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Policy measures to apply the Whole System Approach (WSA) in energy infrastructures

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Policy measures to apply the Whole System Approach (WSA) in energy infrastructures

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1 Introduction [1]

Following liberalization and especially the energy transition, energy infrastructures are developing rapidly and significantly. Electricity networks are expanded to facilitate connection of renewable energies and new load such as heat pumps and electric mobility. On the one hand, gas networks are preparing for a phase-out and, on the other hand, for a possible repurposing for transportation of hydrogen. At a communal level, the heat supply moves towards heat pumps and district heating, both in turn affecting electricity and gas infrastructure. Lastly, infrastructure for hydrogen and CO_2 for CCS are being developed. These developments affect various stages within the energy sectors. These simultaneous and interactive developments require coordination between and within the different energy infrastructure. Improving the coordination of energy infrastructures has been coined Whole System Approach (WSA) (cf. CEER, 2020; CERRE, 2021). Following CEER, we distinguish three levels of the Whole System Approach: 1. cross-sectoral-approach, 2. whole-network-approach and 3. whole-chain-approach.

In this report, we examine approaches for applying the Whole System Approach. Often applying the WSA may require an explicit policy, possibly supported by state action. In this report, we call these policies measures to apply the WSA policy options. This study is part of a research project on the Whole System Approach.[2] Another part of the research project analyzes (misaligned) incentives between different actors and incentives for coordination and cooperation in a game-theoretical setting, using real-world use cases.[3]

This report presents and assesses a list of 14 policy measures to apply the WSA, summarized in *Table 1* below. We grouped the policy measures in three main categories: 1. monetary incentives, 2. cooperation and 3. hierarchies. This list of measures is not intended to be exhaustive but to provide an in-depth impression of measures to deal with the coordination problem between energy infrastructures. We aim to start rather than finish a discussion.

In formal game theory, coordination and cooperation games are actually different. We might say that coordination is an information problem, whereas cooperation is an incentive problem. In this study, as well as in practice, we often touch upon this differentiation and we face both coordination and cooperation problems. As we do not aim for a formal game-theoretical approach, and as the borderline is quite often blurred, for ease of notation, with few exceptions, we use both terms interchangeably.

[1] The authors gratefully acknowledge financial support for the research grant "Whole System Approach: Anpassung der Anreizregulierung zur Verbesserung der Gesamtsystemoptimierung", funded by Stiftung Energieforschung Baden-Württemberg (346-22). Furthermore, the authors are grateful for useful information and insights provided in interview with parties from the energy industry in Germany.

[2] „Whole System Approach: Anpassung der Anreizregulierung zur Verbesserung der Gesamtsystemoptimierung", funded by Stiftung Energieforschung Baden-Württemberg (346-22).

[3] The interested reader may be referred to Flachsbarth et al. 2024 (forthcoming).

Table 1: Overview of policy measures to apply a WSA

A. Monetary incentives	B. Cooperation	C. Hierarchies
A.1 Incentive mechanism	B.1 Round tables	C.1 Rules
A.2 Ex-ante cost-revenue-sharing	B.2 Joint planning	C.2 Arbitration board
A.3 Ex-post financial compensation	B.3. Information sharing	C.3 Competence hierarchy
A.4 Auction		C.4 Joint ventures
A.5 Differentiated tariff-structures		C.5 IESO
		C.6 Horizontal or vertical integration

Source: own table

Section 3 of the study presents and assesses these policy measures. This assessment relies on different criteria, of which two turned out to be the most important and distinguishing features. First, effectiveness: does the policy option address the coordination problem effectively? Second, ease of implementation: how easy or complex is it to implement the option in practice? Section 4 illustrates the use of the policy options with selected use cases, which cover the three WSA-levels, set out above.

The first use case is at the WSA-level whole-network-approach and covers two aspects. Use case 1A addresses the problem of network operator coordination in the *investment* phase using the example of investment in a DC-Corridor to decrease network congestion. Use case 1B covers coordination problems in the *operation* of a DC-Corridor. Use case 2 addresses the coordination problem between regulated network operators and network users using the example of location decision of an electrolysis plant (whole-chain- approach). Lastly, use case 3 addresses the coordination problem between network operators of different infrastructures with a focus on network development coordination between electricity and gas network operators (cross-sectoral- approach).

To summarize the big picture: especially Ex-ante cost-revenue sharing (measure A.2) and Ex-post financial compensation (measure A.3) from the group of monetary incentives on the one hand, and Joint planning (measure B.2) and Information sharing (measure B.3) from the group cooperation on the other hand are the most promising. Quite likely, they can be applied in combination with each other. In this study, we aim to provide the wider picture; details need to be worked out at a later stage.

2 Background and preliminaries

In this section, we will first set the background and discuss the concept of a Whole System Approach. Moreover, we will briefly outline the main method of this study.

2.1 Whole System Approach (WSA)

With the increasing importance of hydrogen becoming apparent in achieving global climate protection goals, in addition to the need to expand the power grid, there is also a need for planning the future hydrogen infrastructure, which coincides with a replanning of the natural gas infrastructure. The infrastructure planning of the electricity and gas networks has so far been carried out largely independently of one another and the regulation of the respective network operators does not provide any incentives for coordination between the sectors. However, the interdependencies between the sectors and their planning are increasing significantly. Accordingly, the actors, who previously acted independently of each other, must be coordinated in the overall system. Even within the electricity sector, in certain cases more coordination between the players would be beneficial for society as a whole, on the one hand between the various network operators (e.g. to eliminate bottlenecks) and on the other hand between regulated network operators and competitive market players (e.g. when deciding on the location of consumption systems). The regulatory framework has not yet provided any incentives for this. This leads to the need for a so-called Whole System Approach.

The McNulty report from 2011 may have been a background to this development. The so-called McNulty report (2011) for the British government examines the efficiency of the British railway system with two main conclusions: 1) the British railway system was (as of 2011) significantly less efficient than comparable railway systems, 2) the main cause of this inefficiency was a far-reaching fragmentation of the system, leading to misaligned incentives. The report makes many recommendations for action, above all, however, the focus is on improved overall system optimisation.

This overall systemic approach is also reflected in the work of transformation research (McMeekin et al., 2019; Olbrich & Bauknecht, 2022). This research area also examines how this perspective is or should be reflected in specific governance fields, including the governance of electricity networks (Bauknecht et al., 2020).

The Council of European Energy Regulators CEER (2018, p. 29) has defined the term Whole System Approach (WSA) as follows: “The WSA requires the [network operators] to look at net benefits on a broader basis than their own grid.” The regulatory challenge, as CEER (2018, p. 29) notes, is that: “in some situations, externalities not fully priced in must be considered by regulators.” Note that the WSA is not limited to the networks but that the networks are at the core of the WSA.

Similarly, the EU promotes optimization of the energy sector as an overall system through its strategy on energy system integration. Efforts to decrease fragmentation along the electricity value chain has been recently pronounced through the flexibilization efforts of the upcoming

EU power market reform (cf. EU, 2023). Efforts to integrate the electric power sector with the other parts of the energy sector, like conventional and renewable gas, have been initiated by the common network planning initiative of the ENTSO-E & ENTSO-G (2018) and are likely to be supported by the cross-sectoral harmonization of network regulation that is planned for the upcoming years (ETIP SNET, 2023; CEER, 2021).

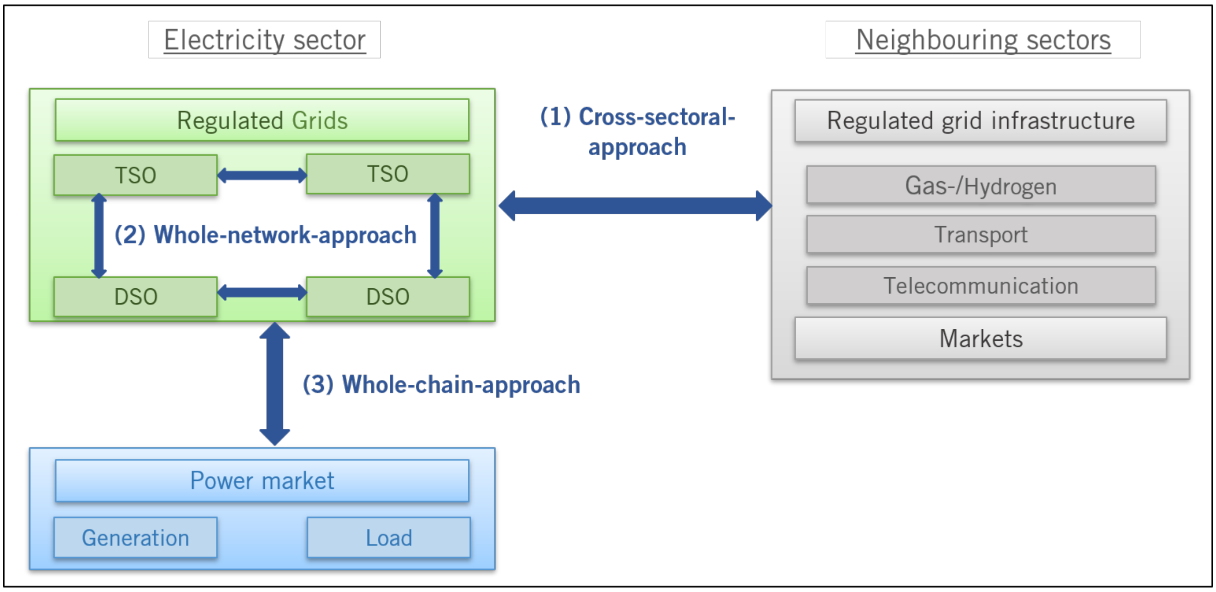

Figure 1: The three levels in the Whole System Approach

Source: own figure, based on CEER (2020)

The WSA aims at three levels of overall system optimization:

1) Between different sectors (*cross-sectoral-approach*). The cross-sectoral-approach concerns the coordination between actors from different sectors (sector coupling), whereby a regulatory problem can always arise when at least one regulated network operator is affected by an actor from another sector. The focus is currently on the efficient and effective development of a hydrogen infrastructure.
2) Between the networks in a sector (*whole-network-approach*). The whole-network-approach addresses the optimization of the network levels (network operator coordination) within one sector. In the case of electricity networks, this affects the coordination between transmission and distribution network operators but also the coordination between transmission network operators.
3) Between the network area and the market in a sector (*whole-chain-approach*). The whole-chain-approach aims at the interface between the regulated networks on the one hand and the competitive markets on the other (network-market coordination).

The coordination problems and possible solutions are diverse and depend on different factors. First, they depend on the WSA-level at which the problems exist, or, more precisely, on the number of sectors and the number as well as the type of actors (e.g., regulated vs. market actor) involved. This means that solving a coordination problem between two regulated network operators will likely need a different approach than solving a coordination problem between a regulated network operator and the numerous network users. Second, it will make a difference whether a coordination problem exists in the investment phase or in system operation. Third, and related to this, is the question of how frequent the problem occurs (e.g., once vs. repeatedly) and how severe it is.

In this study, we will illustrate coordination problems that call for a WSA and suggest and discuss policy measures to address these problems with selected use cases, which cover the three WSA-levels, set out above.

The first use case is at the WSA level "whole-network-approach" and covers two aspects. Use case 1A addresses the problem of network operator coordination in the *investment* phase using the example of investment in a DC-Corridor to decrease network congestion, whereas use case 1B covers coordination problems in the *operation* of a DC-Corridor. Use case 2 addresses the coordination problem between regulated network operators and network users using the example of location decision of an electrolysis plant ("whole-chain-approach"). Use case 3 addresses the coordination problem between network operators of different infrastructures with a focus on network development coordination between electricity and gas network operators ("cross-sectoral-approach").

2.2 Aim and method

The primary aim of the report is a first orientation of possible policy measures to address coordination problems within and between the energy sectors by applying a WSA. We will provide and discuss 14 options standing alone in section 3. These discussions include a qualitative assessment of the measures.

As pointed out above, the problems and solutions are diverse. There is no silver bullet and there is no one-size-fits-all. Instead, we will see in the assessment that the relative merits of the policy measures depend on the factors outlined above. Moreover, we also note that this list of 14 measures is not exhaustive; beyond doubt, readers may come up with further options or refinements. What is more, the discussion on WSA is just starting and the policy approach develops as we speak. Also, we note that the assessment merely focusses on the main arguments and aims to provide an initial indication. In a further stage of the debate, particularly promising measures need to be discussed and worked out in more detail.

Our assessment is a non-formal multi-criteria analysis for the same reasons. In contrast to a formal multi-criteria analysis, it is particularly appropriate when the relative merits of the policy measures are context-dependent and when the measures may be complements rather than alternatives.

We place the greatest focus on the two criteria effectiveness and implementation, i.e.:

- Effectiveness: does the approach achieve the goal, the goal being the improvement of whole system coordination?
- Implementation: can the approach be implemented with reasonable effort? This includes practical implementation, political acceptance and legal adjustments and affects authorities and companies.

These two criteria are emphasized because they give a first orientation on which measures are most suitable and deserve more attention in the new field of a Whole System Approach. In addition, yet to a lesser extent, we apply the following criteria:

- Efficiency: to what extent an approach leads to distorted incentives, so that the investment plan does not correspond to the economically optimal planning.
- Equity issues: this criterion includes the question of who pays, but also the question of whether the interests of relevant stakeholders are taken into account.

In section 4, we will illustrate the combination of policy measures in real-world use cases. The use cases have been selected such that they cover all three WSA-levels as depicted in *Figure 1*. For these use cases, we analyzed qualitatively the regulatory incentive and/or information problem and subsequent policy measures to address these problems. We analyzed the use case on network operator coordination (1B) quantitatively in detail in Flachsbarth et. al. (2024), by implementing the game-theoretical interaction of two network operators in a power market and grid simulation model[4]. With realistic data for the studied year, we find that in the majority of hours the two network operators do not have incentives for cooperation. When considering the effect of repeated interaction, only one of the two operators has long-term benefits of cooperation.

