Transmission Expansion Benefits: The Key to Redesigning the Regulation of Electricity Transmission in a Regional Context

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ABSTRACT

Achieving a sufficient and efficient development of the transmission grid in the new low-carbon and region-wide coordinated electricity markets being created will be central to their success. This requires setting up the required institutional framework and cost allocation arrangements, which is specially challenging when the relevant market covers several independent countries or administrative areas (like states or provinces). The features of the set of institutions to have in place and the interactions among them, as well as the network cost allocation arrangements implemented, are critical issues to ensure an efficient and sufficient development of the grid. This paper addresses those issues and argues that they should be defined with the aim to properly take into account the benefits to be produced by network reinforcements, since these are driven by the benefits they produce. This article discusses how the expected benefits of transmission network expansion projects should affect the organization of the expansion of the grid, the expansion planning algorithms applied and the allocation of the cost of network reinforcements. After discussing the definition of the principles to be applied to these activities in an integrated system, the implications of these in a regional, or multi-system, context are provided.

Keywords: Transmission benefits, Network expansion planning, Network cost allocation, Expansion planning institutional design, Regional markets

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1. INTRODUCTION

The regulation of transmission expansion has traditionally been guided by the need to ease congestion existing in the grid, and to achieve a sufficiently high level of reliability, removing any bottlenecks that local planning authorities (national Transmission System Operators, TSOs, in Europe, vertically integrated utilities and Regional Transmission Organizations, RTOs, in the USA) may have identified (Couckuyt et al. 2015). However, achieving an optimal development of the grid requires taking into account the benefits to be reaped from it, together with the cost of reinforcements. Several types of benefits are to be considered, mainly related to economic, reliability and policy target dimensions, as explained in detail in section 2.2. When selecting the network investments to be proposed for their construction and inclusion in the regulated asset base, the benefits expected to be produced by network investments

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should be compared with their costs to determine the net benefit expected to be produced by each of these projects[1], maybe per unit of costs incurred in them (Bañez et al. 2017 a). In the Internal Energy Market, IEM, of the European Union (EU), see (European Union 2013), ranking the expansion projects on the basis of their (per unit of investment) net benefits can be used to identify the Projects of Common Interest, PCI projects. In a regional context, where benefits produced by reinforcements are obtained by stakeholders from several systems, the approach considered to determine those reinforcements to undertake needs to jointly take into account the effect that these will have on all the systems within the region. Then, the benefits produced by reinforcements should be the drivers of the development of the grid in a region (De Clercq et al 2015). Since the benefits derived from network investments are the main reason for undertaking them (Rivier et al. 2013), the cost of regulated investments may be allocated to network users proportionally to the benefits they are expected to produce (Hogan 2018; Olmos and Pérez-Arriaga 2009; Báñez et al. 2017). Charging network users the fraction of the grid costs they are responsible for should result in efficient grid charges.

A relevant practical additional advantage of this approach is that, if implemented, no stakeholder will be charged more than the benefits it obtains from network reinforcements. In fact, regulation in place in several regions in the world, like the US (FERC 2010 and Adamson, 2018 on " efficient investment"), or the EU (European Union 2013; Agency for the Cooperation of Energy Regulators 2013), establishes that the allocation of the cost of new transmission network investments to network users should be driven by the benefits that the latter obtain from the former. Achieving an efficient development and operation of the electricity system in a country or region requires putting the benefits produced by network reinforcements, country or region-wide, at the core of the approaches adopted for the determination of the investments to undertake and the allocation of their cost.

However, despite the situation is gradually changing, traditionally, power exchanges among local systems have been limited and resulted from bilateral cross-border coordination with long-term contracts. Hence, the benefits produced by network reinforcements were also mainly of a local nature. This has resulted in network expansion decisions and transmission charges traditionally being computed according to the criteria decided by local authorities in each system, which normally do not consider the benefits produced by reinforcements.

Benefit-driven principles for the determination of reinforcements and the allocation of their cost become even more relevant as electricity markets grow in scope towards region-wide ones and the low-carbon generation share increases. Indeed, the integration of large amounts of renewable generation in a regional market requires reinforcing the interconnections among systems to cope with the intermittency of renewable production and ensure that adequate levels of security of supply are achieved at an affordable cost. A paradigmatic example is that of Spain, which has been a pioneer in integrating wind farms in the operation of its power system, but is now facing significant technical and economic difficulties to increase the RES share due to the lack of interconnection capacity with the rest of Europe. Besides, both the further integration of markets and the deployment of large amounts of renewable generation in those specific areas where it is most efficient would presumably result in an increase of the exchanges of energy and other related products (like balancing and firm capacity ones) among areas and systems. This would result in an increase in the use of the transmission grid at regional (pan-European, pan-US) level and would produce large benefits for the system. However, real-

1. Actually, using benefits and costs might result in network investments that do not remove all congestion, as costs become higher than benefits.

