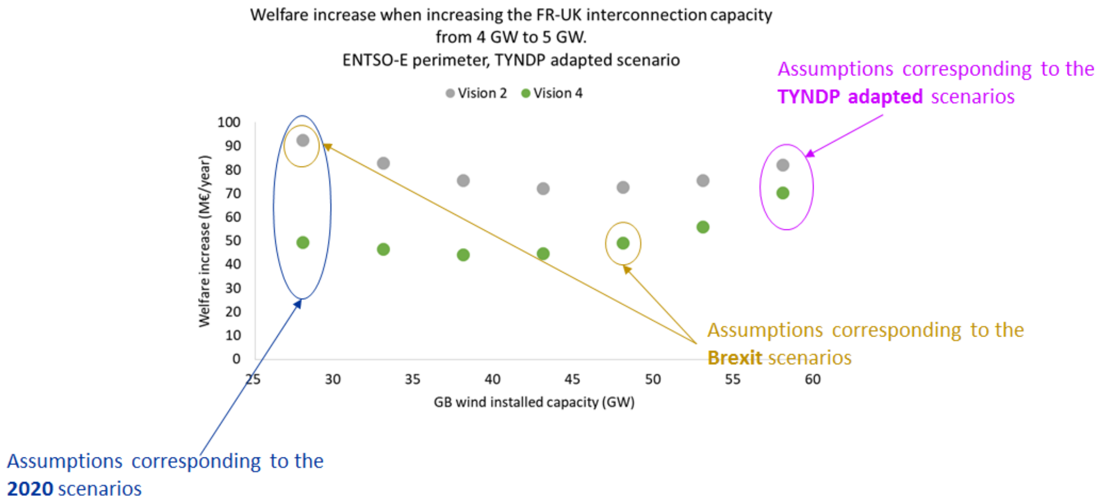

Figure 20 - Impact of wind power capacity in Great Britain on the value of an interconnection project between France and Great Britain

Note: In Figure 20, the orders of magnitude of the assumptions used in this study are highlighted by coloured circles. The simulations performed mostly coincide with installed wind capacities found at the extremities of the U-shaped curve. In other terms, the conditions in which the evaluation of the value of the interconnection between France and England has been performed are rather favourable.

[40] 84 to 124 TWh/year generated in Vision 2 and Vision 4, respectively.
[41] In annual terms, this corresponds to about two thirds of Britain's demand met by baseload units.

5 Impact of an interconnection project between France and Great Britain on flows between the two countries

5.1 Flows between France and Great Britain

Figure 21 represents the evolution of the utilisation rate of the interconnection between France and Great Britain for different scenarios and exchange capacities. A Hard Brexit scenario would cause a slight decrease (0.5%) in the use of the interconnection compared to a Soft Brexit scenario (by comparing the two histograms on the left). However, there is a more significant decrease in the utilisation rate of the interconnection when its capacity is increased (by comparing the left and right parts of the graph); this illustrates the fact that the increase in exchange capacity does not necessarily lead to a proportional increase of the electricity flows between France and Great Britain.

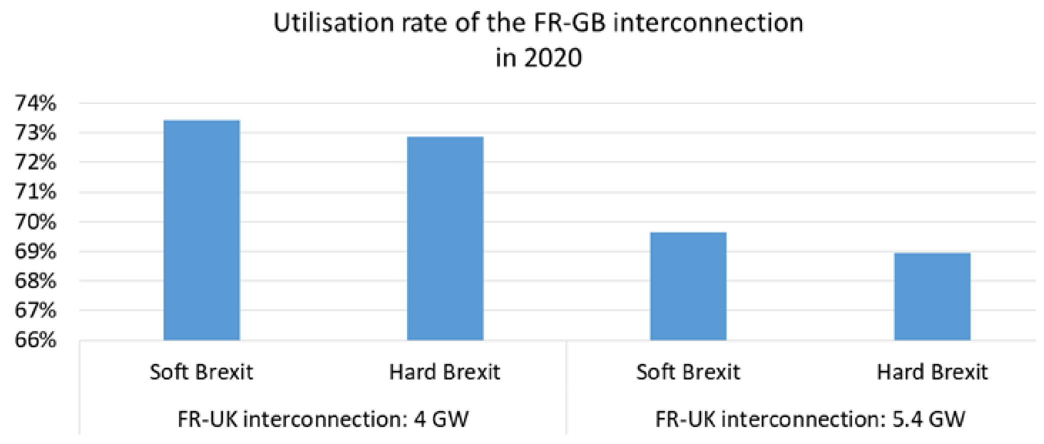

Figure 21 - Evolution of the average utilisation rate[42] (sum of annual flows divided by the interconnection capacity)[43] of the France-Great Britain interconnection

[42] Averaged over the 10 climatic years.
[43] The utilisation rate shown here only concerns flows from France to Great Britain.