2.3 A word on game theory: coordination and cooperation

The Whole System Approach aims at coordination and cooperation problems. Coordination and cooperation (or rather non-cooperation) are used widely in many academic fields. For our analysis, we mainly rely on game theory, as part of economics.

Coordination is an information problem. Coordination problems arise when players have aligned interests but face multiple equilibria, making it challenging to predict which outcome they will collectively choose. Each equilibrium is equally plausible, and players must coordinate their actions to ensure they reach the most favorable outcome for all. Actors face information problems. Classic examples are the "battle of the sexes" scenario, in which a couple must decide between attending different events, or the "chicken" game, in which two drivers must choose whether to swerve or continue straight ahead. In these situations, communication or shared expectations can facilitate coordination.

Cooperation is an incentive problem. Cooperation problems involve situations, in which players could benefit from cooperation but individual incentives may lead to non-cooperative behavior. Here, players must balance their self-interest with the potential gains from cooperation. Players face incentive problems. The classic “prisoner’s dilemma” illustrates this dilemma, in which two suspects must decide whether to cooperate with each other or betray for personal gain. Despite the mutual benefit of cooperation, the temptation to defect often leads to suboptimal outcomes for both players.

[4] Flachsbarth et al. (2024) is output of the same project as this report, funded Research funded by Stiftung Energieforschung Baden-Württemberg (346-22).

In our context of lacking WSA in energy supply, we face both coordination and cooperation problems in widely diverse way. As we do not aim for a formal game-theoretical approach and the borderline is quite often blurred, we use both terms interactively with a few exceptions to simplify the notation, mostly using coordination in a general non-formal way.

3 Policy measures to apply Whole System Approach

Section 3 provides 14 possible policy measures to apply a Whole System Approach (WSA). Section 3.1 will present and assess each policy measure individually. Section 3.2 discusses to what extent the measures can be seen as complements or substitutes. It also provides an overview of how the measures compare in terms of effectiveness and ease of implementation.

The 14 policy measures included in the assessment are presented in overview in *Table 2* below.

Table 2: Overview of policy options to apply WSA

A. Monetary incentives	B. Cooperation	C. Hierarchies
A.1 Incentive mechanism	B.1 Round tables	C.1 Rules
A.2 Ex-ante cost-revenue-sharing	B.2 Joint planning	C.2 Arbitration board
A.3 Ex-post financial compensation	B.3. Information sharing	C.3 Competence hierarchy
A.4 Auction		C.4 Joint ventures
A.5 Differentiated tariff-structures		C.5 IESO
		C.6 Horizontal or vertical integration

Source: own table

We have grouped the policy measures in three categories.

A. Monetary incentives. Misaligned incentives and underlying non-cooperative behavior are typically caused by monetary external costs and revenues: one player incurs costs, while the revenues fall upon another player. Monetary incentives try to internalize external costs and benefits; they aim to reallocate costs and revenues to realign incentives.
B. Cooperation. Cooperation refers to the voluntary interaction and collaboration among individuals or groups within an organization or society to achieve mutual benefits or common goals. This category primarily aims at explicit intention and form of cooperation and the exchange of information.
C. Hierarchies. The measures in the group hierarchies require in one way or another the installation of an institution or entity, associated with roles and responsibilities. Hierarchies refer to organizational structures characterized by levels of authority and decision-making power that cascade from higher to lower ranks. Usually, decision making involves some kind of mandate.

As so often, categorization is at least partly ambiguous; here as well. The borderline is not always clear, and sometimes, options could also be in another category. Notwithstanding these limitations, we think that this categorization is helpful to provide an overview.

3.1 Policy measures: description and assessment

In this section, the individual measures are described and assessed with respect to the above categories, with a focus on effectiveness and ease of implementation.

3.1.1 A.1. Incentive mechanism

Description

Incentive mechanisms are at the core of economic regulation of network operators. They can be relevant for coordination within the whole system approach in different ways: Negative coordination incentives should be avoided, and positive incentives put in place.

Incentive mechanisms aim at providing network operators with economic incentives to reach certain targets or outputs. If targets are met, network operators can benefit, otherwise their revenues may be reduced. Conventional incentive regulation mainly aims at increasing the efficiency of networks, both in terms of investment and operation. As a consequence, network operators may implement measures to become more efficient.

In terms of coordination, first, sometimes, other policy options in the report, should be supported by incentives in the regulation to be effective at all. For instance, option A.2 (cost-revenue sharing) assumes that stakeholders engage in cost-revenue-sharing agreements to align incentives. If, however, re-allocated costs and revenues are fully passed through by the regulation, the companies will have no incentives to consider the cost-revenue-sharing agreement. Part of the benefit should be turned into additional profit.

Second, the efficiency efforts of the network operators may be made at the expense of other targets, such as long-term network development and innovation in line with policy objectives and/or the requirements of network users. Efficiency gains in the network may thus lead to externalities and be in conflict with coordination efforts.

In order to counteract such negative side-effects of incentive mechanisms, output-oriented regulation (OOR) can supplement the existing incentive regulation with revenue elements that are linked to the achievement of specific performance targets (outputs) and are intended to appropriately reflect the social benefits of the outputs. The idea here is therefore not to replace the existing regulation with a new approach. Instead, OOR selectively expands the base model (in Germany, the revenue cap determined as part of incentive regulation) to include individual OOR elements.

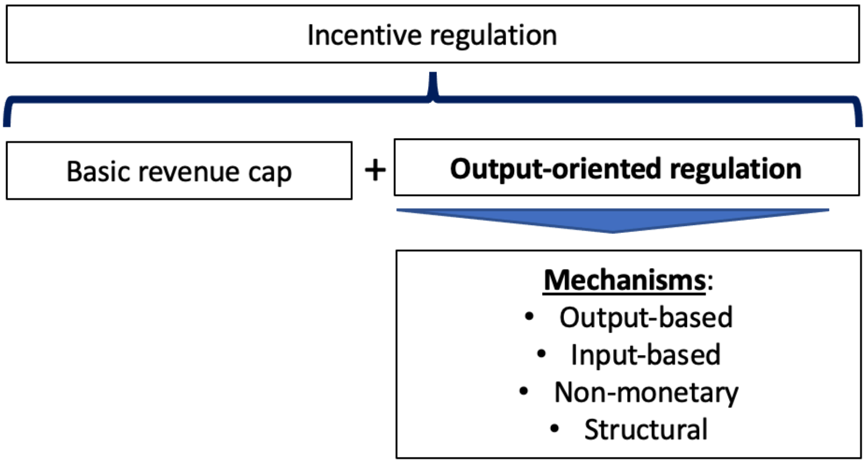

Figure 2: Output-oriented regulation

Source: Brunekreeft, Kusznir & Meyer (2020 (English version)), p. 10.

Thus, OOR builds on incentive regulation approaches but goes beyond efficiency objectives (cf. Brunekreeft, 2023). Many OOR applications are possible (cf. Brunekreeft, Kusznir & Meyer, 2020), many of which are not explicitly related to WSA.

However, as a third relevant effect of incentive mechanisms on coordination, OOR targets can still have negative effects on coordination. For example, typical targets can be:

- Target for increasing utilization rate (for DC-lines)
- Target for reduction of redispatch quantity or expenses
- Target for reduction of network losses

The incentive mechanisms typically address network operators individually, i.e. they incentivise network operators to reach certain targets within their network, but do not incentivise them to cooperate with other network operators. An example would be if network operators are incentivised to reduce the losses in their network, yet not overall losses across the network, which they have hardly any control over.

Therefore, a fourth link between incentive mechanisms and coordination is to explicitly address coordination in the design of OOR targets. OOR-elements can be explicitly designed to improve coordination, or in other words, OOR elements can internalize external effects. This option is the main target here.

Assessment

Generally, economic incentive mechanisms are good at reaching targets in an efficient way, and they can be geared to a range of different problems and targets, including the ones discussed in this report.

It is important to note that this governance mechanism can address a range of different targets, typically with a focus on individual network operators. However, it may not necessarily help to solve coordination problems. In the worst case, it may even reinforce them, if network operators are incentivised to meet their targets at the expense of other network operators. In order to improve effective coordination, it is also obvious that the OOR needs to apply to all network operators. Therefore, for the design of the incentive mechanisms, we have to consider very carefully, whether additional incentives address the coordination problem or actually worsen the problem.

For the design of incentive mechanisms, the general theory is straightforward, but implementation details matter a lot and targets and metrics may not be obvious. Again, we consider this to be particularly challenging when coordination problems are to be tackled. To the best of our knowledge, practical experience with OOR-elements or incentive mechanisms, which address external effects is rare and implementation is challenging.

Designing incentives to support other measures in this report options to avoid full-cost-pass-through is straightforward and we can rely on wider experience.

The OOR approach always requires a general implementation in the regulatory framework. It is therefore not suitable as a governance mechanism if the coordination problem occurs rather ad-hoc and occasional.

3.1.2 A.2. Ex-ante cost-revenue-sharing

Description

Cost-revenue-sharing aims to internalize external (spill-over) effects of one network on other networks or sectors. This is well known and often used in the economy and society at large, sometimes also called cost-benefit-sharing. Investopedia.com (accessed 31.01.2024) uses the following definition of revenue sharing: “The practical details for each type of revenue sharing plan are different, but the conceptual purpose is consistent: It uses profits to enable separate actors to develop efficiencies or innovate in mutually beneficial ways. The practice is now a popular tool within corporate governance to promote partnerships and increase sales or share costs.” The key idea is to re-align misaligned incentives of independent actors by using side-payments for cost or revenues allocation. The stakeholders (specifically the network companies) can cooperate effectively project-based.

Cost-revenue-sharing in the regulated network sectors may be impeded by regulation as such. Regulation may set weak or even flawed incentives for cost-revenue-sharing. Quite often in regulation, additional external revenues are passed through in allowed revenues, and thus would be no gain for the regulated network operator. Or, in cost-plus approaches, cost can be fully passed through and thus cost-sharing may achieve little gain for the network operator. It is thus important, that cost-revenue-sharing is acknowledged and incentivized in the regulation (see Item A.1, section 3.1.1).

We have explicitly used the addition “ex ante”; the idea is that parties explicitly agree into a cost-revenue-sharing agreement before they enter into a project or start an activity. It aims at relatively large, well-defined projects, which need to be developed and which require investment. Explicitly formulated cost-revenue-sharing agreement provide relevant information before the investment is made (ex ante), thus guiding optimal investment.

We can distinguish two approaches. First, as a full regulatory approach, covering all cross-network effects in a systematic way. In analogy to the above mentioned CBCA, we call this "cross-network cost-allocation" (CNCA). The ambition of a CNCA would be to internalize a wide set of external effects. Clearly, however, this may be too much asked. Many external effects will be opaque and quantitatively small; the transaction costs for an overall cost-revenue-sharing agreement appear high. Second, we think off a reduced form of cost-revenue-sharing agreements for selected cooperation projects only. These should have significant size and scope and it should be feasible to demarcate both the projects and the external effects.

Assessment

In theory, effectiveness to address coordination problems, or more precisely, misaligned incentives, with a complete set of side-payments will be very high. If money is the problem, side-payments can solve it. This is essentially the Coase theorem about external effects (Coase, 1960). Coase also pointed out that transaction costs can be too high to allow voluntary agreements. Above we distinguished between a full regulatory approach (CNCA) and an approach to selected projects only; the difference precisely being the transaction to implement a cost-revenue-sharing agreement. Clearly, a full regulatory approach (CNCA) would be more effective, but also difficult and costly to implement, and the limitation to selected projects will reduce overall effectiveness, but ease implementation. These effects will have to be balanced.

Implementation may be challenging. However, in the wider economy, there is a wide experience with cost-revenue-sharing models in general; just not in this context and not per se under regulation. For ad-hoc project-specific cost-revenue-sharing, implementation seems manageable. Transaction costs might be limited by the number of participants, i.e. it may be manageable if few TSOs are involved, but agreements may be difficult to reach if many actors are involved.

Several challenges need to be addressed.

A first challenge for cost-revenue-sharing would be to calculate the costs and revenues/benefits of the spillover effects. It depends on the case whether this is easy or hard. Estimating revenues may be manageable but estimating (economic) benefits more generally will be difficult and open for debate.

These costs and revenues subsequently need to enter the regulation of the network companies. As such this is mere bookkeeping, although the exchange of costs and revenues will have to be approved by the regulator. The bigger challenge is to avoid potential for strategic behavior, exploiting loopholes in the regulation. The difficulty here is to demarcate this project from other parts in the revenue base to avoid strategic cross-subsidies. This will have to be checked carefully. Also, cost-revenue-sharing might set perverse incentives for strategic cost-shifting between affiliated entities of an integrated company, with a regulated and an unregulated business.

3.1.3 A.3. Ex-post financial compensation

Description

The key notion is that the stakeholders (mostly firms), with or without the regulator or otherwise mediator, negotiate an ex-post financial compensation for incurred costs and benefits, summed over a predetermined period. Optionally, this can be extended to be summed over several activities, which may be called a package approach.

Ex-post means that cost and revenues are reallocated after the events and activities have taken place. There are two reasons. First, required information for cost- and revenue-sharing is available only after the activity has taken place. In contrast to activities under A.2, for the activities here, cost and revenues are uncertain and difficult to estimate in advance. Second, transactions may be repetitive and there may be many related activities. It may be easier to negotiate an agreement if all these are negotiated in a package, summing up a predetermined period (e.g. a year). The downside of an ex-post package approach is that it does not support investment decisions. Therefore, this approach seems to support activities where investment is not the main issue.

Stakeholders take a risk if they incur upfront cost with external benefits, in the expectation that these will be levelled out in the ex-post financial compensation round. They will only do so to a full extent, if they have sufficient trust in this process. Therefore, it seems important that these compensation negotiations occur regularly and in a familiar setting in order to build up trust and reputation.

Many details need to be considered.

- Can these be free negotiations as private initiatives, or should they be initiated by the state?
- Are the negotiations the sole responsibility of the stakeholders, or should the regulator participate, supervise and possibly mediate?
- What is the scope of a package; what should be included, and where is the borderline?
- How long should the period of financial compensation be?
- Are these a set of bilateral negotiations or rather one collective negotiation?
- Does the allocation need pre-agreed allocation keys, and which would these be?