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izing these benefits would only be possible if the network reinforcements hosting incremental exchanges of energy related products among areas in the region are built. Hence, the relevance of improving network regulation would probably increase in modern power systems. However, all these are changes that do not alter the set of principles to be considered for the development of "good" regulation on planning the expansion of the grid and network cost allocation.

Modern power systems are also integrating more distributed generation. The implications of this, like the need to achieve an adequate level of TSO-DSO coordination, mainly relate to the distribution network and are, therefore, out of the scope of this paper. Michael Pollitt (2018) explores the network charging principles for the electricity distribution network in the light of potential significant changes in the share of distributed energy resources. Perez-Arriaga et al. (2017) outlines a market, regulatory, and policy framework aimed at establishing a level playing field for the provision and consumption of electricity services and enabling the integration of a cost-effective combination of centralized generation, conventional network assets, and emerging distributed resources. ther aspects of regional market integration, like market design, generation adequacy, the need for more flexibility, and frequency control are discussed in Grigoryeva et al. (2018) in the context of the Nordic countries.

Our article discusses the role that the benefits of reinforcements should play in transmission network development, in section 3, and cost allocation, in section 4, and how the solutions to be adopted to organize both aspects of network regulation are closely related. Even when regulation in several regions in the world states that benefits should guide network expansion and costs allocation, criteria applied in practice are far from being based on a holistic cost-benefit analysis. Besides, the article provides guidelines on the computation of these benefits in section 2. Lastly, in section 5, the article addresses practical problems related to the implementation of the regulation proposed for network expansion and cost allocation, such as the way to make compatible the ex-ante determination of the benefits of projects with the acceptance of these projects by local authorities; the adequate level of centralization of decisions made on the allocation of the cost of new projects at regional level; and how the granularity of the network model considered in market and system operation affects the benefits produced by network reinforcements. Finally, section 6 concludes.

2. COMPUTATION OF THE BENEFITS AND COSTS RESULTING FROM THE EXPANSION OF THE GRID

This section focuses on the several aspects related to the computation of the benefits produced by expansion projects. First, some general considerations are made on the computation of the benefits and costs of projects. Then, the types of benefits produced by projects are briefly mentioned. Lastly, the computation of the benefits of individual projects within a plan and the definition of projects are discussed.

2.1 Some general considerations on the computation of expansion project benefits and costs

Network reinforcements normally take place in the form of bundles, which are named projects. Regulatory authorities decide the undertaking of several projects, which make an expansion plan. The benefits and costs associated to a transmission project, or a set of them (like a transmission expansion plan), are normally computed by deducting the benefits of this type obtained by the system stakeholders in the situation where this transmission project, or

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projects, have not been undertaken from the corresponding system benefits in the situation where these projects have been undertaken. The fact that the benefits produced by the several network reinforcements taking place at the same time, as well as those obtained by generation and demand in the system, are interdependent may result in the decision not to undertake a network project triggering changes in the development of the demand, generation and the network in the system (Bañez et al. 2017 a; 2017 b). However, no satisfactory solution to the computation of these changes has been proposed in the literature. Thus, normally, the with-and-without-project situations to compare are assumed to differ only in the existence of the project considered. An interesting work by Hogan (2018), very much aligned and complementary to ours, discusses the principles underlying the cost-benefit analysis methodology applied to transmission expansion planning and cost allocation, and then discusses practical implications concerning the computation of benefits taking advantage of workable models of transmission investment and cost allocation.

2.2 Types of benefits and costs produced by expansion projects

All the types of benefits and costs produced by projects should be considered. These are related to the three pillars of the energy policy, namely economic profitability, security of supply and sustainability (Migliavacca et al. 2014).[2] Benefits and costs of expansion projects related to their economic profitability include the lifecycle costs of each network expansion project considered; the increase in the social welfare in the economic dispatch resulting from the implementation of this project (Wu et al. 2006); and the impact of this project on the future development of the transmission and distribution network. Among other things, the social welfare increase resulting from a network project is also affected by the increase in the level of competition (market power mitigation) in the market achieved through this project. The sustainability benefits and costs of expansion projects, comprising largely their socio-environmental ones, include the decrease in CO_2 emissions and the concentration of other pollutants brought about by the deployment of these projects; the biodiversity and landscape costs caused by these projects; the decrease in the level of curtailment, or increase in the level of integration of RES generation achieved through these projects; and the decrease in electricity prices achieved through the increase in competition rendered by projects, which would allow more consumers to access electricity. Last, the security of supply, or reliability, benefits and costs produced by network expansion projects include those related to the increase in the reliability and resilience of the system (CEER 2010; ENTSO-e 2015), and the decrease in the level of interruptible load mobilized to achieve a sufficient level of reliability in the system.