Figure 22 presents the duration curves of the net flows from France to Great Britain. The upper graph compares the flows for a 4 GW interconnection capacity (blue curve) and a 5.4 GW interconnection capacity (orange curve) for a Soft Brexit in 2020. One finds that the interconnection is used up to saturation close to 5,500 hours per year[44] when its capacity is limited to 4 GW, against about 4,800 hours of saturation per year for a capacity of 5.4 GW. In the context of a Hard Brexit (lower graph of Figure 22), the number of hours of saturation of the interconnection is significantly reduced, reaching 2,000 and 1,200 hours per year with 4 GW and 5.4 GW of capacity, respectively, compared to the context of a Soft Brexit. This is largely attributable to the decoupling of markets (and in particular to our mode of representation of decoupling, explained in appendix 7.5).

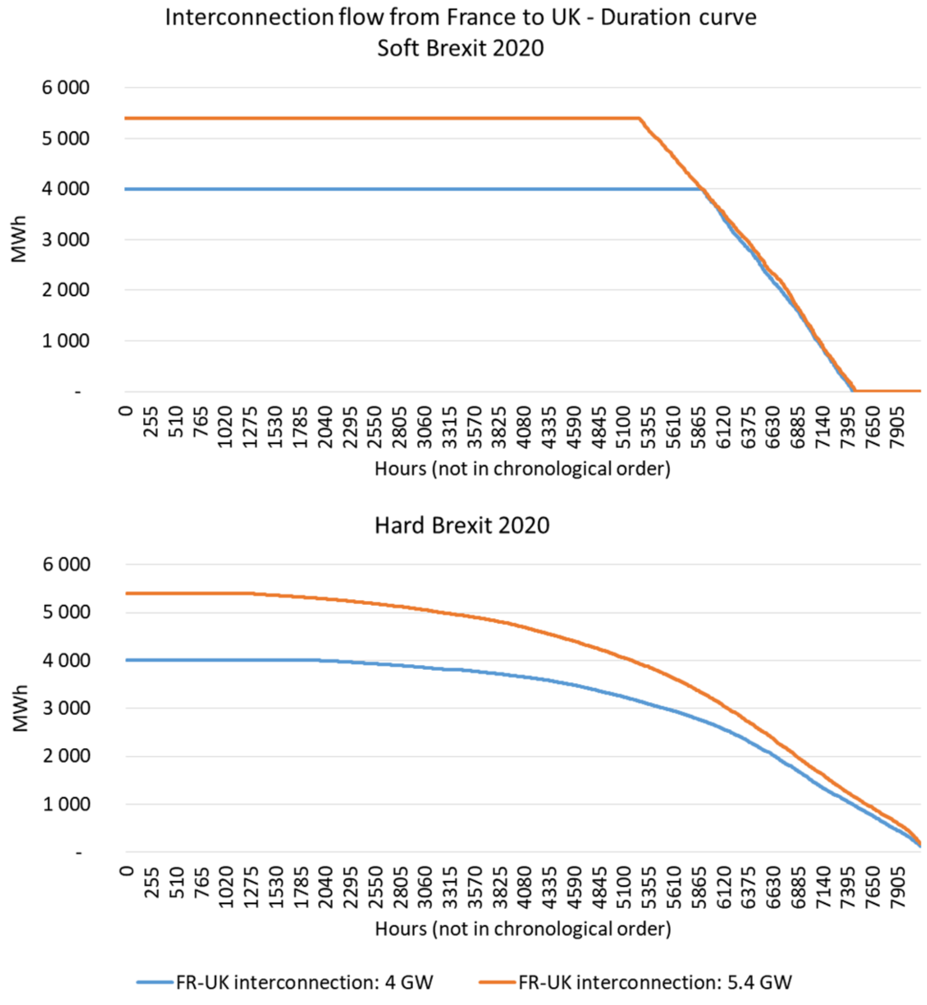

Figure 22 - Comparison of duration curves[45] of net flows[46] from France to Great Britain, for a given climatic year

[44] Average over the 10 climatic years.
[45] Plotted in descending order of value and not chronological.
[46] Difference between imports and exports.

5.2 Impact of interconnection on all ENTSO-E countries

More generally, Figure 23 sets out the impact of the additional interconnection on the net imports of each of the modelled ENTSO-E countries; the United Kingdom and Ireland are found to exploit the interconnection to import electricity (blue triangles), while other countries are found to have to reduce their imports or increase their exports (green triangles). Exports from France to Great Britain are flows that cannot benefit other European countries anymore (as explained in more detail in subsection 3.2).