Assessment

The effectiveness is ambiguous. The main difficulty was mentioned above: the ex-post compensation should set a signal for ex-ante decisions. Stakeholders make decisions in the expectation to be compensated later. This is unlikely to work perfectly. Even if stakeholders can reasonably expect that compensation will take place, the extent of the compensation is still uncertain. We should expect that the indirect effect of ex-post compensation for an ex-ante decision impedes effectiveness. We would therefore expect ex-post financial compensation to be important only in a context with reversible decisions, and less so in a context with irreversible investments.

Effectiveness may also suffer if many activities and transactions are simultaneously negotiated in one big package. This may blur incentives in individual cases and causes and consequences may go lost; it would not be clear what precisely is incentivized or coordinated. Moreover, theoretically it is not clear whether trading off the cost and benefits of various activities to come up to one single solution, actually leads to optimal incentives.

On the other hand, package negotiations may be effective to reach compromises. We know this well from bargaining theory and practice. In politics, package negotiations are normal. In fact, package negotiations may offer solutions, which would otherwise be unfeasible.

Implementation is relatively straightforward and is a key advantage of this item. Even in a highly complex context where causes and effects are opaque and ambiguous, and cost-based allocation keys are difficult, parties may still reach a compromise. This compromise is perhaps not an efficient outcome, but implementation would not be a challenge.

3.1.4 A.4. Auction

Description.

Auctions are a way of selling a certain good or service by predefined rules and settling mechanisms by one auctioneer (in the energy sector, e.g., by a market operator or TSO). They can involve single or multiple buyers as well as single or multiple sellers. Auctions are typically applied, when the (single) seller is unsure about the value that the buyers attach to the good or service being sold (cf. Krishna 2010); or vice versa the (single) buyer is unsure about the sellers' costs of providing it, e.g. because the valuation or availability varies greatly over time. The revelation of information for instance on willingness to pay, is their central advantage compared to fixed pricing.

Auctions are commonly applied in the electricity market, e.g. forward and spot markets, and by TSOs to procure balancing energy from market actors. Furthermore, auctions are already applied to coordinate between limited network capacities and cross-border electricity trade in Europe. This is done via explicit auctions, e.g. for cross-border trades in future markets or the access to some interconnectors, and via implicit auctions, e.g. for cross-border trades in the spot markets by flow-based market coupling. Within some countries implicit auctions are also applied for the same purpose, i.e. zonal pricing (e.g. in Sweden) and nodal pricing (e.g. in the US and New Zealand).

Assessment

As can be seen in cross-border trade in Europe, when the object to be auctioned is well defined (e.g. transmission capacity), auctions can be effective means to increase the coordination between different actors in the energy system (e.g. TSOs and market parties). Efficiency can be reduced by strategic behavior, which is not uncommon in auctions, and by market power.

The greatest challenge in applying auctions for a whole system approach is that it is not always clear what should be auctioned to improve coordination between the different actors and that the implementation might be very complex. Regarding the coordination of grid investment between different sectors, for example, one might think about introducing Demsetz auctions[5] to allocate capacities in certain regions or certain corridors between e.g. electricity and gas transmission operators. However, the implementation would be made more difficult by the need for comparability of offers from cross-sectoral competitors compared to similar auctions within one sector. A prerequisite for such an auction would also be a (centrally) specified need for network capacity. Auctions also appear to be less suitable for improving location-based coordination between network user and operator, because their central advantage of revealing information via bids does not seem to apply. First, it is not straightforward why network operators would not want to disclose the effect of a new network connection on costs e.g. via connection charges. Second, it seems unlikely that network operators would compete to connect a certain capacity to their grid, or even a single network operator for different nodes of the network.

Since at least one regulated actor would participate in an auction, either as buyer or seller, the regulation would likely need adjustment to prevent perverse incentives. In addition, the setup and execution of auctions may involve high transactions costs. The introduction of nodal pricing, for example, would mean a substantial change in the market design.

3.1.5 A.5. Differentiated tariff-structures

Description

In most electricity markets, the pricing of the generation of electricity and of the network are separated. Network tariffs are charged to finance the grid and can be used to set signals for efficient short-term network use and long-term development of the network, as the timing of the network use and the choice of location of the users can have considerable effects on the network costs. Tariff structures that reflect these effects can help to improve the coordination between network users and operators and thus to optimize the system.

In practice, tariffs often vary for different network user groups: First, generators are often exempted from network charges (e.g., in Germany or the Netherlands) or incur only a smaller share of network costs (e.g., 3% in France, 38% in Sweden) (ENTSO-E, 2018). Second, consumer tariffs often differ for the groups of large industrial, commercial or small industrial and residential consumers in the different weighting of the two (or three) parts of the tariff,

[5] Named after Harold Demsetz, who proposed to replace price regulation of utilities by procurement auctions, in which the bidders compete for the right to be the monopolistic supplier by specifying the lowest price they would accept for the output (Demsetz, 1968).

i.e. fixed (per connection point), energy-based (per kWh) and/or capacity-based (per kW). Tariffs often remain constant for long time periods, typically one year.

There are different approaches in theory and practice to signal network scarcity and to prevent excess capacity. Peak load pricing, for instance, is a concept that principally charges capacity costs only to peak demand; whereas off-peak demand is only charged operating costs (see Crew et al., 1995). In practice, for large industrial consumers in Germany, for instance, part of the network charge depends on a so-called “simultaneity function”, which means that their charge depends on the probability with which their maximum load contributes to the annual maximum load of the grid. Also aiming at efficient grid use are time-varying network tariffs, which can either differentiate tariffs for predefined, static time periods (time of use tariffs, e.g. peak/off-peak) or even adjust the tariff dynamically to the actual network usage and scarcity (dynamic or even real-time pricing). Static time-varying network tariffs are already common in several European countries. More dynamic network pricing, which technically depends on smart metering, is currently discussed in several countries.

To signal the effect of new connections on grid costs other approaches have been developed. Long run incremental cost pricing (LRIC), for instance, is an instrument for including grid expansion costs in the use of system charge (cf. Brandstätt et al., 2011). If the choice of location avoids grid investments in the region in question, the fees are low (and might be even negative), and vice versa. The fees are calculated ex ante for typical cases at strategically important grid connection points. The UK applies such pricing at the highest and high voltage level. A similar instrument are deep connection charges. While common “shallow” charges only cover the direct connection costs to the nearest grid connection point, deep charges additionally include reinforcement costs that become necessary in other, deeper parts of the grid. In contrast to LRIC, deep charges are case specific and can only be positive. In practice, deep charging has only been applied in the US so far. A third approach are smart connection agreements, as an alternative to standard connection agreements, which shall incentivize the user to behave in a grid-serving way. In Germany, since recently, agreements have to be concluded between controllable consumers (e.g. heat pumps, electric cars, etc.) and the connecting distribution network operator on grid-oriented control of the devices in return for reductions of the tariff.

An alternative to separated energy and network pricing is an integrated approach, which is done to different degrees in nodal and zonal pricing. Nodal pricing, also known as locational marginal pricing, is a benchmark for efficient electricity grid pricing (cf. Stoft, 2002, Part 5). It is a calculation method for determining the marginal costs of supplying a specific grid node with electricity that has been transported through the electricity grid. The calculated nodal spot price therefore analytically consists of an energy component, which reflects the value of additional generation, and a grid component, which takes grid congestion into account. It is currently applied in New Zealand and in parts of the United States.

As part of zonal pricing, several nodes of the electricity grid are aggregated into price zones based on structural bottlenecks. Zonal pricing divides the electricity grid into a smaller number of price zones than the competitive market would do under nodal pricing, which considers all grid restrictions. Accordingly, zonal pricing represents a simplification of nodal pricing. The calculation of electricity prices in the price zones follows the same logic as nodal pricing; however, the grid restrictions within the price zones are not considered in the calculation (for a comparison of the zonal and nodal approach see e.g., Pérez-Arriaga et. al., 2013).

Assessment

The effectiveness of differentiated network tariffs to address coordination problems is limited to the WSA level "whole-chain-approach", i.e. between network operators and market actors. If the current practice of exempting generators, and also storage units, from network tariffs is upheld, it further restricts the effectiveness of this instrument to coordination problems between electricity consumers and (distribution) network operators. Moreover, price elasticity of network users to network charges is low: in many cases, users have no obvious alternatives and can reasonably respond only long term.

By internalizing external effects of the network use and/or connection, differentiated network tariffs can increase the efficiency of the system. Yet, efficiency gains depend heavily on the specific implementation and are limited by the lack of information on the willingness to pay of network users and their flexibility. They could be further limited or even reversed when network operators have perverse incentives to signal false external costs and benefits to increase their profit. To prevent this the implementation would have to be carefully analysed.

The main disadvantages of this approach are implementation issues and low political acceptance. First, network pricing apart from cost reflectivity underlies other principles that are likely to be violated by tariff differentiation (cf. CEER, 2020b). These include non-discrimination, predictability and stability of tariffs and cost recovery, which prevent a local or temporal fine-grained differentiation of network tariffs. Second, an adjustment of the tariff structures can have substantial distributional effects, e.g. when network connection becomes more expensive in one region compared to another.

3.1.6 B.1. Round Tables

Description

In a round table a discussion group made up of various specialist representatives comprehensively discuss a specific topic in a complex situation. The discussion is moderated and initially serves to collect and exchange different views and assessments on a specific topic. The aim is to involve all those who may be affected by the topic at an early stage in order to take all the different concerns on this topic into account.[6]

The main idea is to set up a communication platform, where the relevant stakeholders can exchange information, methods, state preferences and views systematically and build up an environment of trust. Stakeholders talk to each other in an informal setting and there is no

[6] Adapted from: http://www.schlichtung.de/program/roundtable.html

hierarchy between them. More formally, a round table builds up social capital, which Wikipedia (accessed 24.02.2024), relying on the work of Robert Putnam, defines as follows: "Social capital is the networks of relationships among people who live and work in a particular society, enabling that society to function effectively. It involves the effective functioning of social groups through interpersonal relationships, a shared sense of identity, a shared understanding, shared norms, shared values, trust, cooperation, and reciprocity."

In our understanding here, the round table does not make decisions; the round table has no competence. It is merely a platform to exchange views. Therefore, the round table does not need rules or a mandate. The round table can be initiated on demand, it can be organized flexibly and informally, it can start and end at any time and can include any topic.

The borderline with an annual compensation system (see A.3) is somewhat opaque, as both require collective communication. They may be complements.

Details need to be discussed.

- Which stakeholders should be included in a round table? Presumably this is context-dependent. An important question is whether to include stakeholders with conflicting interests put differently, should a round table of network operators include the regulator?
- Even in an informal setting, do we need a minimum set of roles and responsibilities, and who decides on these?
- What is the role of associations (e.g. ENTSOE)? Associations usually already provide round tables, but these can be exclusive for members. Depending on the topic, associations could initiate and organize further round tables, include relevant stakeholders.

Assessment

Effectiveness is likely limited, because:

- Round tables do nothing against flawed incentives. In fact, stakeholders may act strategically.
- The round table (as meant here in B.1), which is a communication platform, is likely ineffective without the means of monetary compensations. And reverse, negotiations about monetary compensation are probably most effective with a common platform.
- Talks are non-binding. Binding commitments would require formal rules in the round table, which makes organization more difficult.

The arguments above reflect the notion that talk is cheap. Without consequences, the participants may say anything and moreover, the round table does not make binding decisions or commitments. On the other hand, the round table seems very useful to prepare a more formal setting where decisions are made. The round table can align views and state of knowledge and creates an environment of trust. In that sense, a round table may be highly effective. The round table can be used complementary to other more formal measures, which address the incentives.

As long as a round table is informal, implementation is easy and at low cost. We would expect, that such informal round tables (talks) are organized spontaneously, or by sector associations, possibly requested by a ministry.

3.1.7 B.2. Joint planning

Description

Joint planning requires various relevant and eligible stakeholders to plan network development collectively. Another name for the same development might be "investment plans"; however, investment plans need not be joint or collective, but might well be individual; therefore, we prefer joint planning as a name. By nature, joint planning focusses primarily on the investment level, not so much on operation.

This is an important development, which seems to gain momentum at the moment. For instance, at the EU level, we observe a stronger use of sectoral ten-year network development plans. In Germany, dena (2020) provides a first outline of a cross-sectoral system development plan. Also in Germany, "communal heat plans" are being used to guide the development of the infrastructure for heating.

For our purposes here, we should distinguish between two different types of joint planning.

Sector-specific network development plan (NDP). A sector-specific NDP sets out the investment plans or network development plans for a specific sector only. In the WSA-framework, this concerns the levels whole-network-approach and whole-chain-approach. Obviously, relevant interfaces with other sectors need to be considered, but these other sectors are explicitly not part of the sector-specific NDP. Such sector-specific NDP are well known, with for instance the TYNDP.

Cross-sectoral system development plan (SDP). A System Development Plan (SDP) combines the network development plans of various relevant energy sectors. The precise institutional setting, and further roles and responsibilities are as yet open. Dena (2020) took up the topic and made an initial push for a system development plan (SDP). Dena (2020) sees the role of the SDP as a stage upstream of the sector-specific network development plans (NDP), in which the common scenario framework and the common vision of the future are primarily drawn up and coordinated (see *Figure 3*).