2.3 Determination of the benefits produced by individual projects within an expansion plan

Even when network expansion projects are identified within an expansion plan, determining the specific benefits produced by each project is necessary because some of the projects in the plan may end-up not being built for a multiplicity of reasons, including budget constraints, local opposition to their construction and administrative delays. However, despite some of the projects in the plan may not be built, normally, at the time that the cost of projects needs to be allocated through charges, there is large uncertainty about which projects may end-up

2. The benefits and costs of network projects may be significantly conditioned by the regulation and financing conditions, and network ownership structure existing in the system or region.

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being blocked. This is due to the fact that, as explained in section 4, charges to allocate the cost of new projects should be computed ahead of the construction of these projects. Thus, when allocating the benefits of the plan to individual projects, one should probably make the assumption that all the remining projects are going to be built as well.

As mentioned above, one should define the benefit produced by a project as the incremental one resulting from the deployment of this project. However, network expansion projects being deployed at the same time are interdependent regarding the benefits they produce. A part of the benefits produced by a plan are contingent on the joint deployment of several projects in the plan. At the same time, there are some other benefits that may be achieved through the deployment of any of several projects or combinations of them. This concerns both the total increase in the welfare they bring about to a system or region and the benefits that individual stakeholders obtain from these projects. Due to this, the computation of the benefits produced by each expansion project within a plan must be carried out taking into account the interactions taking place between this project and the rest of projects in the plan regarding their impact on the functioning of the system. At the same time, one must take into account the fact that there is a multiplicity of accidental circumstances that may alter the actual order of deployment of projects in an expansion plan, like the different level of difficulty to obtain the permits to deploy different projects. Then, no specific order should be considered to compute the benefits that projects create. Instead, all the possible ways of deploying the projects in the plan should somehow be considered.

Then, those methods not considering a specific order of deployment of projects, but somehow taking into account the possible interactions that may take place among these projects, should be preferred over the methods that assume a specific order of deployment of projects. Within the later family of methods, assuming a specific order of deployment of projects, we have the TOOT (Take Out One at the Time) and the PINT (Put IN one at the Time) methods (ENTSO-e 2013) considered for the computation of the benefits of individual projects in Europe. These assume that the project being assessed is the last one (for TOOT) or the first one (for PINT) to be deployed (Bañez et al. 2017 a; 2017 b). Methods taking into account interactions occurring among projects include the Shapley (Hasan et al. 2014) and the Aumann-Shapley (Bañez et al. 2017 a; Junqueira et al. 2007) methods. The Shapley method involves computing the incremental benefits produced by each project as the average of those created by the project over all the possible orderings of deployment of the projects in the plan. The Aumann-Shapley method involves dividing each expansion project within the plan in elemental subprojects, all of the same size, and computing the benefits produced by the former by adding up those assigned to the latter when deploying them in all the possible orders. This avoids making the value assigned to a project per unit of capacity dependent on the size of this project, and potentially avoids perverse incentives for promoters in the definition of projects, see (Bañez et al. 2017 a). The latter two methods may be perceived as complex, but, contrary to others, do not require making any arbitrary decision on the order of deployment of projects, which could raise strong local opposition.

2.4 Definition of expansion projects

The way network reinforcements are grouped into expansion projects may largely condition the benefits deemed to be produced by these reinforcements, since the benefits created by projects are not additive. Due to the strong interactions existing among the several network reinforcements to be deployed, the definition of the set of reinforcements that makes a self-suf-

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ficient unit of analysis, as Sartori et al (2014) put it, is not straightforward (von der Fehr et al. 2013). Traditionally, TSOs have proposed groups of reinforcements that were linked to specific network needs. However, when planning the expansion of large regional networks involving several TSOs, as in the EU or the USA, the interactions among the reinforcements proposed by all of them are difficult to assess. In this case, there is a growing need for automatic candidate project proposal mechanisms (Lumbreras et al. 2014).