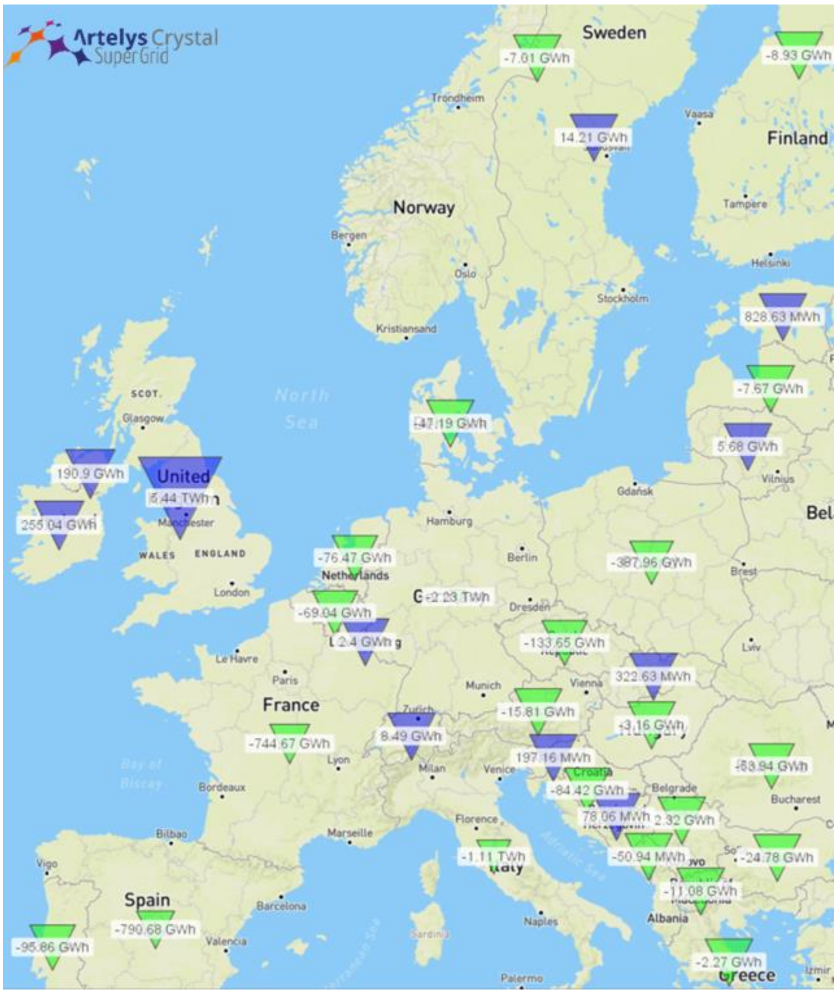

Figure 23 - Impact[47] of an additional interconnection of 1.4 GW on the average annual[48] net imports[49] of each country for the Soft Brexit 2020 scenario: the blue triangles correspond to an increase of net imports and the green triangles to a decrease

These changes in flows at the European level have an impact on the production levels of different countries and thus on CO_2 annual emissions (Figure 24): for example, the United Kingdom overall CO_2 levels are found to decrease (as identified by green choropleths) due to the reduction of local

[47] Difference between a simulation with and a simulation without reinforcement of the France-Great Britain interconnection.
[48] Average over the 10 climatic years.
[49] Difference between imports and exports.

generation as a consequence of the exploitation of the increased import capacity, but this is not the case for all modelled countries (increases in annual CO_2 are characterised by red choropleths).