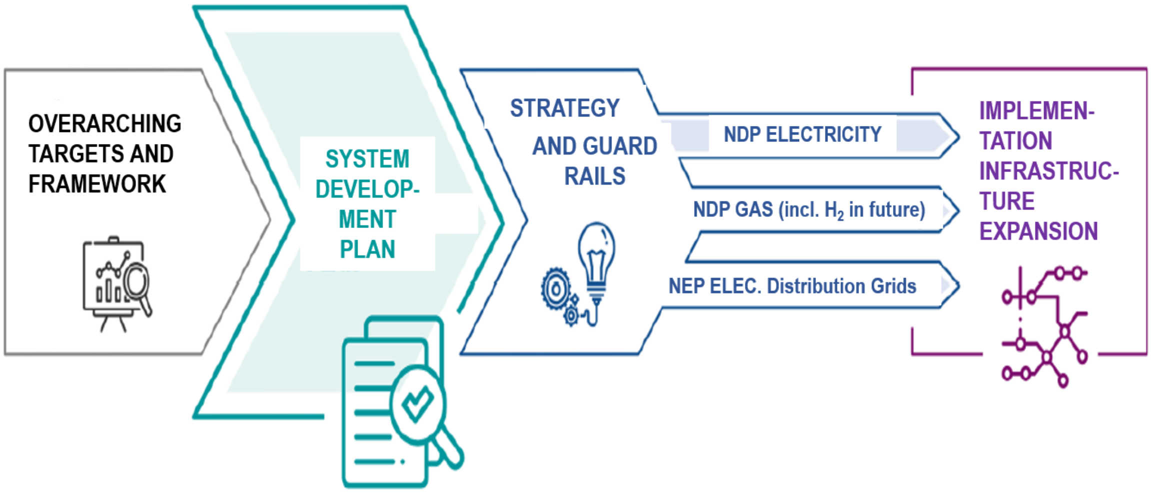

Figure 3: The system development plan as a pre-stage of the sectoral network development plans
Source: dena (2020, p. 5, own translation)

This common picture therefore serves as the basis for the respective network development plans. Dena (2020, pp. 17-19) describes the following advantages of such an approach:

1. Systemic optimization potential and consistency in terms of time and content
2. The need for social and political advice is largely met because the scenario framework at the SDP is set up very openly and discussed widely.
3. SDP enables broad participation and acceptance because the process is transparent and early so that influence is still possible and sensible.

The interlinked model of ENTSO-E and ENTSO-G may serve as another practical example (ENTSO-E & ENTSO-G, 2018). Similar to the dena approach, it provides a common scenario framework for the sectoral ten-year network development plans and, in addition, introduces guidelines on how to consider the other sectors when evaluating an investment project within the NDP stage (cf. ENTSO-G, 2023).

Key notions of joint planning are that plans are made simultaneous and coordinated. An important question to be answered is who are relevant and eligible stakeholders? This is particularly important if all stakeholders have to agree to the planning. This is context-dependent and should probably be addressed case by case. If the group of stakeholders and the governance structure are well chosen, joint planning can serve as a system of checks and balances where to some extent the stakeholders control each other. Presumably, this would be supported if data and models are shared and transparent. A system of checks and balances would support the regulator and would ease regulation, as the information in the investment plans could be used for regulatory purposes.

It is important to limit the group of stakeholders. There is no need to plan everything with everyone; in fact, that would likely be counterproductive. It seems necessary to allow subgroups; depending on what precisely needs to be planned, or what the coordination problem is, a small group of relevant stakeholders will suffice. For instance, in use case 1.A. (see section 4.1.2), we argue for a “4-TSO-NEP”.

A further important question to be addressed is the degree of centralization of the planning. A variety of approaches would be possible. Starting point seems to be a core planning, which is highly centralized (presumably initiated and under supervision by a ministry), but from there on introduce decentralized, possibly private plans and initiatives, which interact with the core planning. Decentralized initiatives should not be foreclosed.

Yet another important question would be whether the investment plans are binding. What happens if scenarios change, or if decentralized third-party investors make an investment outside the investment plan, thereby upsetting the plan? Presumably, planning updates on a regular basis and different scenarios should be part of the planning process.

Assessment

The key advantage of joint planning is high effectiveness; the primary aim of joint planning *is* to improve coordination and thus we may unambiguously expect that it benefits the WSA.

The effects on overall economic efficiency, however, are ambiguous and depend on implementation details. First and foremost, as set out above, some centralized planning seems desirable; however, to the extent that central planning excludes market activities and initiatives, economic efficiency will likely suffer. Therefore, it is important to allow decentralized market activities where possible. On the other hand, too much market will counteract central planning and coordination may suffer.

As set out above, with a good governance structure joint planning can be set up as a system of checks and balances, where the stakeholders control each other; this is why stakeholder selection is so important. Transparency of data and models will help. The stakeholders will have to justify their plans and choices to other experts and possibly publicly. A system of checks and balances in joint planning will improve the investment plans towards the preferences of society and away from interests of individual stakeholders. As a result, the information in the investment plans can be used for network regulation and thereby ease and improve regulation. This may greatly benefit economic efficiency. For instance, a used-and-useful check of an investment by the regulator is obsolete, if the investment is part of the already approved investment plan. This might also allow refinement of benchmarking approaches. It seems worthwhile to further explore the option to use the information of investment plans for the regulation.

Having said that, we should note that planning as such does not change the incentives for the stakeholders. The stakeholders will first set up plans according to their incentives; this need not comply with preferences of society. This is precisely why a governance system of checks and balances may help to control flawed incentives.

Joint planning aims primarily at the investment stage; it does little for system operation once the network exists. Whether the aim is investment or system operation, depends on the problem at hand. It may be necessary to combine different measures; for instance, joint planning with information sharing as in B.3.

Implementation of joint planning seems manageable; joint planning is well known in the economy in general. Investment planning for energy networks already exists, and required further steps follow from these. Yet, implementation details may be challenging. Interlinked model of ENTSOs is up and running for gas and power infrastructure, but has difficulty to move beyond. The problem is to include market elements into the model, like market-driven sectors (transport, hydrogen) or the interdependencies (external effects) between energy markets necessary to define the overall demand in the system (Buchmann et al., 2021). Dena (2020) is less ambitious and aims at unified input parameters for sector-specific planning scenarios.

3.1.8 B.3. Information sharing

Description

An important prerequisite for coordination is transparency and mechanisms that make as much information as possible available to all involved or affected parties. Information can be about (planned) actions of one party or about known effects of these actions on other parties.

Information sharing can have some overlap with joint planning (B.2), but we do consider it as a separate mechanism. First, one overlap can be that joint planning requires the involved parties to share information. However, we consider information sharing as a mechanism whereby coordination is to be achieved by the information sharing as such, rather than as a result of any further interaction that is based on that information and that leads to a joint product as in the case of joint planning. As a consequence, for joint planning a key question is who is involved, whereas for information sharing it is which information is shared.

Second, the plans resulting from joint planning (or indeed any kind of planning whether joint or not) can be shared as information with other parties that were not involved in the planning process. For example, network operators plan network roll-out and share this information with network users, who can adjust their plans accordingly based on that information. Similarly, network users can share their plans with network operators. In both cases, this would be the sequential combination of two coordination mechanisms: Joint planning and information sharing.

As opposed to joint planning, information sharing is not restricted to the investment phase. Rather, information sharing can be broader and can include operational information.

Information sharing seems closely related to round tables (B.1). However, while round tables are informal talks, information sharing intends to make the information exchange more formal and automated. Information sharing is more relevant when the task is relatively clear and standardised and transparent availability of information can make the execution more effective and efficient. Round tables are more suitable for explorative questions. Moreover, round tables are not just about information and data exchange but also about joint trust building and interpretation of data.

Information sharing can be regular or ad-hoc, as well as voluntary or mandatory with a legal basis.

Assessment

If all information is available to all parties, this does not imply that all coordination problems are resolved, as there may still be incentives or rules in place for some parties that are not aligned with coordination requirements. In this case, available information may simply be ignored and parties may, despite better knowledge, act in a way that is not optimal from a system perspective. However, if there is a lack of transparency about what other parties are doing and what the effects of everyone's actions are, then it is hardly possible to act in line with overall system requirements. Thus, information sharing is a necessary but not sufficient condition for coordination.

Formalized information sharing can affect behaviour and reputation directly or indirectly. As is well known from game theory, availability of information and transparency will affect the outcome of cooperative games, e.g., collusion in oligopoly situations. Formalized information exchange will make cheap talk more difficult, if statements can be checked and remembered. Stakeholders will be more careful with decisions, if others can check these with the same information. Lastly, information sharing can support reputation building, which will arguably support coordination, by building up trust.

In many cases, information sharing can be expected to be relatively easy to set up. Especially in the case of operational information, where data needs to be shared on a regular basis, information sharing can be formalized and automated and can involve the use and extension of (existing) data exchange platforms. Artificial intelligence can play a role and can increase effectiveness, also because more information is available to share. It can also reduce the need for information sharing as the data can be derived based on other publicly available observations. On the downside, more information availability can also entail cybersecurity risks.

3.1.9 C.1. Rules

Description

Network operators and other actors in the WSA context act within a set of rules, which by and large define the boundary conditions for individual and collective action. These rules thereby also explicitly or implicitly influence the extent of coordination. Coordination can be improved by adjusting these rules.

On the one hand, the rules can relate to the other governance mechanisms presented here. For example, there can be rules for joint planning.

On the other hand, there are also rules that directly influence infrastructure development and operation and as such impact on WSA coordination. One example would be network codes. In this case the rules also represent technical requirements related to network stability, that cannot be violated without putting the network at risk.

We differentiate between top-down imposed rules through legislators or regulator, and self-imposed rules, such as in case of standardization or technical norms.

In many cases, markets, especially market platform and auctions, have an explicit set of rules (eg. on bidding, scope, frequency, qualification, or price determination). Changing the rules will have an effect on behaviour and thus can influence incentives for coordination and cooperation.

One example for rules that influence network operators, the coordination between them and their interaction with market participants are redispatch rules. This includes both rules for who involved in redispatch as well as rules related to the coordination of redispatch between network operators. In Germany, for the first point, the so called redispatch 2.0 framework has for example changed the rules for who needs to participate and for how renewables are integrated and compensated. It also introduced different models for balancing and billing. As for the coordination between TSO, there is a central optimiser that determines the redispatch for the whole of Germany. Each TSO receives the instructions from this optimiser and only accesses plants that are connected in its own grid area. Theoretically, a TSO can deviate from the instruction, but then this TSO must provide an adequate replacement.

Assessment

Adjusting rules can be an effective mechanism, ideally if combined with appropriate incentives and enforcement mechanisms. However, there is an obvious limitation to effectiveness of this measure. Adjusting rules to improve coordination is only effective if there is a formal setting with rules. For instance, rules can be adjusted in an auction mechanism, but not in voluntary bilateral trading. In the latter case, it may be necessary to introduce new rules.

Changing the rules might effectively address a specific problem, but can have large possibly detrimental side-effects. This might impede efficiency.

Transaction costs may be relatively high if adjustment of rules requires changing law, ordinances, or codes. However, adjustment of a rule, where they already exist, might involve low costs.

3.1.10 C.2. Arbitration board

Description

An arbitration board has the competence to rule in case of conflicts. It needs to be independent of involved stakeholders, so that it can make neutral decisions that improve the overall system performance. Importantly, the arbitration board is not a court; it is not a judicial review. An example is the Clearingstelle EEG|KWKG in Germany.[7]

There are different options for the design of the arbitration board:

As for the legal basis, the arbitration board can either be put on a legal basis or can be based on a voluntary agreement between market actors. In the first case, the arbitration board could be appointed for example by the ministry and would have legally defined competences. In the second case, the market parties would set up the arbitration board themselves and declare that they will comply to the ruling.

As for the general role, there can be two variations. First, the arbitration board may be mediator in case of conflicts. Second, the arbitration board might be a rule-setting institution (this relates to C.1). Our primary notion is the first option, but the two options may also be combined.

For implementation, various important details need to be clarified. First, are the results legally binding for the involved parties? Second, will the result be made public? In any case, it can be expected that the information generated as part of arbitration procedures can be useful for future cases and should be documented accordingly. Third, to what extent is the result binding for other parties that encounter the same conflict? Several procedures may be offered in parallel by an arbitration board.

The decisions made by the arbitration board can in principle be based on different criteria (economic efficiency, fairness etc.) that are ideally combined. In any case it should contribute to solving coordination problems and thus improve overall system performance.

Finally, the arbitration board can be set up ad hoc or operate on a permanent basis. Supposedly, this depends on the frequency and severity of the conflicts. As the board requires detailed expert knowledge as well as trust by the involved parties, a permanent board is preferable. One option would be to extend the competences of already existing arbitration boards to cover a range of WSA issues.

Ideally, the arbitration board is complemented by other mechanisms that enable and incentivise network operators to accept the arbitration board and comply with its decisions.

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[7] "The Clearingstelle EEG|KWKG offers all market players the opportunity to settle disputes neutrally and independently without costly procedures and to obtain answers to questions on the application of the Renewable Energy Sources Act (EEG), the Combined Heat and Power Act (KWKG) and the Metering Point Operation Act (MsbG)." (www.clearingstelle-eeg-kwkg.de).

Assessment

The key advantage of an arbitration board is that it avoids going to court; it fills the void between an unresolved conflict and the court. Presumably, this saves a lot of time and effort and thus can be an efficient coordination mechanism.

On the one hand, if it is set up on an ad-hoc basis, transaction costs would presumably be low. On the other hand, the effectiveness of the arbitration board may increase if knowledge, competence and trust is accumulated over a longer time and many cases, which is the case if the board has a permanent infrastructure and deals with cases on a permanent basis.

This obviously requires that conflict cases occur on a regular basis. This also points to a potential shortcoming of this mechanism with regard to improving coordination: The board can only become active if there is a conflict between parties. In cases where there is no such conflict but still a coordination problem, the arbitration board cannot contribute to resolving the coordination problem.

The design options mentioned above entail both different levels of effectiveness and various transaction costs. This can be an argument for offering different types of procedures so that they can be geared towards the case at hand.

3.1.11 C.3. Competence hierarchy

Description

In a competence hierarchy, stakeholders coordinate by using firm-like structures with respect to a specific task. Hence, there are two main characteristics to a competence hierarchy.

First, coordination of stakeholders is organized in an authoritative system of orders. Put differently, stakeholders are assigned hierarchically organized roles with clearly defined authorities, boundaries of responsibility, reporting mechanisms, and decision-making procedures. Coordination is ensured in this system through administrative processes where higher-level positions make binding decisions for the lower-level ones.