Few works have focused on the definition of projects, including the work by the European Network of Transmission System Operators for Electricity (ENTSO-E) (ENTSO-E 2013) and that in Lumbreras et al. (2014), which uses a flow based approach to determine the relationships among reinforcements[3]. These relationships can also be identified using graph theory in the same way as currently applied to the analysis of social networks.

3. REGULATION OF THE EXPANSION OF THE TRANSMISSION GRID BASED ON BENEFITS

The benefits and costs produced by network expansion projects should be at the core of the regulation on the expansion of the grid (European Union 2013; Federal Energy Regulatory Commission 2016). This section deals with the consideration to be made of the benefits to be produced by expansion projects and the allocation of the responsibilities/roles in the process of development of the grid, according to the benefits produced by new transmission assets. The distribution of these benefits among agents and the type of benefits produced are central to determining which stakeholders should be responsible for the identification of investment needs and the promotion of the corresponding reinforcements. This should, in turn, guide the business model in place for these stakeholders (their sources of revenues). Then, this institutional framework shall be applied specifically to the case of regional markets, which are largely replacing local ones. Aspects to deal with here are discussed next.

3.1 Models for the consideration of the benefits produced by projects in transmission expansion planning

Selecting the projects to undertake requires jointly considering the benefits of all types expected to be produced by these projects. This involves assigning a weight to the benefits of each type produced by a project and, making use of these weights, combining the benefits of all types into a single indicator that can be compared across projects. There are two main approaches to this:

- Cost-benefit analysis (CBA) – whereby the benefits of all types are expressed in monetary terms and, then added up to determine the overall equivalent monetary benefits produced by each project. According to this approach, network investments, also including the cross-border or regional ones, should be undertaken when their net benefits, taking into account all types of them, outweigh the life cycle cost of the former according to a set of well-defined CBA criteria;
- Multi-criteria approach (MCA) – whereby different metrics are kept for different types of benefits related to the several objectives to be achieved through the development of

3. Following this approach, there is also the option to apply hierarchical clustering to identify preliminarily the interdependence relationships existing among candidate reinforcements.

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the grid (increase in economic efficiency, reliability and security of supply, and sustainability, including the environmental one, with aspects like the penetration of RES generation). Then, the benefits of each type are given a certain weight proportional to the relative importance of the corresponding objective with respect to others. Using these weights, all benefits are combined into a single dimensionless scoring parameter used to compare alternative investments.

Beria et al. (2012) carry out a review of the MCA and CBA approaches highlighting their advantages and drawbacks. MCA may be adopted to identify projects that produce significant social, economic or environmental benefits to promote based on the relevance of the considered benefit dimension in the context considered. On the other hand, CBA allows one to massively, and systematically, assess investment projects producing benefits of different kinds and select an, allegedly, optimal set of them to promote.

3.2 Mainstream institutional design of the development of the grid based on the benefits produced by transmission projects

It is well known that conditions applying to the electricity transmission activity make it a natural monopoly able to affect the market benefits of agents and the social benefit of the system (Rivier et al. 2013). Then, a single network should exist over the whole system, or region, considered, and its development should be largely managed centrally by a fully unbundled entity, or a group of them, working in close cooperation while preserving the functioning of the system. When deciding which projects to undertake, this institution or institutions should jointly consider the benefits produced in the whole system by all the investment projects.

Besides planning the expansion of the network and operating it, this entity may own the network, being called a Transmission System Operator (TSO) in the European jargon, or may not own it, being called a System Operator (SO). Owning the network allows the TSO to avoid potential conflicts (for instance who decides and pays for small investments in metering, fault protection activities, power system control, etc.) between the System Operator and the owner of the assets. The Transmission System Operator can carry out more efficiently the maintenance and operation of transmission assets, since both activities can be fully integrated within the same company. However, this may also create perverse incentives for this entity to affect the development and operation of the network so as to increase the revenues earned (De Clercq et al. 2015).

TSOs reinforcing the network may be of two types: a) Passive TSOs who promote the construction of network reinforcements but do not decide over the approval of the corresponding expansion projects, or b) active TSOs that identify which reinforcements would be most beneficial, or efficient, and also decide on whether to finally undertake them. These last ones are, in any case, also subject to some minimum performance requirements, as defined by a Network Code (National Grid 2017). Besides, their remuneration is finally computed by regulated authorities, as explained below.