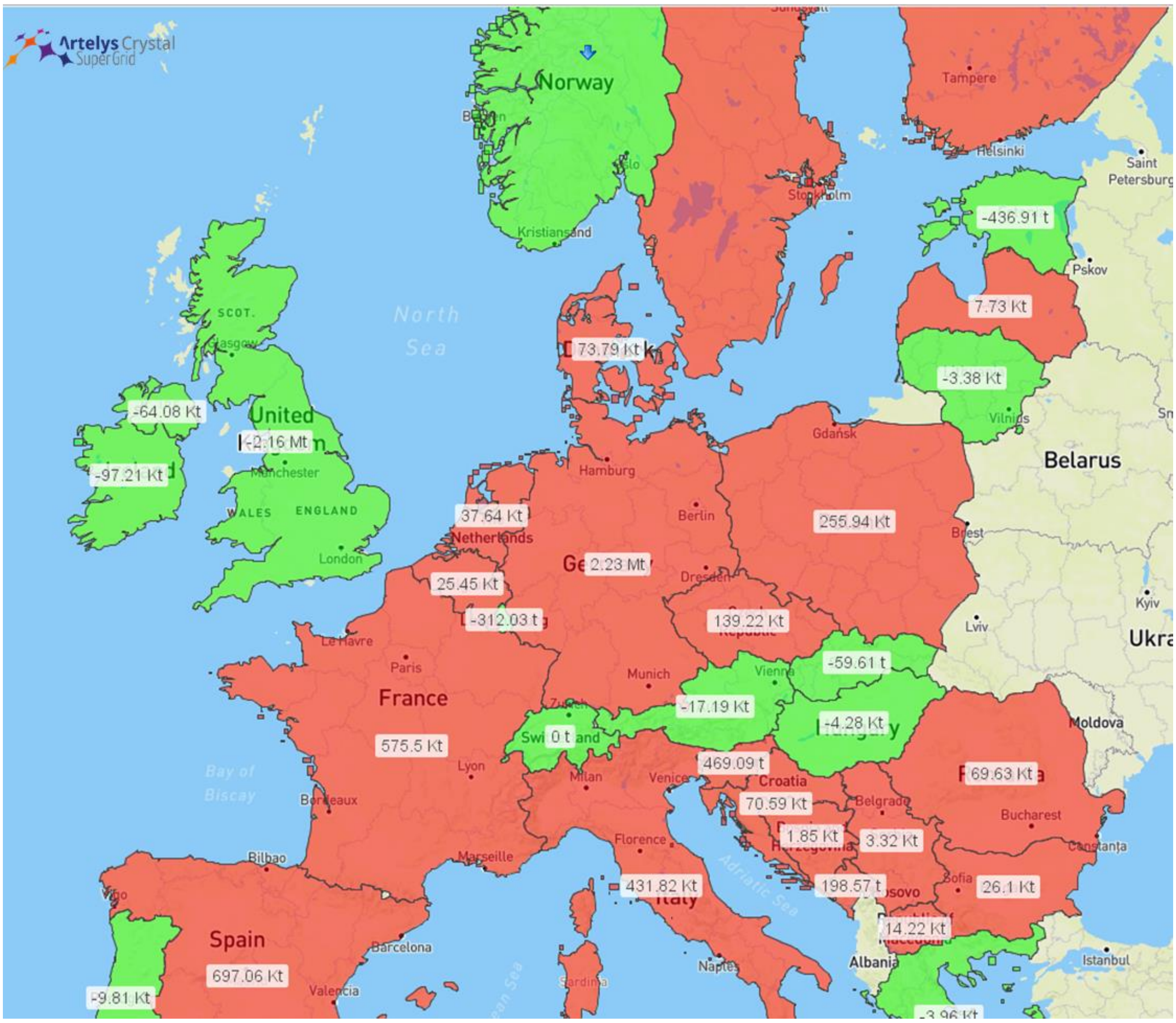

Figure 24 - Impact[50] of an additional interconnection of 1.4 GW on annual CO_2 emissions[51] of each country for the Soft Brexit 2020 scenario. Emissions are reduced in countries shown in green, while those shown in red see their emissions increase.

Finally, Figure 25 shows that an additional interconnection between France and the United Kingdom would result in a better integration of renewable energies, allowing a significant reduction in their curtailment in an ambitious scenario, such as the ENTSO-E Vision 3.

[50] Difference between a simulation with and a simulation without reinforcement of the France-Great Britain interconnection.
[51] Average over the 10 climatic years.