Second, competence hierarchy is limited only to a specific task that is defined ex-ante. In this respect, competence hierarchy differs from the arbitration board discussed above (see C.2 in section 3.1.10). Whereas an arbitration board addresses occasionally occurring conflicts at the ex-post stage, competence hierarchy is established ex-ante and aiming at high-frequency interactions. The adopted organizational structure is designed according to the task to be addressed.

Competence hierarchies are common in the operation of power networks and are associated with tasks like frequency maintenance, redispatch, or management of interconnector capacities (ENTSO-E, 2024).

Assessment

Introducing a competence hierarchy implies replacing a decentralized individual decision-making setting by a hierarchical administrative organization. The impact of this change on the effectiveness and efficiency of performing a certain task depends heavily on the environment, within which stakeholders interact. Hierarchies are known to outperform markets in environments, which are difficult to predict, settings with small numbers of stakeholders, and in a presence of persistent information asymmetries (Williamson 1975). In such environments, contracts might suffer from unforeseen contingencies, require significant transaction-specific investments, or include unintended incentives. Hierarchical organization addresses these problems by its reliability and accountability, i.e. provides stakeholders with guarantees for unanticipated contingencies and documents the stakeholder behaviour.

This is why competence hierarchies are common in the operation of the power networks and rather rare in case of network planning and investment. Ensuring system stability requires an effective coordination among a limited number of network operators in a setting where network operators interact virtually continuously while having almost no information on the network status in other parts of network and can hardly predict all contingencies that might affect their own or the network of others. In such a setup, network operators must rely on the information and decisions provided by others as coordination failures are very costly.

A question is how competence hierarchies are initiated. One option is that the policy maker explicitly obliges stakeholders to establish a competence hierarchy when the need for coordination under above-described conditions is expected. This approach is likely to ensure the implementation of such hierarchies, but is unlikely to identify all fields where the introduction of competence hierarchies would be socially desirable. A second option would be that competence hierarchies emerge voluntarily, when stakeholders find themselves unable to fulfil a legally binding requirement by themselves. This would be the case where TSOs are obliged to ensure power system stability while each TSO is controlling only a part of the overall system. This option relies on the self-interest of the participating stakeholders. Still, even if the initiative is voluntary, simply because the stakeholders see the need for a competence hierarchy, we would expect some kind of formal mandate facilitated and enforced by the state. A formal mandate needs to be formulated carefully and requires legal backup. Thus, we expect significant legal effort to implement a competence hierarchy.

3.1.12 C.4. Joint ventures

Description

Wikipedia (accessed 02.02.2024) defines a joint venture as: “a business entity created by two or more parties, generally characterized by shared ownership, shared returns and risks, and shared governance.” In our context, a joint venture is very similar to cost-revenue-sharing, (item A.2) with a notable difference though: cost-revenue-sharing is a contractual agreement on costs and revenues of a project, without ownership involvement, whereas a joint venture involves ownership sharing of the project. It takes cooperation a step further than cost-revenue-sharing. Through ownership, profits, risks and responsibilities can be precisely allocated and thus incentives can be aligned. However, as there are different owners in the background, cost-revenue-sharing requires precise rules and allocation keys. This can apply to cases of positive externalities, but perhaps more importantly also to negative externalities

Wikipedia (accessed 02.02.2024) notes that "companies typically pursue joint ventures for one of four reasons: to access a new market, particularly emerging market; to gain scale efficiencies by combining assets and operations; to share risk for major investments or projects; or to access skills and capabilities." Presumably, firms would not set up a joint venture just for better coordination or to align misaligned incentives, but it may be a positive side-effect, if firms set up a joint venture for other reasons.

Joint ventures are well established in business; they are not, or at best less well-known, in regulated sectors. To avoid distorted competition and to avoid risky adventures on markets not related to the core business, rules on network unbundling and financial ringfencing may prohibit regulated network operators to enter into joint ventures beyond the network. Therefore, a first task of the regulator would be to allow exemptions, if joint ventures would improve whole system coordination.

Assessment

It is well known from the literature (Coase, 1937; Williamson, 1975), that ownership sharing is a powerful tool to internalize external effects. Joint ventures are highly effective to address coordination and cooperation problems. However, there is a limit to effectiveness: as mentioned above, as there are different owners in the background, cost-revenue-sharing requires precise rules and allocation keys. As such allocation keys are inevitably imperfect, effectiveness will be impeded. Moreover, as long as there are different owners, inevitably, misaligned incentives will remain to some extent. We may hardly observe this in practice: if stakeholders cannot agree on the allocation of cost-revenue-sharing, the joint venture will simply not take place.

Implementation costs may actually be relatively high.

First, the cost of setting up a joint venture may be higher than a simple cost-revenue-sharing agreement. During the period of the joint venture, staff from different firms will have to manage the joint venture. And afterwards, the joint venture will have to be decommissioned. Forming a joint venture will be complicated. However, there is a lot of experience in business; in practice, formal project-based joint ventures are well-established.

Second, depending on the rules and regulations of the specific country, joint ventures where at least one party is a regulated network company may be subject to regulation. The joint venture would have to be applied to and be approved by the regulator, which is resource consuming. If the joint venture is approved, cost and revenues will have to be acknowledged in the regulatory cost-base and the allowed revenues. Again, this can be resource-consuming activity.

For these reasons, we would expect that this measure focuses on project-specific individual cases and should be restricted to few cases of large projects.

3.1.13 C.5. IESO

Description

IESO stands for independent energy system operator. It builds on the concept of independent system operator (ISO) which separates system operation (SO) from ownership of transmission assets (TO). The concept of an ISO has been introduced in the process of power sector liberalization with the aim to ensure network operation neutrality while leaving the ownership of the network assets in the hands of integrated utilities that own generation facilities. Today, there are several examples of ISOs in the US, but the concept is hardly used in Europe.

The IESO model builds on the ISO model by separating SO from TO for infrastructure in different energy sectors (power, gas, hydrogen, CCS, etc.). It extends the ISO model by merging the SO parts from these different sectors into a single IESO entity. Therefore, an IESO cannot only ensure neutrality of system operation among competitors in energy market, as an ISO is supposed to do, but also enhances coordinated infrastructure development and operation across different sectors. Put differently, an IESO additionally ensures neutrality in infrastructure development among different energy sectors.

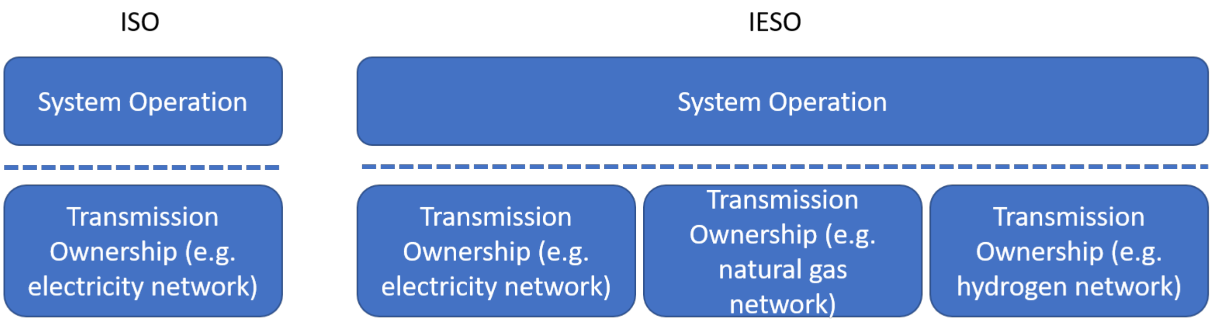

Figure 4: Difference between Independent System Operator (ISO) of one energy network and Independent Energy System Operator (IESO) of several energy networks

Source: own figure

The IESO reminds of competence hierarchy (section 3.1.10), as it promotes coordination by replacing market mechanisms by hierarchical organization (Palovic & Poudineh, 2022). It does not align incentives by integrating asset ownership, as is the case by joint ventures (section 3.1.12) or horizontal or vertical integration (section 3.1.14). As opposed to competence hierarchy, which is limited to an ex-ante defined single task, the IESO covers a broader spectrum of activities. These might cover different tasks like control room operations, network planning and development, market facilitation, long-term forecasting, emergency management, policy advisory functions, dispute settlement, etc. Importantly, an IESO does not imply taking over all SO functions in all participating energy sectors. The intended implementation in the UK nicely demonstrates the case. Whereas in the electricity sector the ISO is supposed to take over all SO tasks, the IESO is intended to take over only strategic network planning, long-term forecasting and market facilitation in the gas sector. Other gas network SO functions are supposed to stay in the hands of the current gas network operator or are open for discussion (Ofgem, 2021).

At the time of writing (Spring 2024), there exists no real-world example for an IESO thus far. However, UK proposed in 2021 introducing an IESO under the name 'Future System Operator (FSO)' and will likely be renamed in National Energy System Operator (NESO) and is currently in the process of its implementation (cf. Pollitt et al, 2024).

Assessment

Given the IESO similarities to competence hierarchies, the discussion from section 3.1.11 applies also here. The IESO replaces decentralized market-based coordination by a hierarchical administrative organization, i.e. the form of stakeholder coordination changes (Palovic & Poudineh, 2022). This change is likely to make coordination more effective in environments, where the outcomes are difficult to predict, only small numbers of stakeholders are involved, and information asymmetries are difficult to address at a reasonable cost (Williamson 1975).

The impact of an IESO on the efficiency of the coordination seems to be more difficult to assess. Separation of the SO from the TO does not necessarily align investment incentives of TOs in different sectors. Problems of misaligned incentives might hence limit the efficiency of the IESO performance, especially when IESO has only advisory function in the infrastructure development, as is common in the conventional ISO model. Furthermore, separation of SO and TO might lead to efficiency losses in some energy sectors. Due to this reason, the British FSO is for example not supposed to take over all SO functions in the gas networks. The IESO model may lead to coordination losses between the stages SO and TO. This argument is classical and has been discussed intensively in the unbundling debate (cf. Balmert & Brunekreeft, 2010).

Implementation costs of the IESO model are likely high. It implies reorganizing several thus far independently governed energy sectors. Such a step is likely to require substantial legal changes that, in Europe, are likely to touch upon European legislation. Hence, as opposed to competence hierarchies, a voluntary approach towards implementing IESO is difficult to imagine, as the stakeholder acceptance towards a further vertical split is likely to be low. Note that the UK implementation of FSO was not only driven by the goal of improving cross-sectoral coordination, but also by concerns about network neutrality issues in conventional power and gas sectors.

As a part of the implementation, the SO areas that are transferred at the IESO need to be ex-ante defined and influence the efficiency of the overall system, as suggested above. This opens up space for mistakes. Furthermore, one should also consider the incentives of the IESO. This should be neutral and hence unaffected by the development of any energy sector that is governed by the IESO decision. This raises the questions about the ownership of the IESO. In the UK for example, the problem has been addressed by transferring the IESO ownership into the public sector.

To sum up, the IESO approach does have the potential to address coordination problems effectively, but its implementation hurdles are at least in the present so significant that the coordination problems to be addresses should be considered wide, severe and persistent.

3.1.14 C.6. Horizontal or vertical integration

Description

Horizontal or vertical integration aims at changing the ownership structures of entire firms; it foresees to merge entire companies horizontally and/or vertically. Following the literature by Coase (1937), Williamson (1975) and Powell (1990), ownership integration is the ultimate answer to align incentives. The same holds here.

We note an important difference with joint ventures as in section 3.1.12. A joint venture shares ownership of a specified project. However, as the project has different owners, incentives can still be misaligned and profit-sharing rules would be required to allocate costs and revenues. In contrast, with full ownership integration of entire firms, there is only one owner and thus profit-sharing rules are no longer required and incentives are aligned per definition.

Horizontal integration primarily aims at companies in different sectors and addresses the WSA-level cross-sectoral approach. Horizontal integration can also be in one and the same sector, if for instance different network operators in one level in the value chain merge. Horizontal mergers of firms in the competitive stages in the value chain can have detrimental effects on competition and may require approval of competition agencies. Vertical integration aims at integration within the value chain. This can concern different successive network levels, which addresses the WSA-level whole-network-approach. But also, vertical integration can be between a network and network user; this addresses the WSA-level whole-chain-approach. For the latter, we have to distinguish. First, vertical integration is not reasonably feasible between the network operators and most network users, if these users are not part of the production process in the value chain, for instance households; we exclude this case. Second, vertical integration between the network and successive stages in the value chain, e.g. retail or trade. This option is feasible, but may be in conflict with unbundling polices. The value chains in gas and electricity have been unbundled to separate the monopoly networks from competitive stages (like retail), to avoid discriminatory leverage of market power and to promote competition. In a way, vertical integration would be re-integration and would quickly reach the limits of current regulation. We note explicitly, that we do not intend to reverse unbundling; we merely point out conflicting goals: unbundling promotes competition, but possibly at a loss of coordination (cf. Brunekreeft, 2015).

Assessment

Theoretically, effectiveness of horizontal and/or vertical integration to address coordination and cooperation problems is high. Clearly, ownership integration would address the coordination and incentive problem, but possibly at high costs and it would be a radical step.

Effectiveness will be higher than with joint ventures. With a joint venture, as there are different owners in the background, cost-revenue-sharing requires precise rules and allocation keys. This would be a major difference here: ownership is completely integrated, and therefore cost-revenue-sharing rules are not required; it goes to one and the same owner.[8]

Effectiveness is surely high, as incentives are aligned, if there is one and the same owner. Yet, there is a natural limit to the effectiveness. In many cases, ownership integration would not be feasible: a network company cannot merge or is unlikely to merge with various types of network users (e.g. households). Therefore, application to the WSA-level whole-chain-approach will be limited.

Implementation costs are high. The set-up costs to merge entire companies are likely disproportionally high compared to the problem at hand.

More importantly, political acceptance is likely low (especially in Brussels), as it would question and possibly violate the policy on network unbundling. In many cases, the network companies are directly or indirectly involved. With vertical integration (whole-chain-approach), unbundling rules will be violated quickly. With horizontal integration (cross-sectoral-approach), unbundling is economically not much of an issue, but nevertheless, the authorities seem to be quite suspicious on such potential extension of the monopoly power of the network. Most likely thus, cases of vertical and horizontal integration will be subject to lengthy and costly legal process for clearance.