Complementing these regulated network investments, there may be others undertaken by private promoters seeking a profit out of the commercial exploitation of the new transmission capacity they built, or by an association of network users who would be largely benefited by the existence of the reinforcements they promote and pay. These last ones would be investments carried out by private parties at their own risk, and, therefore, of a different kind from that of regulated investments. They will require anyway the authorization of the regulatory body in

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order to prevent investments that actually may decrease the global social welfare of the rest of stakeholders in the system.[4]

3.3 Remuneration of network investments

Regulated network investments, as network investments in general, normally affect large numbers of agents in the system increasing the market benefits of some of them and decreasing the benefits of others. Overall, efficient network investments by definition create an amount of net benefits that must exceed their costs (European Union 2013; Federal Energy Regulatory Commission 2016). Then, the TSOs or TransCos owning these investments cannot appropriate the benefits they create. If this were the case, the remuneration perceived by the owners of these investments would not be commensurate with their costs and the risks born by the entities undertaking the former. Still, the revenues of the owners of regulated network investments should depend on the nature of the entities undertaking these investments.

When regulated network investments are undertaken by a passive TSO or independent TransCos, these investments should be remunerated according to their costs, as determined through some kind of competitive process to allocate the construction of these assets. Transcos, in fact, should be assigned the ownership of these investments through this same competitive process. Alternatively, if this is not possible, the remuneration of these assets should be set by regulation trying to reflect a reasonable level of costs to be incurred in building, operating and maintaining them (De Clercq et al. 2015).

When an active TSO decides over the construction of regulated transmission assets, the remuneration scheme that applies should not exactly correspond to the costs actually incurred in undertaking the resulting network investments. Instead, this scheme should set some incentives driving the TSO to carry out the network expansion planning, network construction, operation, and maintenance activities efficiently. Thus, the remuneration perceived by the TSO corresponding to a certain regulatory period, should reflect the costs incurred in developing, operating and maintaining an efficiently adapted grid, while taking into account the conditions applying to the system and the network at the beginning of this period (Rivier et al. 2013).

On the other hand, when stakeholders undertaking network investments carry them out at their own risk, allowing these parties to retain part of the benefits created by these investments, not setting a pre-established limit to their revenues, should drive them to promote at least some of the investments that would be beneficial for the system as a whole. At the same time, this could compensate for the higher level of risks they incur when undertaking these investments compared to the risks incurred by investors in regulated expansion projects.

Normally, private network investors at risk are allowed to keep for themselves the congestion rents produced by their investments, or revenues resulting from the commercial exploitation of these investments. Alternatively, in those cases where new transmission assets are to be used by a reduced number of agents in the system, their private promoters could negotiate with the future users of these assets the level of access charges to be applied on the former. Potentially, this could create extra incentives to build these lines as merchant ones. However, clear

4. Electricity grids, due to the physical laws governing their behavior, may be the unique case of network infrastructure for which new investments, if not properly decided, may deteriorate the transport capacity of the network. Moreover, private investors (non-regulated investments) do have the incentive of undertaking such "wrong investments", as they may lead them to get larger incomes.

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conditions should be set to determine when applying a negotiated access regime is advisable in order to avoid the market foreclosure for some agents (Rivier et al. 2013).

3.4 Treatment of negative benefits in the computation of the reinforcements to undertake

Not considering negative benefits earned by specific system stakeholders due to the construction of each reinforcement to the grid when deciding over the approval of this reinforcement would make the network development more dynamic, or agile. Indeed, in this case, the development of the grid could encompass all those reinforcements that would create positive benefits exceeding their investment, operation, and maintenance cost.

However, some of these projects could also create some negative benefits that may make the overall net benefits produced by the former actually lower than their costs. These projects are not efficient from a social point of view, at least when not taking into account the benefits associated with the potential acceleration of the evolution of the power industry the projects could bring about. Given that these benefits are difficult to estimate, one may conclude, adopting a conservative view, that no regulated network investment should be approved unless the net benefits it creates, including the negative ones, exceed the costs associated with this investment. Similarly, network investments at risk should only be approved if the net operational benefits that they create, excluding those perceived by the private promoter, are positive (Rivier et al 2013).

3.5 Adaptation to the context of regional markets

Developing appropriate governance for regulated transmission network investments of a regional, or cross-border, nature involves achieving a sufficient level of coordination among the systems and stakeholders in the region and devising an efficient, albeit workable, methodology for project identification, proposal and approval. The planning approach adopted should maximize to the extent possible the increase in the net social benefit produced by the selected reinforcements while, at the same time, being effective in achieving the construction of these reinforcements, which requires providing the conditions for the relevant regional and local stakeholders to support these investments (De Clercq et al 2015).