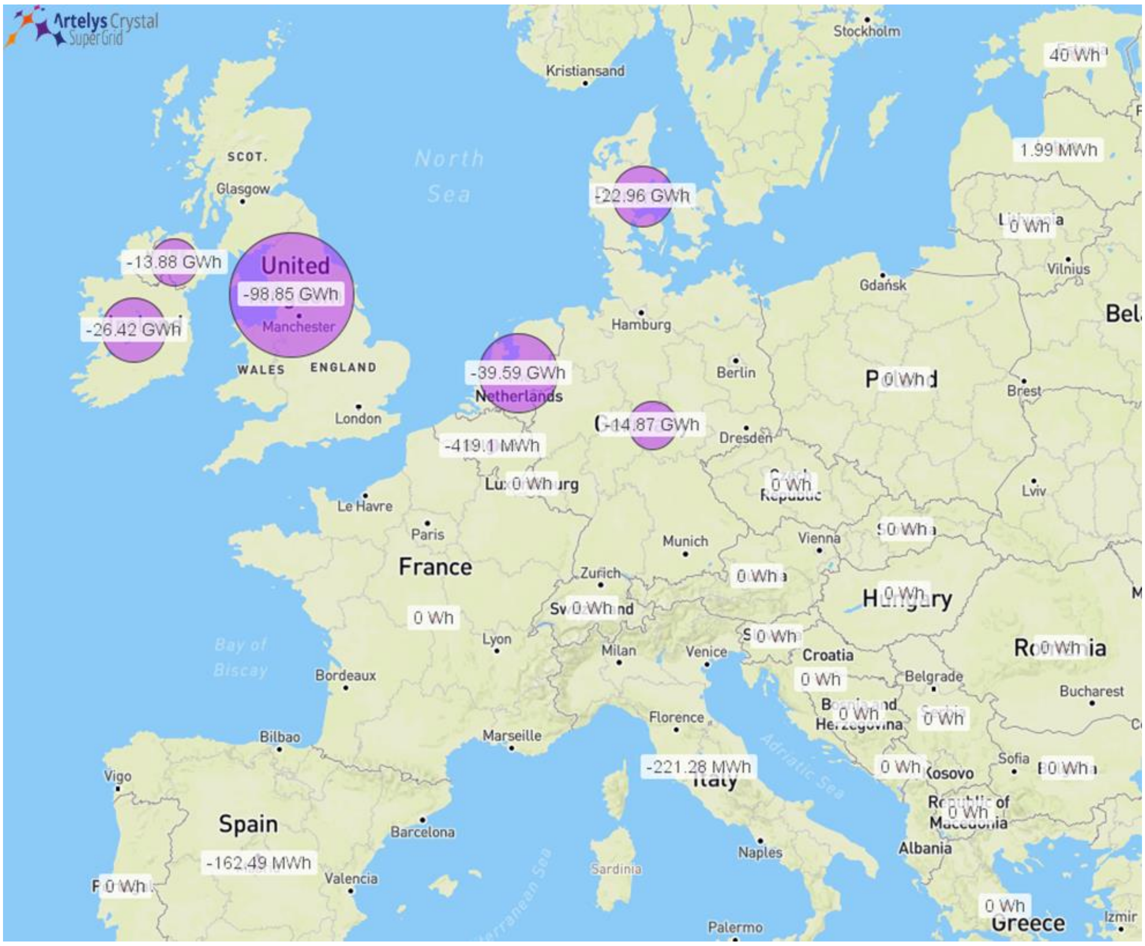

Figure 25 - Impact[52] of an additional 1.4 GW interconnection on the average curtailment[53] of renewable electricity in each country for the Soft Brexit 2030 V3 scenario. The size of the circles is proportional to the curtailment avoided by the interconnection.

[52] Difference between a simulation with and a simulation without reinforcement of the France-Great Britain interconnection.
[53] Average over the 10 climatic years.

6 Conclusion

The results of the calculations and analyses presented in this report enable the highlighting of the following points:

- Regardless of the Brexit context, gains related to an increase in the level of interconnection between France and Great Britain on the short term will eventually be **reduced on a mid-term horizon** due to changes in future energy mixes. **Some projects will not be able to generate sufficient revenues to exceed their costs in 2030; their net present value is therefore found to be negative.**
- Most of the value (almost all of it in 2020 scenarios) of an additional interconnection between France and Great Britain is captured by the United Kingdom; **the interconnection will be of low value (or no value in 2020 scenarios) for ENTSO-E countries outside the United Kingdom**. However, this value is unevenly distributed among continental Europe countries; **some countries, such as France, derive substantial benefits**, while others lose out.
- **Brexit**, as modelled for this study**, is found to reduce the value of interconnections between France and Great Britain.** This phenomenon is especially important in scenarios assuming a strong independence of the United Kingdom from the EU, i.e. **in the context of a Hard Brexit**.
- **Therefore, it seems preferable to wait to know the Brexit context before deciding to finance projects**, unless a Hard Brexit is unlikely to occur.

7 Technical annexes

7.1 NPV sensitivity to project costs

The NPV (and option values) calculated in the previous sections depend on the project annuities, which are evaluated by using several cost assumptions, some of which are uncertain (discount rate, interim interest, underestimation of CAPEX[54], etc.).

Figure 26 illustrates the sensitivity of NPV to project annuities. While the NPV of the reference project is positive under the TYNDP and Soft Brexit scenarios, but has a clearly negative value in the context of a Hard Brexit, it becomes negative in all cases if its costs are increased by 25%[55]. Conversely, the NPV of the project becomes positive in all cases if its costs are reduced by 25%.