Overall, this option is a truly big step. If regulated network companies or competing companies are involved, authorities (regulators or competition agencies) will have to approve the process. Nonetheless, in exceptional cases (with clear and large benefits) this may be a beneficial option.

[8] Of course, a further allocation emerges when profits need to be allocated to the company's shareholders. This is standard procedure. We disregard this case here.

3.2 Discussion

How to apply the measures presented in section 3.1? Are they substitutes or complements?

When dealing with an energy infrastructure project, we propose that stakeholder interactions can be distinguished by four types of coordination problems. The choice of an instrument from section 3.1 should be guided by the specific problem type in order to enhance cooperation among the stakeholders involved. It is important to note that poor stakeholder coordination might stem from more than one type of coordination problem. Therefore, multiple policy instruments may be required to address the issue. Apart from that, as discussed in section 3.2 on several occasions, more instruments might need to be combined (e.g. cost-revenue-sharing with incentive mechanisms) to effectively address the coordination problem at stake.

One common source of coordination problems in energy infrastructure projects is insufficient information or information asymmetries about the external effects of stakeholder performance and its impact on the project outcome. We refer to these as information problems. Information problems have been extensively discussed at the whole-network (cf. CEDEC et. al. 2019) and cross-sectoral levels of WSA (cf. dena 2020, ENTSO-E & ENTSO-G 2018). Therefore, instruments that facilitate information exchange among stakeholders are most effective in addressing these problems.

Cooperation problems can also arise from misaligned incentives, i.e., when actions driven by individual stakeholder incentives diverge from those that benefit the entire stakeholder group. Incentive problems have been identified across all levels of the WSA (cf. Pechan et. al 2023, ETIP SNET 2023, Palovic 2022). They are best tackled by mechanisms that can redistribute the allocation of costs or benefits within the group of cooperating stakeholders.

It is crucial to understand that both incentive- and information-problems can occur during the investment and operational phases of an energy infrastructure project. The nature of stakeholder interactions differs between these two phases. The investment phase is marked by a single or a few significant stakeholder decisions, while the operational phase involves numerous repeated decisions, potentially at very high frequencies. This difference in the frequency of stakeholder interactions necessitates different coordination mechanisms for each phase.

Table 3: Overview of distinct coordination problem types in energy infrastructure projects

	Investment phase	Operation phase
Information Problem	Type I	Type II
Incentive Problem	Type III	Type IV

Source: own table

Table 3 provides an overview of this. In addition to the type of coordination problem, other case-specific factors are likely to influence the choice of a policy measure. For instance, the cost of implementing the instrument should not surpass the benefits of improved stakeholder coordination. Similarly, the number of stakeholders to be coordinated can affect the implementation cost of the instruments reviewed in section 3.1, and thus may influence the selection of the instrument.

We have classified the policy measures from section 3.1 according to the two main criteria: effectiveness and ease of implementation. In the analysis in section 3.1, these two criteria turned out to be dominant; other criteria only played a supporting role. Effectiveness indicates whether the policy measure achieves the goal of addressing the coordination problem. Ease of implementation indicates whether the measure can be implemented with reasonable effort. This takes into account practical implementation (including network regulation), political acceptance and legal adjustments and concerns authorities and companies.

Figure 5 depicts the classification. The classification provides a comparative impression of what works and what does not; this is inevitably a simplification and reduces the analysis to only a few key points. A more differentiated, but non-comparative analysis has been provided in section 3.1.

It might actually be informative to differentiate the classification below, according to the two dimensions set out above in Table 3. To avoid too much complication in exposition, we have decided not to include this in the figure, but will address these dimensions where applicable in the text below the figure.

The figure has been constructed such that the measures in the top-right corner are most promising, while the measures in the bottom-left are more difficult on both accounts and are, therefore, less promising. To make the figure intuitive, we have used the criterion of “ease of implementation”, such that high is on the right side and low on the left side, meaning that measures on the right side are relatively easy to implement. The scales are relative; “low” and “high” have no absolute meaning; the figure merely intends to make a relative comparison.

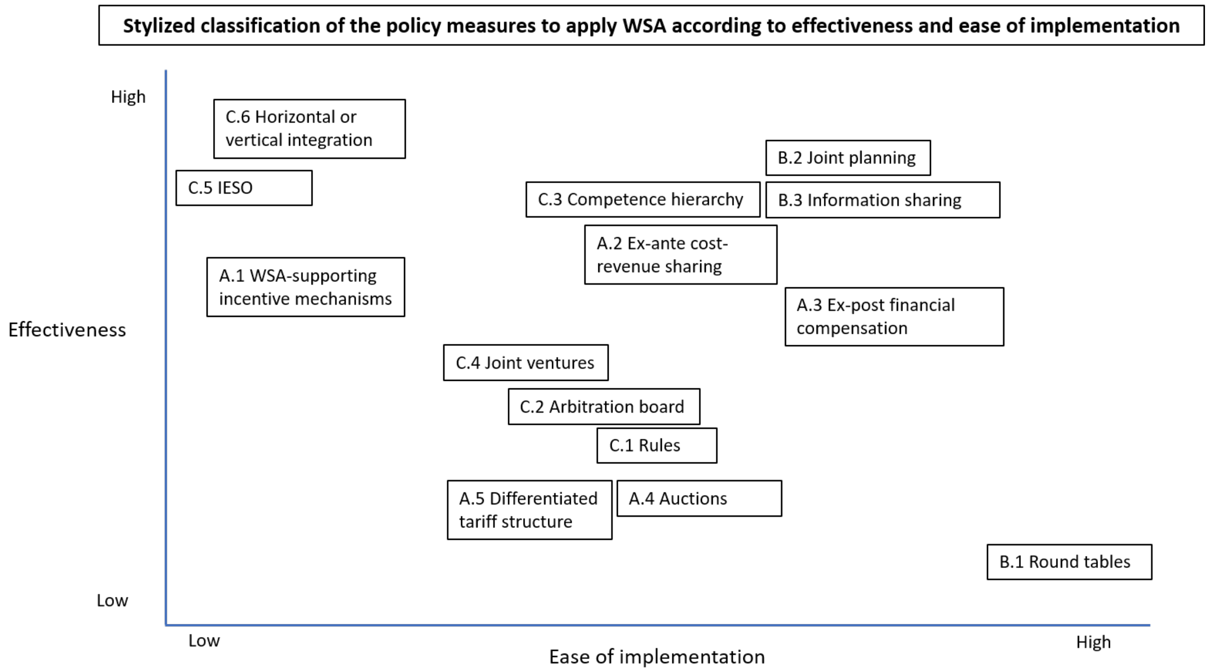

Figure 5: Classification of policy measures to address coordination problems according to effectiveness and ease of implementation

Source: own figure

In the top-right corner, we find a small group of particularly promising policy measures.

Foremost, we find B.2 Joint planning and B.3 Information sharing in the top-right corner, indicating high effectiveness and high ease of implementation. Joint planning and information sharing explicitly aim at coordination; this is the main idea. Therefore, we would assume high effectiveness. The difference between the two is basically that joint planning would be most useful for the investment phase, and information sharing for the operational phase. Joint planning and information sharing are already widely used in business in general and in energy infrastructure specifically, such that we can rely on experience. For very specific coordination problems, both will have to be adapted though, which may be challenging at times.

Also in the right top corner, we find A.2. Ex-ante cost-revenue sharing and A.3. ex-post financial compensation. Both are well suited to deal with cooperation problems and to realign incentives; in fact, at least partly, this is the main aim of such measures. In our view, in one way or another these measures will be necessary to address many coordination problems. Effectiveness of these two measures is likely slightly less than B.2. and B.3 above for the following reasons. First, precise calculation of external cost and benefits can be challenging and may impede effectiveness, if they are not accurately included. Second, especially for B.3, ex-post sharing may have a limited effect on previous decisions. Lastly, the coordination problem is not always monetary, or cannot always be addressed with side-payments. Implementation seems challenging, but then again, there exists wide experience with cost-revenue-sharing approaches and negotiations in business in general; therefore, in our view, implementation seems manageable.

Lastly, C.3 competence hierarchy is also located in the top-right corner. This is clearly an important option. In case of doubt, and where processes are technically critical, one party has a mandate to decide and others follow. This is clearly effective and is applied in practice. In our view, however, it is a measure of last resort for selected cases, as it limits the freedom of choice of the stakeholders. Practical implementation will be straightforward, but it may require legal changes; presumably, the mandate will have to be laid down in a formal agreement or ordinance. Legal changes may impede the ease of implementation.

In the bottom-right corner (i.e. high ease of implementation with low effectiveness), we placed B.1. round tables. We actually value the round tables highly, especially as they are easy to implement. Stakeholders agree to meet and talk in an informal setting; this can be done any time in any way. The downside is that they are non-binding talks in which no decisions are made; no stakeholder has to agree to anything. In that sense, in our view, round tables, as useful as they may be, are not effective in addressing coordination problems. The role of the round table is building trust and we would expect to see round tables on a voluntary basis to prepare for more formal meetings.

In the top-left corner, which indicates high effectiveness and low ease of implementation, we placed two measures: C.6 Horizontal and vertical integration, C.5 IESO. In our view, horizontal and vertical integration and the IESO are highly effective to address coordination problems: information, incentives and decisions are aligned by definition within one and the same hierarchy. There are limitations, however, where private end-users are involved in the coordination problem. In these cases, (ownership) integration would not be possible. Moreover, vertical integration may reach the limits of network unbundling. Notwithstanding high effectiveness, implementation may be a hurdle. Transaction costs of these measures to make the organizational changes will be high. The measure may be disproportionately large as compared to the problem; it depends very strongly on the severity of the coordination problems whether the benefits outweigh the cost. Moreover, depending on the specific country, the measures may require legal changes.

Somewhat lower in the top-left corner, we find A.1 WSA-supporting incentive mechanisms. We stress that for the figure we explicitly limit ourselves to incentive mechanisms which are used to address coordination problems, and exclude more general incentive mechanisms. As explained above in section 3.1.1, general incentive mechanisms, which tend to strengthen profit-motives, can actually worsen the coordination problems. Therefore, we limit the figure to WSA-supporting incentive mechanisms. Effectiveness is relatively high because realigning incentives is precisely what WSA-supporting incentive mechanisms are designed for. On the other hand, it seems unrealistic to include all external effects in a systematic set of WSA-supporting incentive mechanisms; the measure will inevitably be incomplete, which limits effectiveness. Moreover, to our knowledge, there is almost no experience, neither theoretical, nor practical, with WSA-supporting incentive mechanisms. For these reasons, implementation will be highly challenging.

In the middle, where both effectiveness and ease of implementation are moderate, we placed a group of five measures, which can be subdivided into two subgroups.

The first group comprises A.5 differentiated tariff structures and A.4 auctions. We have placed these two measures relatively low in the figure, indicating relatively low effectiveness. This may be somewhat surprising, as these mechanisms are well-established market-based instruments to guide incentives. We fully agree to this as a general principle. However, the application in our context of quite specific whole system coordination problems is limited. In many cases, neither differentiated tariff structures nor auctions can actually be used. Effectiveness is limited to those whole system coordination problems, where the measures can be applied at all. We see that this is the case in whole-chain coordination problems. Moreover, even if experience with differentiated tariff structures and auction design is really wide in general, practical implementation for our WSA-cases is not always straightforward and, in fact, in some cases really challenging. And especially innovative network tariffs may face public and political opposition.

The second group consists of C.1 rules, C.2. arbitration board and C.4 joint ventures. In our view, context-dependent and at an ad-hoc basis, these measures can contribute usefully to addressing individual coordination problems. Yet, their scope will be limited. Despite this, the ease of implementation seems moderate, so it seems worthwhile to consider these measures. The role of these measures is complementary to other measures. Of the three, joint ventures may be the most promising to address very specific cases.

4 Application to selected use cases

Section 3 above introduced a detailed presentation and discussion of various policy measures to apply a whole system approach (WSA) and thereby improve coordination (information exchange) and cooperation (align incentives). Whereas section 3 provides a discussion on an abstract level, section 4 illustrates a selection and combination of these policy measures more practically with the help of three use cases. These use cases are:

- Use case 1: Network operator coordination with respect to a DC-corridor
    - Use case 1A: Coordination problem with DC-corridor investment
    - Use case 1B: Coordination problem associated with DC-corridor operation
- Use case 2: Location decision for flexible load
- Use case 3: Network development coordination between gas and electricity networks

We have selected these three use cases as they each cover coordination problem in one of three WSA-levels.

4.1 Use case 1: Network operator coordination with respect to a DC-corridor

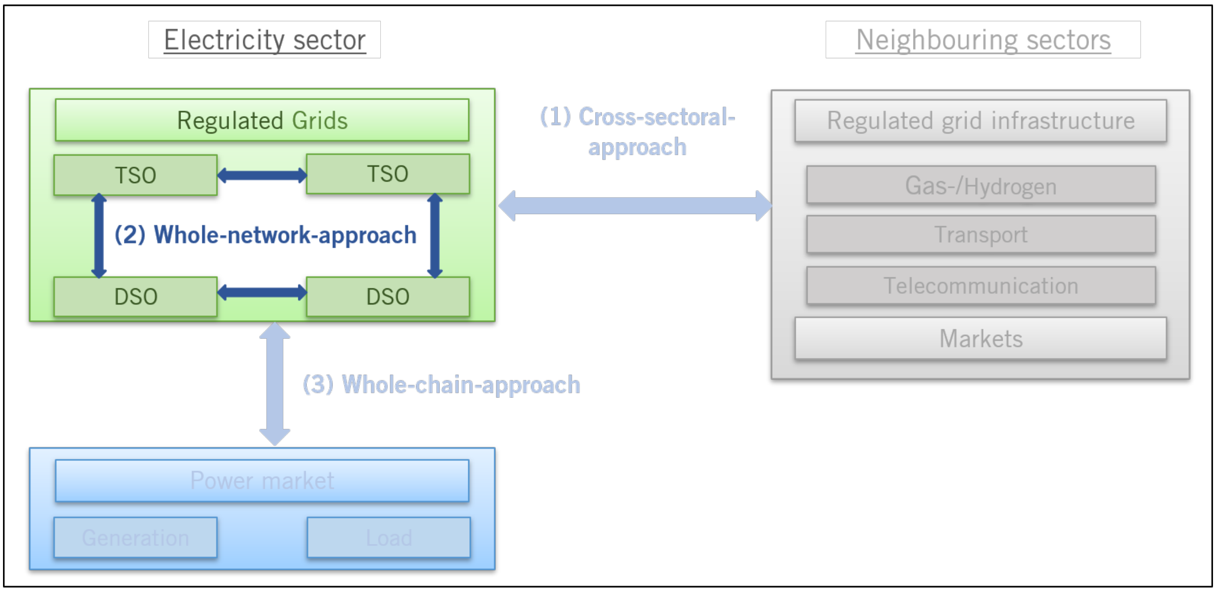

Figure 6: WSA-level "whole-network-approach"

Source: own figure, based on CEER (2020)

In the first use case, we discuss a DC-corridor that connects power network areas managed by two different transmission network operators (TSOs). This use case focusses on the WSA-level whole-network-approach as highlighted in Figure 6.