An interesting approach to select practices to apply in the selection of relevant cross-border, or regional, investments is focusing on promising ideas implemented in single, perfectly integrated, systems. A paradigmatic case is the case of Brazil, where the expansion of the transmission network has been integrated with that of generation, which should increase the efficiency of the planning process. Auctions have been set up for this. There, the system central planner (EPE), aided by the system operator (ONS) produces an indicative transmission expansion plan based on the development of the generation, resulting in new energy auctions taking place both for RES generation including hydro, which signs 30-year energy supply contracts if winning the auction, and thermal generation signing 15-year contracts, see (Maurer and Barroso, 2011). Thus, the results from renewable generation auctions, and also from other technologies, could be used to guide the network expansion planning process serving as an input to the definition of the scenarios considered in this process. Other methodological approaches that address the interdependency of transmission and generation are discussed in Grimm, et al. (2016). The interdependency of the transmission expansion with that of batteries to solve security of supply problems in South Australia is addressed in Mountain (2018).

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However, one must take into account that deeply rooted energy regulation in regional markets like the IEM in Europe or the ones developing in the USA, together with the multi-level governance structure that has been developed in these regions, prevents setting up central institutions like a central planner or regulator with authority to unilaterally decide on the development of the regional grid. Therefore, instead, regional and local (national, or State) authorities in these regions should cooperate to define the cross-border projects to deploy in these regions. Given the interactions taking place among projects, the assessment of all the investment alternatives should be coordinated across the entire region (De Clercq et al 2015). Thus, in Europe the planning of the expansion of the regional grid is still defined using a bottom-up approach, although expansion projects proposed by the several countries and regions are, then, jointly considered by regional institutions, namely the ENTSO-E and the Agency for the Cooperation of Energy Regulators (ACER), to build a pan-European transmission expansion plan, the Ten-Year Network Development Plan (TYNDP), of an indicative nature except for the case of PCIs. Recently, the Commission and ENTSO-E have worked on the definition of more advanced network expansion planning methodologies that are truly integrated at European level, see (eHighway2050, 2015).

As discussed in FERC (2012), three main types of network upgrades are identified within the US system, economic, reliability, and policy ones. A specific governance model is applied to the upgrades of each type, including different specific decision makers and rules applied to the selection of the required reinforcements. This approach makes it difficult to identify the most beneficial reinforcements to carry out altogether and prevents the construction of some of these due to the fact that different reinforcements may fall under the jurisdiction of different authorities. Although set in their gross regulation principles, a holistic region-wide cost benefit approach is still far from being actually applied in the EU and USA.

Following a top-down planning approach at a regional level, similarly to what has been said to be required at a perfectly integrated system level, the benefits of all the cross-border projects obtained by the stakeholders in all the systems in the region should be jointly taken into account, together with their costs, to compute the investments to carry out. Based on this, authorities should determine the amount of new transmission capacity to be built in each corridor and when to build it. The cross-border reinforcements so computed should be compatible with the conditions existing in national networks and the reinforcements computed for them. Thus, national planning authorities should also assess cross-border investments to determine whether they are compatible with preserving the reliability of the local system operation and with local network expansion plans avoiding, for example, overlaps among local and regional reinforcements in the benefits they produce. Besides, when developing the regional expansion plan, the regional planning entities should be given access to local planning and operation data and provided with the technical expertise required to process all these data.

Given the high level of uncertainty existing about the future development of power systems, especially in a regional context, the benefits of network reinforcements should be computed in a multiplicity of future scenarios representative of all those that may unfold in the future. Weighting the benefits computed for each scenario with its probability of occurrence would allow authorities to determine the expected net benefits of reinforcements and compute expansion plans that are efficient regarding their expected net profits. Robust expansion plans could be computed applying specific planning criteria for this, like the minimization of the maximum cost of regret (De Clercq et al 2015).

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Given the fact that regulated expansion planning may not be able to identify all the efficient reinforcements, merchant investments and those promoted by associations of network users could also be allowed. Promoters of this type may identify additional investment opportunities to render extra benefits to the region. Normally, there are more investment opportunities for merchant promoters in regional markets, where interconnections among system are frequently weak. Merchant investments should be assessed by regional, and also local, authorities, who should make sure that they are not decreasing the system welfare or creating further operational problems. Authorities should put in place return/risk sharing schemes concerning network promoters and users that result in the construction of beneficial reinforcements privately promoted.[5]

4. COMPUTATION OF THE TRANSMISSION CHARGES DRIVEN BY THE BENEFITS PRODUCED BY THE TRANSMISSION NETWORK

Here we focus on the allocation of the cost of new projects to network users through network charges in the case of regulated network investments. As discussed previously, according to some economic principles and obeying to tractability and practical issues, the cost of these lines should be allocated to the network users proportionally to the size of the benefits that the latter obtain from the former. This is a principle commonly accepted. However, several aspects of the computation of charges should still be discussed. We first discuss the definition of expansion projects. Then, we briefly analyze the design of the structure of the network charges allocating the cost of network reinforcements.