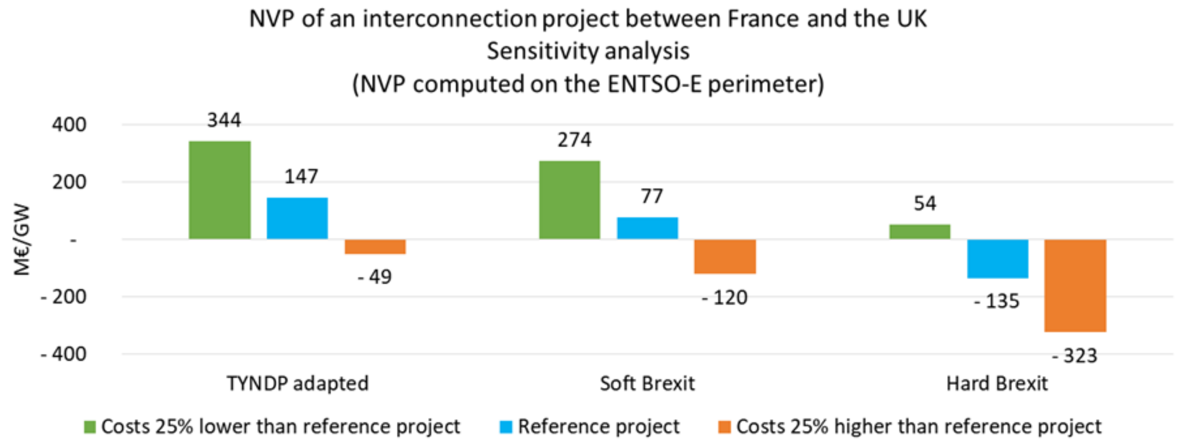

Figure 26 - Comparison of the NPV of the proposed interconnection projects between France and Great Britain for the various scenarios

7.2 Details of gross welfare increase by scenario and by vision for France

The gross annual welfare increase due to an additional interconnection are detailed by scenario and by vision in Figure 27 for France. In 2020 and for Visions 1 and 2 of 2030, these surpluses are higher than half the annuity of the reference project (around €25 million/GW/year) while they are lower to half of that annuity in Visions 3 and 4. This phenomenon can be explained in particular by examining the French nuclear capacities of the various scenarios: 63 GW in 2020, 58 GW in Visions 1 and 2 2030

[54] Related to Brexit as envisaged in Grantham Institute, Imperial College, 2017, or to an uncertainty related to the construction of the project, as ENTSO-E for example, envisaged for FAB Link.
[55] Note that the uncertainty interval proposed by the TYNDP for the CAPEX of FAB Link proposes a margin of more than 25% increase.

and 38 GW in Visions 3 and 4. The French gross welfare generated by a new interconnection decreases substantially in the scenarios assuming a low nuclear capacity in France.

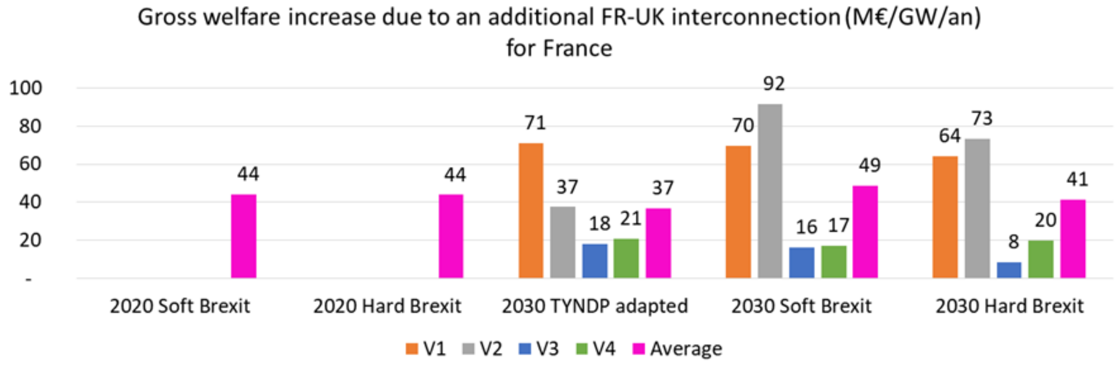

Figure 27 - Collective surplus gross gains (excluding additional costs related to additional losses) on the ENTSO-E perimeter due to the installation of a 1.4 GW interconnection project between France and Great Britain

7.3 Collective surplus - "Socio economic welfare"

Collective surplus or "socio economic welfare" is the indicator usually used[56] to assess the potential benefits of interconnection projects to the community.

The approach consists in summing the consumer surplus, the producer surplus and the congestion rent of all the market areas: their sum represents the "collective surplus". The profit associated with a project is then the difference in collective surplus (in €/year) with and without the considered project.

Comments:

1. *The following definitions from* European Commission, Artelys, May 2016 and from ENTSO-E, 2014 *were retained:*

- *The* change in consumer surplus[57] *corresponds, in a context of non-elastic demand, to the sum of all the hours of the year of*
    - (marginal cost of zone x consumption of the zone) without interconnection
      - (marginal cost of zone x consumption of the zone) with interconnection
- *The* producer surplus *is the difference between production revenues and variable production costs.*
- *The* congestion rent *is calculated, for each oriented interconnection, as the sum of the absolute values of:*

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[56] Indicator recommended by the ENTSO-E Guideline for the cost-benefit analysis of network development projects (ENTSO-E, 2015).

[57] In absolute terms (as opposed to the "differential" definition given above), consumer surplus is defined as the difference between the price the consumer is willing to pay for a product and the price actually paid.

- (marginal cost of the export zone - marginal cost of the import zone) x flows on interconnection.