DC-corridors are network components primarily used to transport electricity over long distances, due to relatively low line losses. In contrast to AC-power lines, power flow in the DC-corridor can be influenced by the TSOs. Given that the capacity of DC-corridors is relatively high compared to the rest of the system, this flexibility allows TSOs to readjust power flows in the system's AC-lines. In the case of Germany, this is used to relieve congestion in the AC-system that is caused by regional imbalances of demand and (renewable) generation. DC-corridors can be also used to reduce power network losses.

The following example, depicted in Figure 7, illustrates the effect of a DC-corridor on congestion. Assume two transmission networks, N(orth) and S(outh), that are connected by an AC-line (in grey) and a DC-corridor (in blue). In a given hour, nodes A, B and C are net generators while the node D is the net consumer, i.e. the sink towards which all net generation in the system is flowing. Let us assume that both network operators experience intrazonal congestion, i.e. the AC-lines within each network are overloaded (as indicated by the lightning signs in Figure 7(a)). There are two alternative strategies to address congestion: (1) intrazonal redispatch by each TSO, i.e. power production within each network area is readjusted (see Figure 7(b)), or (2) interzonal redispatch, i.e. power flow over the DC-line from N to S is increased (see Figure 7(c)).

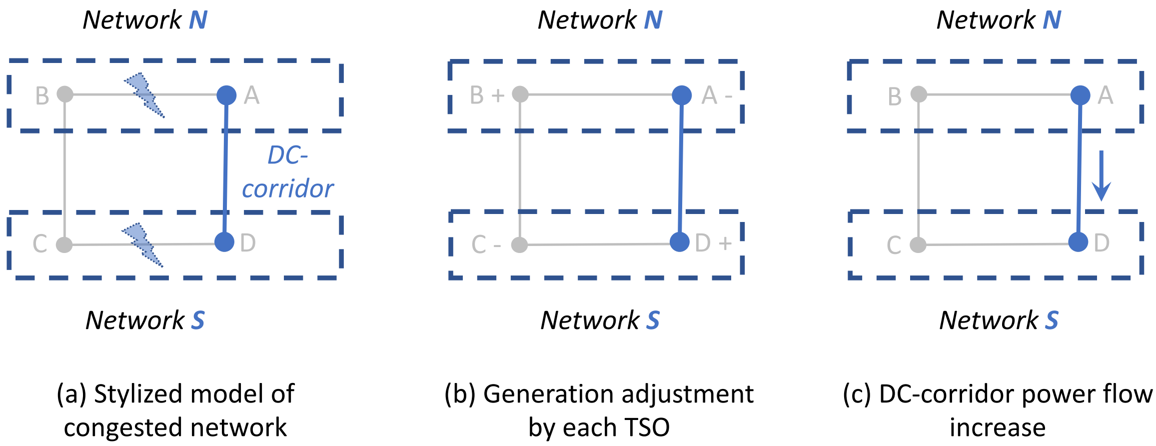

Figure 7: Illustration of a DC-corridor effect on congestion [AC-lines in grey, DC-corridor in blue]
Source: own figure

While congestion can be resolved by both remedies, each implies a different cost distribution. This is relevant when one considers that network operators have an incentive to minimize their own cost. Such cost-minimization, without additional regulatory measures, might make coordination among network operators difficult or inefficient.

Below, we introduce two such coordination problems. In sections 4.1.1 and 4.1.2, we focus on a TSO that decides on building a DC-corridor; this focusses on the *investment* decision. This decision is likely inefficient if the external effects of the DC-corridor on the other network operators in the system are not properly internalized by the deciding TSO. In sections 4.1.3 and 4.1.4, the focus lies on the *operation* of a DC-corridor. This is suggested to redistribute the cost of power network losses between transmission network operators and herewith to motivate strategic behaviour. While staying at a relatively abstract level in the analysis, these use cases might emerge among multiple TSOs within one country like Germany (with 4 TSOs) or with respect to cross-border DC-interconnectors.

4.1.1 Use case 1A: Coordination problem with DC-corridor investment

The coordination problem in this use case is straightforward. We assume that one of the two TSOs makes the investment decision on building the DC-corridor. The coordination problem in this case arises as the decision of the investing TSO1 has effects on TSO2. In the decision-making, TSO1 considers only the own costs and benefits (e.g. reduced redispatch costs or network losses) resulting from the investment. For example, TSO1 considers investing in a DC-corridor with a cost of 100 and a benefit for TSO1 of 90. However, the DC-corridor also reduces costs of TSO2, e.g. by 30. Although the overall net benefit of the corridor is positive (90 + 30 – 100 = 20), TSO1 will decide against it if bearing all the costs, because the net benefit for the TSO1 alone is negative (-10). The same holds for TSO2 standing alone. Only if the two TSOs cooperate and share costs and revenues, the investment will take place.

4.1.2 Use case 1A: Policy measures promoting efficient DC-corridor investment

For this use case 1A, focusing on the investment decision, we propose the following core policy package:

- A.2: Ex-ante cost-revenue-sharing.
    - Addition to A.2: A.1 Incentive mechanism
- B.2: Joint planning
    - Addition to B.2: Information sharing

The first policy measure is straightforward: cost-revenue-sharing will realign the incentives. In the numerical example above, TSO2 should contribute between 10 and 30 to TSO1. In which case TSO1 would build the corridor and both TSOs and society would have a net benefit.

A recent example from the electricity sector is the proposal for cost-benefit-sharing of cross-border renewable energy cooperation projects (EU-commission, 2022). An example from electricity networks would be the notion of cross-border-cost allocation (CBCA), a European mechanism to promote investment in projects of common interests (PCIs), worked out by ACER (2015). The key idea of a CBCA is that interconnectors typically have cross-border benefits for parties who do not incur the costs. If the cost-bearing parties do not consider these external benefits, not all interconnectors with overall net benefit will be built. The CBCA-rule aims to internalize this externality.

Transferring the CBCA-rule to our policy here, we would call this CNCA: cross-network-cost-allocation. This can be done widely, to include many external effects, but this will cause high transaction costs; presumably, transactions will be too high for many small cases. We suggest to focus on well demarcated single large cases, where the problem is well specified. Therefore, we suggest to focus on project-specific cost-revenue-sharing.

In addition, it is important to align the regulation. The numerical example above implicitly assumed that the benefits are revenues for the TSOs. This will normally not be the case. The revenues for the TSOs can be totally independent of the benefits for society and depend strongly on regulation. If the costs for the corridor are fully passed through to network charges, the TSOs will not be interested in any sharing mechanisms and the system will be ineffective. It may be necessary to implement some kind of incentive mechanism to support this policy measures.

To address information asymmetries, we also suggest joint planning for this use case, which we specifically call a "4-TSO Network Development Plan". "4-TSO" because of the four TSO in Germany; in another country this would be different. Joint planning, as used here, focusses on coordinating investment decisions. This is not a System Development Plan, precisely because this is about electricity networks only; in fact, it is only about TSOs, and therefore TSO-TSO-coordination. Our suggested limitation to the four TSOs is a minimal approach: for this use case, including further stakeholders would unnecessarily complicate the process.

In the context of Germany, the four TSOs are well positioned to design a 4-TSO Network Development Plan. The TSOs have the information and the knowledge and they are the investors. Moreover, such a joint plan already exists. Following § 12b of the Energy Act (EnWG), the TSOs are required to design a joint Network Development Plan every two years, which covers the subsequent 10 to 15 years.

There will be a small differentiation if the use case is not about a national corridor, but instead on a pan-European cross-border interconnector. Joint planning would then have to be covered by the Ten-Year Network Development Plan (TYNDP) designed by the association of European TSOs ENTSO-E.

In addition to joint planning, information sharing may be necessary. Various stakeholders (TSOs or countries) may have the incentives to understate benefits. Institutionalized transparent information sharing of costs and benefits may help to avoid flawed incentives.

4.1.3 Use case 1B: Coordination problem associated with DC-corridor operation[9]

The amount of power losses, and their respective cost, depends on the amount of power flowing through an AC-line. Given that a change in the DC-corridor operation is capable of changing the distribution of power flows in the AC-system and herewith the allocation of power losses among the TSOs, operational decisions of one TSO (TSO1) are likely not only to affect the network area of this TSO, but also the performance of network areas managed by other TSOs (TSO2) and vice versa. This effect, be it positive or negative, is initially an external effect to the optimization of the TSO1, but might cause a reaction of the TSO2 though. Put differently, the cost allocated to TSO1, i.e. the performance of the TSO1 network area, not only depends on the decision of TSO1, but also on the decision of TSO2. Similarly, the cost allocated to TSO2 is defined not only by the own decision, but also by the decision of the TSO1. This setup is susceptible to strategic interactions that are studied by the non-cooperative game theory. In other words, it is rational for both TSOs to compare different behavioural strategies, with cooperative behaviour representing only one possible strategy among many.

[9] This is a summary of a use case described in Flachsbarth et. al. (2024). The paper is output of this research project and provides a detailed analysis of this use case by using a German electricity network model.

Let us demonstrate this argument with a simple numerical example. For a given hour, assume TSO1 minimizes own network losses by maximizing the DC-corridor utilization, resp. demand DC-corridor to operate at maximum capacity (100%). At the same time, TSO2 minimizes own network losses by minimizing the DC-corridor utilization, resp. reaches the lowest network losses when the DC-corridor does not operate (0%). Furthermore, assume the power line losses of the overall system to be minimized, i.e. to reach the social optimum, when the DC-corridor operates at 80% of its capacity. In case of a disagreement, i.e. when the two TSOs demand different operation levels, the DC-corridor is operated at the average of the TSOs demands (see Flachsbarth et. al. (2024) for more detail).

Do the TSOs have an incentive to cooperate and adopt the socially optimal solution? Table 4 summarizes TSO payoffs for the different scenarios that might emerge.

Table 4: Operation of DC-corridor resulting from different TSO operational strategies

Numerical example on the utilization of a DC-corridor		TSO-1	
		Cooperate (Demand 80%)	Defect (Demand 100%)
TSO-2	Cooperate (Demand 80%)	80%	90%
	Defect (Demand 0%)	40%	50%

Source: own table

When TSO2 is assumed to cooperate, i.e. demands 80% utilization of the DC-corridor, it is beneficial for TSO1 to defect and demand 100% DC-corridor utilization. Assuming TSO2 now to follow a different strategy and to defect (demand 0%), it is still the best strategy for TSO1 to defect. This means that defection is the dominant strategy for the TSO1. For TSO2, it is the best strategy to defect when TSO1 defects. Defection is actually the dominant strategy also for the TSO2. Therefore, the TSOs in the given example should not be expected to cooperate on the operation of the DC-corridor unless the cost-allocation is altered by an institutional setting.

4.1.4 Use case 1B: Policy measures for coordinated DC-corridor operation

In contrast to use case 1A, which focusses on the investment decision, use case 1B focusses on the operation of the DC-corridor, given that the corridor exists. For use case 1B, we propose the following core policy package:

- A.3: Ex-post financial compensation
- C.3: Competence hierarchy
    - Additional to C.3: B.3.: Information sharing

To align incentives by cost-revenue sharing we propose a formalized ex-post financial compensation mechanism. This is in contrast to use case 1A, where we proposed an ex-ante cost-revenue-sharing mechanism. The structure of use case 1B calls for ex-post financial compensation for the following reasons. Precisely because this use case focusses on operation, given that the corridor exists, detrimental effects on investment in irreversible assets of ex-post compensation is not a problem here. Moreover, in use case 1B, we would expect many frequent and repeating coordination problems, which will be better addressed in a one-off all-inclusive negotiation round after the events. Lastly, in the operation of the DC-corridor, we expect that many types and frequency of strategic interactions are not known ex ante. These events are important for the pay-offs, and therefore decisive for compensation payments. Under uncertainty, these can best be addressed ex post.

Ex-post compensation can likely internalize incentive problems to a large extent, but is unlikely to resolve all incentive problems, and more importantly, ex-post compensation may not address urgent problems, which require immediate and unambiguous decisions. Thus, in addition, this use case can be addressed effectively with competence hierarchy, say, some TSO has a mandate to decide in case of doubt or conflict. The mandate can be provided by law or by mutual agreement among relevant stakeholders, here, the TSOs. In our view, competence hierarchy alone may not adequately address the problem. The competence hierarchy may well make effective decisions, but these may not well reflect the parties' financial interests and thus overall the decisions of a competence hierarchy may be suboptimal. Therefore, we would restrict the competence hierarchy to urgent, high impact cases only.