4.1 Design of the structure of transmission charges

As already mentioned when arguing the need to compute the benefits produced by individual projects in an expansion plan, benefits considered when computing transmission charges providing efficient signals related to the development of the transmission grid should be computed ex-ante, and these benefits will be those expected to be produced by the investments in this grid, at the time that these investments are approved. It is at that time when the undertaking of the corresponding reinforcements can be avoided through the application of efficient transmission charges that could affect the investment decisions by network users. Computing transmission charges related to certain network reinforcements ex-post, based on the real benefits finally provided by these reinforcements once they are built. would not prevent these reinforcements from taking place. Therefore, these transmission charges would not be efficient, since they would not achieve a reduction in the network development costs, see (Olmos and Perez-Arriaga 2009). Besides, computing transmission charges ex-post would not reflect the responsibility of the agents paying these charges on the network development costs. The actual benefits that agents obtain from a network asset may largely differ from the benefits expected to be obtained by agents from this asset at the time its construction was decided, which were the ones originally driving the construction of this asset.

Additionally, only if these charges are computed ex-ante would authorities be able to convey strong locational signals guiding the investment decisions by network users. Computing

5. Besides, merchant assets and those promoted by associations of users could end up being integrated into the regulated asset base. The time when this occurs should probably depend on the features of the investment considered (De Clercq et al 2015).

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ex-post network charges would blur the separation between investment and operation signals and would substantially weaken the locational signals submitted through these charges.

Lastly, transmission charges should not interfere with the dispatch, which should be guided by short-term costs. In line with this, transmission charges should be applied as annual amounts determined ex-ante and paid as lump sums (Olmos and Perez-Arriaga 2009), maybe split into monthly installments.

4.2 Treatment of negative benefits in the allocation of the cost of network investments

Once the construction of a network reinforcement has been approved, one should conclude that those paying for it should be the stakeholders benefiting positively from its undertaking. The stakeholders being harmed by a reinforcement, once this has been deemed to be socially efficient, should not pay any fraction of the former. However, these stakeholders should not be compensated for the construction of the reinforcement, either. Stakeholders involved in power markets should not be protected from the losses incurred as a result of the increase in the level of market competition created by network investments.

However, there may be situations where stakeholders that are negatively affected by the undertaking of an efficient network investment project have the ability to block it. In this case, carrying out this socially efficient reinforcement would only be possible if some sort of compensation is paid to the aforementioned agents rendering the concerned project beneficial for them as well. This could justify, also from a social point of view, the decision by all, or some, of those stakeholders being positively affected by a project to pay a compensation to those other stakeholders being negatively affected that have veto power over this project (Coase 1990). Positive benefits and losses rendered by a socially efficient project should suffice, when accompanied by a well-designed allocation of costs, including compensations, to make the project beneficial for any stakeholder in the system.

5. SOME PRACTICAL CONSIDERATIONS

Finally, we briefly discuss some practical aspects of the implementation of network expansion planning and costs allocation based on benefits. These include the adequate level of centralization of the allocation of the cost of priority network expansion projects at regional level; the way to make compatible, from a practical point of view, the ex-ante determination of the benefits of projects with the acceptance of these projects by local authorities; and how the granularity of the network model considered in market and system operation affects the benefits produced by network reinforcements.

5.1 Level of centralization of the allocation of the cost of priority network expansion projects at regional level

Centralized expansion planning algorithms need to be implemented in order to identify those reinforcements that are most beneficial from a regional point of view. As suggested above, the cost of these reinforcements should be allocated proportionally to the benefits that stakeholders are expected to obtain from them according to a previously defined benefit assessment method. However, this may raise strong local opposition due to the need to make ex-ante assumptions on an uncertain future. Then, instead, the affected parties (systems) could be left

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to negotiate multilaterally a solution to this problem. If they manage to find a cost allocation solution that is satisfactory to all them, then, this solution would be implemented. Otherwise, after some time, the cost of these projects would be assigned centrally according to the previously described benefit assessment methodology.