2. *When dealing with the collective surplus over a limited geographical area, for example, the United Kingdom, by convention, the interconnection income of the interconnections between the zones it links is distributed homogeneously. For example, half of the France-Great Britain interconnection congestion income is allocated to France and half to the United Kingdom.*

7.4 Assumptions related to Ireland

Given the uncertainties concerning the impact of Brexit on the relation between the UK and Ireland (in particular concerning trade between Ireland and Northern Ireland), the following assumptions have been adopted:

- Regarding the decoupling of markets:
  - Coupled continental European and Irish Markets[58]
  - Coupled British and Irish markets
  - Decoupled UK and European markets[59]
- Regarding security of supply criteria (gas fleet):
  - Participation of Ireland and Northern Ireland in UK security of supply
  - Ireland connected to the rest of Europe.

7.5 Decoupling of markets

Taking into account the decoupling of markets is not an easy exercise. In the absence of precise data on the impact of decoupling on the flows exchanged between zones, and of models explicitly representing all the actors and their bidding behaviour on the markets, a simplified representation has been adopted.

More precisely, the simulations representing a decoupled market context were carried out in two stages:

- A *dynamic* simulation carried out without constraining the flows other than by the interconnection NTC capacities.
  - From this dynamic simulation, a time-series of power flows has been calculated over a year with an hourly time-resolution (for each hour of the year, the average of the

[58] Irish is understood in a broad sense, namely the Island of Ireland.
[59] The coupling between the European and Irish markets on the one hand, and between the UK and Irish markets on the other hand, implies a form of coupling between the European and British markets. Nevertheless, given the low level of interconnection (500 MW), the effects of this "transitive" coupling are weak.

flows over the 10 simulated climatic years has been calculated), called the *static flow time-series*.

- A *static* simulation for which the flow between decoupled zones was set in advance[60] and corresponded to the static flow time-series.

The results corresponding to the decoupled market situation were then assumed to be the (equally weighted) average of the dynamic simulation and the static simulation.
This choice of representation aims - modestly - to represent the fact that in a context of market decoupling, some of the flows are fixed in advance, based on statistical analyses, and part of the flows are dynamically readjusted.

7.6 Hypotheses for the reconstitution of annuities

The annuity of the "reference" project has been restored using the following hypotheses:

- CAPEX: €600 million/GW
- Discount rate: 4.5%[61]
- Project lifetime: 25 years[62]
- Share of annual OPEX on CAPEX total: 1.5%[63]
- Impact of interests during construction (interim interests): CAPEX increase of 8%[64]

Comments:

1. *The CAPEX of the reference project is of the same order as the CAPEX[65] average of the projects under study between France and Great Britain:*
   - FAB Link (1.4 GW): €850 million[66]
   - Aquind (2 GW): €1,400 million
   - GridLink (1.4 GW): €600 million
2. *Net total welfare increases (to which project annuities were compared) were calculated by subtracting the cost of losses on the additional interconnection from gross welfare increases. These additional costs[67] amount to €8 million/GW/year in 2020 and €11 million/GW/year in 2030.*
3. *For all analyses aiming to distribute surpluses among different geographical areas, CAPEX, OPEX and loss costs were equally distributed between the United Kingdom and the UE27.*

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[60] And therefore was not able to dynamically adapt to the hourly variations of renewable energy production and demand, depending on climatic years.
[61] Source: *CRE*
[62] Source: *ACER*
[63] Source: Estimation *Frontier Economics*
[64] Source: *CRE, averages on several projects*
[65] Source: (ENTSO-E, 2016)
[66] The annuity of the reference project is also of the same order as the annuity of FAB Link.
[67] Source: (CRE, 2016)

7.7 How NPV are calculated

From the hourly simulations of the dispatch over the years 2020 and 2030, the annual net revenues (difference between net welfare increases attributable to a project[68] and project cost) have been estimated over the lifetime of the projects by making the following assumptions:

- Date of commissioning of the projects: 2022 in the context of a Soft Brexit and 2023 in the context of a Hard Brexit
- Net revenue from a project
  - For a year between its date of commissioning and 2030: linear interpolation of estimated net revenues by simulation in 2020 and 2030
  - For a year subsequent to 2030: net income identical to 2030

From the annual net revenue, the net present values of the projects have been calculated according to the following formula:

$$VAN = \sum_{i=0}^{24} \frac{recetteNette\_i}{(1+\tau)^i}$$

with $recetteNette\_i$ the income for the year i and τ the discount rate.

7.8 Models and data used

7.8.1 Assumptions mainly based on the TYNDP 2016

The energy mix assumptions for all European countries were based on the TYNDP 2016 2020 projection and 2030 Visions (ENTSO-E, 2016). These assumptions are shown in Figure 28. Some of these assumptions have nevertheless been updated for the United Kingdom in order to ensure a better coherence between the scenarios used herein and the projections of BEIS and National Grid. The following adjustments were made to elaborate the "adapted TYNDP" scenarios:

- Annual demand of the United Kingdom not exceeding 366 TWh (National Grid proposing no scenario with a demand exceeding 346 TWh/year) in 2030: this amounts in particular to the same volume of demand for Visions 3 and 4;
- Increased solar capacity in the United Kingdom and at least 14.7 GW in 2030 (the minimum assumed in the National Grid scenarios) and 12.8 GW in 2020[69];
- Wind turbine capacity in the United Kingdom between 28.6 GW and 47.3 GW in 2030 (i.e. the minimum and maximum capacity proposed by the National Grid scenarios),
- Interconnection between the United Kingdom and Ireland reaching 1 GW in 2030 (GreenLink approved by Ofgem).

[68] Calculated by comparing the result of a simulation with and simulation without the project.
[69] The 2020 capacity was also increased, by the same factor as the 2030 capacity.

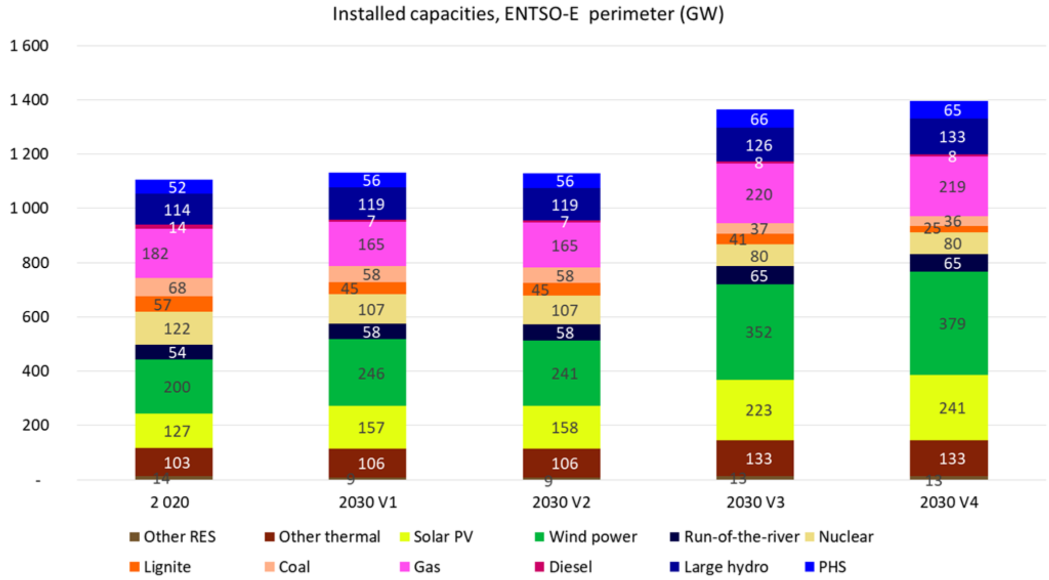

Figure 28 - Production by technology in the ENTSO-E perimeter in the various scenarios

The interconnection NTC capacities between the ENTSO-E countries are also derived from the TYNDP (ENTSO-E, 2016). In particular, the interconnection capacities of Great Britain in 2030 with its neighbours are listed below:

- Netherlands: 1 GW
- Belgium: 1 GW
- Norway: 1.4 GW
- Denmark: 1.4 GW
- Republic of Ireland: 1 GW
- Northern Ireland: 1 GW

Note: The ENTSO-E datasets have been enriched, where necessary, by the elements of the Artelys database, in particular for each ENTSO-E country:

- Decomposition of hydraulic capacity by technology (large hydro, run-of-the-river, PHS);
- Renewable production time-series with an hourly time-resolution for 10 climatic years;
- Demand time-series with an hourly time-resolution correlated to the same climatic years as the renewable production (produced by a statistical model using the time-series at a normal temperature provided by ENTSO-E and temperature logs).

7.8.2 Modelling of thermal production groups

The thermal production units have been modelled taking into account a number of technical constraints (yield, CO_2 emissions, start-up costs, production ramps, minimum on/off times, etc.). The models and data used refer to those described in European Commission, Artelys, May 2017, with the exception of the fuel and CO_2 prices that are derived from the data provided in ENTSO-E, 2016. The resulting variable production costs are provided in Figure 29. The undistributed energy is penalised up to €3,000/MWhe.

€/MWhe	2020	Vision 1 2030	Vision 2 2030	Vision 3 2030	Vision 4 2030
Lignite	22	29	29	88	94
Coal	35	41	41	83	82
CCGT	59	64	64	68	69
Gas-fired combustion turbine	103	113	113	119	122
Oil-fired combustion turbine	143	163	163	164	168

Figure 29 - Variable production costs (calculated at maximum power and including the cost of CO_2) per technology in the different scenarios

List of figures

8 Bibliography

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