5.2 Practical considerations on the timing of the computation of the benefits of new transmission assets for the allocation of their cost in a regional context

As mentioned in section 4.1, transmission charges should be defined before carrying out the transmission investments whose cost we are allocating through the former. However, information considered ex-ante for the computation of charges will prove to be inaccurate. The prospect of having to pay a fraction of new transmission assets that is significantly different from the actual benefits that network users end-up obtaining form new assets could create strong local opposition to the construction of these assets. At this point, one should bear in mind that the recovery of the cost of these assets will extend over a long period of time, typically 30–40 years (the economic life of these assets). Then, an appropriate trade-off could involve computing before the installation of new network users only the network charges to apply to these users for some limited period of time, which could be 5–10 years long. At the end of this period, the charges to apply to the users in the following 5–10-year period could be updated to reflect the change that has actually taken place in system conditions and, therefore, how the aforementioned agents are expected to benefit in this new period from the network assets concerned. Following this scheme, network charges to apply on network users should be updated every 5–10 years. Updating periodically these charges should allow one to reconcile, to some extent, the actual benefits obtained by agents from assets and the expected ones used to compute network charges, which should limit the opposition of network users to the implementation of these charges. The time to pass before network charges are updated should be long enough for the locational investment signals conveyed through these charges to be strong, and therefore be considered by agents in their investment, or decommissioning, decisions.

5.3 How the granularity of the network model considered in market and system operation affects the benefits produced by network reinforcements

When computing the benefits of transmission expansion projects, one cannot disregard the fact that these may be dependent on the features of the network model considered for system and market operation and price computation. Both the overall amount of benefits produced by a network reinforcement and the way these benefits are distributed among market agents may be affected by the bidding areas defined. The network congestion that occurs within a bidding area may probably not be appropriately considered in the computation of the dispatch and prices. However, this congestion may have an impact on both the dispatch and prices, since the dispatch should be computed in order not to result in overflows in the corresponding transmission assets. A new set of bidding areas should be defined according to which the aforementioned network congestion does not take place within an area, but on the borders among areas. Then, this congestion would not affect the trade within any area, but only that among areas, and a more efficient dispatch and prices could be applied.

However, one has to accept the fact that the set of bidding zones defined may not be the optimal ones for a multiplicity of reasons, including the socio-political constraints set by local authorities in the region. Then, one should realize that, given that the definition made of bidding zones can have an impact on the system operation and prices, the set of bidding

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zones defined may also impact the changes to the operation and prices resulting from network reinforcements. Therefore, the global benefits of these reinforcements, and the specific ones perceived by each agent, or group of agents, may also be affected by the features of the network model considered in the dispatch. This involves that the estimate of benefits considered when deciding over the expansion of the grid and the allocation of the cost of new assets being built should be coherent with the network model considered.

6. CONCLUSIONS

Benefits rendered by network expansion projects should guide the decisions made related to the development and cost allocation of the transmission grid. Taking the benefits of transmission projects into account, planning and regulatory authorities could devise a framework for the assessment and approval of network reinforcements, as well as for the allocation of their costs, that maximizes the social benefit both in the short and the long term.

However, this requires that all the benefits created by each project in the relevant market are taken into account in the corresponding processes, and that the beneficiaries of efficient projects, as well as the size of the benefits the former obtain from the latter, are correctly determined. To achieve this, the interactions taking place among reinforcements to the network regarding the benefits they create must be considered. Besides, we need to factor in as well the specific nature of these benefits, meaning their type and their relationship with the network investment decision-making process. This should allow one to efficiently define the expansion projects as the elemental investments to assess by planning authorities. Network charges determined according to the benefits obtained by agents from each investment should be computed at the time when investments are made and should not be altered afterwards, at least for a sufficiently long period of time. This determines the structure that network charges must have to drive efficient investment decisions by agents while not distorting the operation ones.

From an institutional point of view, authorities in charge of identifying the required reinforcements and approving their construction should be the central ones looking after the interest of all the system stakeholders in the relevant region. This, however, needs to be made compatible with local (national, or State) authorities being able to affect the network investment decisions according to their own perspective and knowledge about the system local needs. Besides, in order to gain local acceptance, these local authorities could be left to negotiate multilaterally the allocation of the cost of regional reinforcements according to their own estimates of the benefits they are to obtain from the latter. Only if this fails, should the allocation of the cost of these reinforcements be computed based on the centrally determined benefits they are expected to produce. The construction of some critical reinforcements to regional networks may be contingent on being able to identify them and allocate their cost according to the benefits they are to produce, even when these are subject to multiple uncertainties.

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