In fact, in Germany, a competence hierarchy among the four TSOs exists (cf. also section 3.1.11).[10] Redispatch is done for Germany as a whole. There is a central optimizer that determines the redispatch for Germany. Each TSO receives the instruction from this optimization and only requests redispatch facilities that are connected in its own network area. This network operator is referred to as the instructing network operator (or connecting network operator). However, since there is a holistic optimization, facilities outside the network area are also used to resolve the bottlenecks. This means that the individual TSOs do not solve the bottlenecks in their own network independently but wait for the instructions from the central optimization. The optimization consists of various planning steps that follow one another and build upon each other. The planning process begins a week in advance and becomes increasingly fine-grained as one is approaching calling on the redispatch facilities virtually in a real time. Theoretically, a TSO can deviate from the instruction, but then this TSO must provide an adequate replacement. Finding an equivalent replacement is difficult because this is a replacement for an overall optimal system. In practice, the TSOs usually do not deviate from the results of the optimizer. More specifically, deviations are supposed to occur only due to unexpected technical defects.

Additionally, we see a role for institutionalized information sharing. Flawed incentives to cooperate can be limited to some extent, if the process, including data and modelling, is

[10] This information was provided in interviews we held with TSOs in the course of this study.

transparent. Transparency can be limited to relevant stakeholders, but can extend to relevant third parties, including, of course, especially the regulator.

Lastly, we note that installing an ISO (see C.5. in section 3.1.13) would not be a good option here. Installing an ISO would be overshooting; it may address the problem, but the roles and responsibilities of an ISO cover far more than that. Moreover, installing an ISO would require significant legal changes, not justified by the severity of the problem.

4.2 Use case 2: Location decision for flexible load

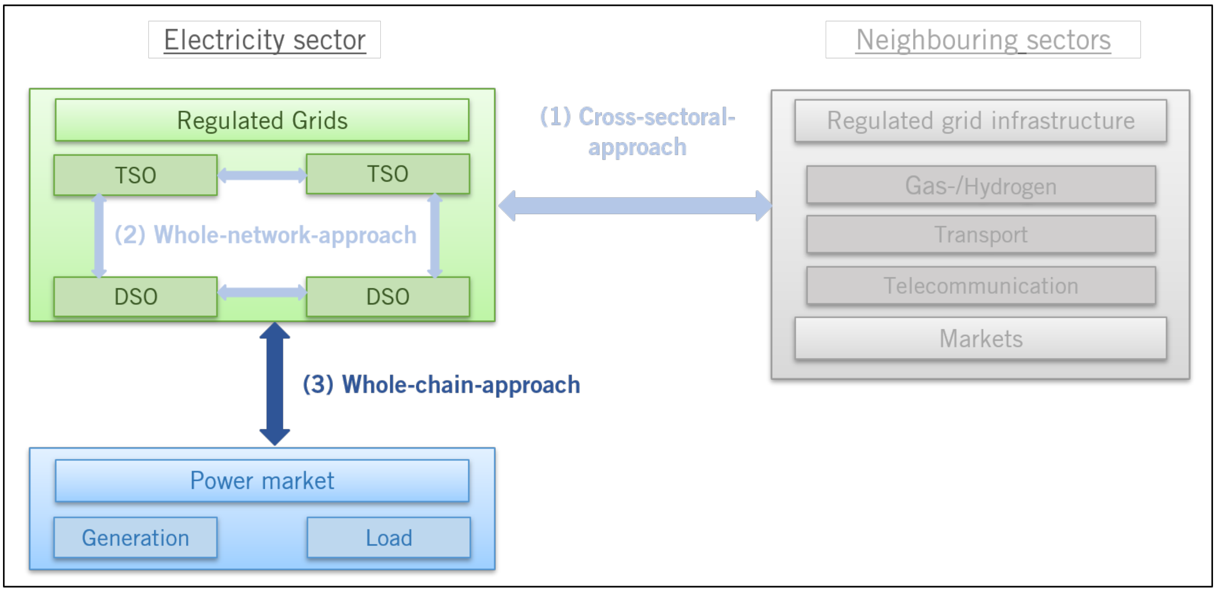

Figure 8: WSA-level "whole-chain-approach"

Source: own figure, based on CEER (2020)

While the focus of the previous use case was on the coordination of regulated infrastructure operators, this use case focuses on the coordination between regulated network operators and non-regulated market actors. Thus, this use case focusses on WSA-level whole-chain-approach.

The unbundling provisions require the far-reaching independence of grid operators from other areas of energy supply activity. Network unbundling promotes competition between network users but reduces coordination between network and network users. As a result, promoting explicit coordination between grid and market activities is particularly critical.

4.2.1 Coordination problem of use case 2

Decisions on the construction and operation of generation and consumption plants, including electrolysis plants, are generally reserved for market investors and are therefore based on the market revenues of the plants. At the same time, the regional distribution (and operation) of the plants has a significant influence on the demand for electricity grid infrastructure. This means that grid bottlenecks can be either increased or reduced by the operation of these plants, or grid expansion can be either necessary or redundant.

A stylized example and Figure 9 illustrate. Assume an investor of an electrolysis plant, who can decide between two locations, A and B, of a network. Location A is in a region with net generation, whereas Location B is in a region with net consumption of electricity. Thus, power typically flows from A to B and the connecting line is regularly congested. The electrolysis plant increases consumption at the respective location. If it was built at location A it would reduce the power flow to B and hence also congestion, and vice versa if it was built at location B, which would instead increase the need for grid expansion.

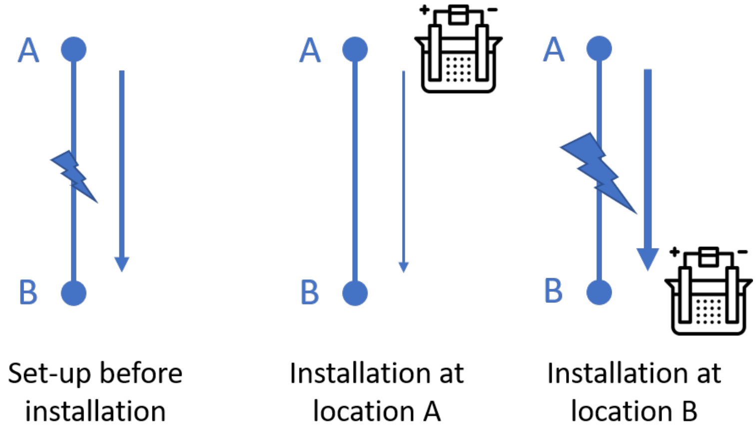

Figure 9: Stylized network model of two connected locations A and B before installation of electrolysis plant (left-hand side) and effect of locational choice on congestion (middle: location at A relieves congestion; righthand side: location at B increases congestion)

Source: own figure; free icon from flaticon

A current study for Germany in 2030 shows that a regionally uncoordinated expansion and operation of 9.5 GWel of electrolysers would increase redispatch costs by 17 %, while a spatially coordinated expansion and operation of this electrolyser capacity can even lead to savings of up to 20 % (Vom Scheidt et al., 2022).

In this use case, we consider the location decision of an electrolysis plant operator. Depending on this decision, the plant has different effects in the network operator's costs. Yet, as the electricity grid is assigned the "serving role", the network expansion and redispatch costs caused by a location decision are not considered: They are not included in the electrolyser operator's investment calculation in any way. The network operator concerned has no possibility of sending appropriate signals to the market actor to influence the choice of location in a way that benefits the grid. The grid expansion costs of the location decision therefore represent a classic external effect.

4.2.2 Policy measures for use case 2

The coordination problem in this use case, as described above, is actually well known and has been discussed a lot in the literature (cf. e.g., Baldick & Kahn, 1993; Brunekreeft, 2015). The key problem is that the network needs to send efficient signals to the network users for short-term and long-term network use. Surprisingly often, this is not the case.

For use case 2, we suggest the following core policy package:

- A.5.: Differentiated tariff-structures
- B.3.: Information sharing

First and most obviously, we suggest the use of more differentiated tariff structures. As set out above in section 3.1.5, a wide set of options are available, for instance, dynamic peak-load pricing, zonal markets, nodal spot pricing, deep charging and capacity contracts. Theoretically and in implementation, they all have pros and cons (cf. e.g. Brunekreeft et al., 2005). It is nonetheless striking, how little use is made of such signaling instruments in practice. Network charges are predominantly seen as instruments to finance the network, not so much as signaling devices. Moreover, it is often claimed that price elasticity of network charges is low, such that effectiveness of differentiated network charges is low. Lastly, differentiated network charging can have wide distributional effects, raising political opposition. Nonetheless, we hold that differentiated tariff structures can significantly contribute to addressing coordination problems in the whole-chain context.

Differentiated tariff-structures will support informed decisions to improve overall efficiency, but will have only limited effect. In particular, stakeholders will need advance information to make informed decisions. Therefore, to address the information asymmetries, we further suggest a role for information sharing (section 3.1.8). The idea would be that individual network planning is such that network users actually know sufficiently far in advance what the TSOs are going to do, and perhaps more importantly, reverse, network users should announce their plans in advance. This requires some kind of institutional setting, in which the provision of information (when and in which form) is specified and is possibly made mandatory. The effect of information sharing alone will be limited, as it does not address the incentives.

This is not joint planning; it is “merely” information sharing, such that both sides can individually make advance planning. We note that joint planning is not a good option in this use case, simply because many stakeholders are general network users, for whom network use plays only a minor role is a larger process. More to the point, many network users are private households or small enterprises, who simply are not part of joint network planning.

The problem reminds of a similar discussion on what was called generation adequacy. Generation adequacy indicates whether there will be sufficient generation capacity, being existing capacity plus new investment minus decommissioning of generation plant, to meet demand plus a reserve margin. The forerunner of ENTSO-E, UCTE, annually estimated generation adequacy, typically some ten years in advance. The forecasts beyond 3-or-so years were typically pessimistic, which was a systematic phenomenon, due to a lack of information on new, unknown or un-declared additions and decommissions (cf. Brunekreeft, 2005). In the “old” world, before liberalization, generation plans (investment and decommissions) were by and large commercially non-sensitive information, which was provided way ahead; after liberalization, this information became commercially sensitive information, such that generators provided the information last minute and not always accurate. Consequently, UCTE changed the procedure and started to make estimates based on scenarios, which included commissions which were reasonably probable, trying to give an estimate of potential future developments. This approach reduced reliability of the estimates but added realism. The lesson here is that, certainly in a commercial world, details of information sharing matter.

4.3 Use case 3: Network development coordination between gas and electricity networks

The cross-sectoral approach focuses on the interaction between different sectors, also known as sector coupling. This is a wider field. In the use case, we focus on the coordination between the gas transmission system operators and the electricity transmission system operators.

4.3.1 Coordination problem of use case 3

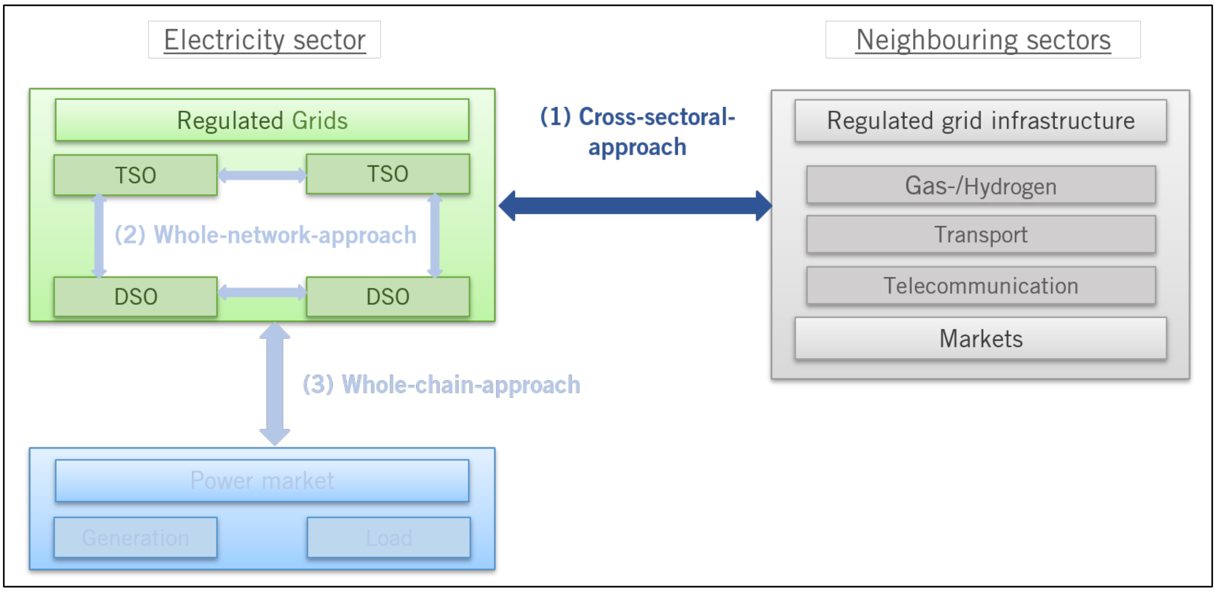

Figure 10: WSA-level "cross-sectoral-approach"

Source: own figure, based on CEER (2020)

In Germany, as in many other countries, electricity and gas network development planning has until recently been carried out in separate processes and the regulation of network operators still does not include any incentives for the coordination between the sectors. The need for cross-sectoral coordination is particularly evident regarding hydrogen (see ACER & CEER, 2021; EU, 2020). Currently, both on the European as well as the German level attempts are being made to better link the planning processes between electricity and gas networks (see Section 3.1.7). Compared to the European level, the integration of the planning processes of electricity and gas networks is less advanced in Germany. In the future, the focus lies on finding coherent assumptions for the sectoral development plans, through mutual harmonization of the input data used for creation of scenarios and infrastructure planning (from interview with dena experts; BMWK, 2023). So far, in development plans of electricity and gas infrastructure in Germany, for example, the spatial allocation of electrolysis plants is not explicitly harmonized. While the gas network operators base the allocation on market surveys, the power grid operators assume that allocation is predominantly close to consumption and partly grid-friendly (50Hertz et al., 2021; FNB Gas, 2021).

In this use case, we assume an electricity transmission grid operator and a gas transmission system operator in Germany against the background of a structural electricity grid bottleneck in the transmission grid, e.g. due to increased RE feed-in, and a demand for hydrogen in the South, which needs to be covered by an electrolysis plant either located close to consumption or close to RE power generation. This initial situation is illustrated in Figure 11 on the left-hand side.

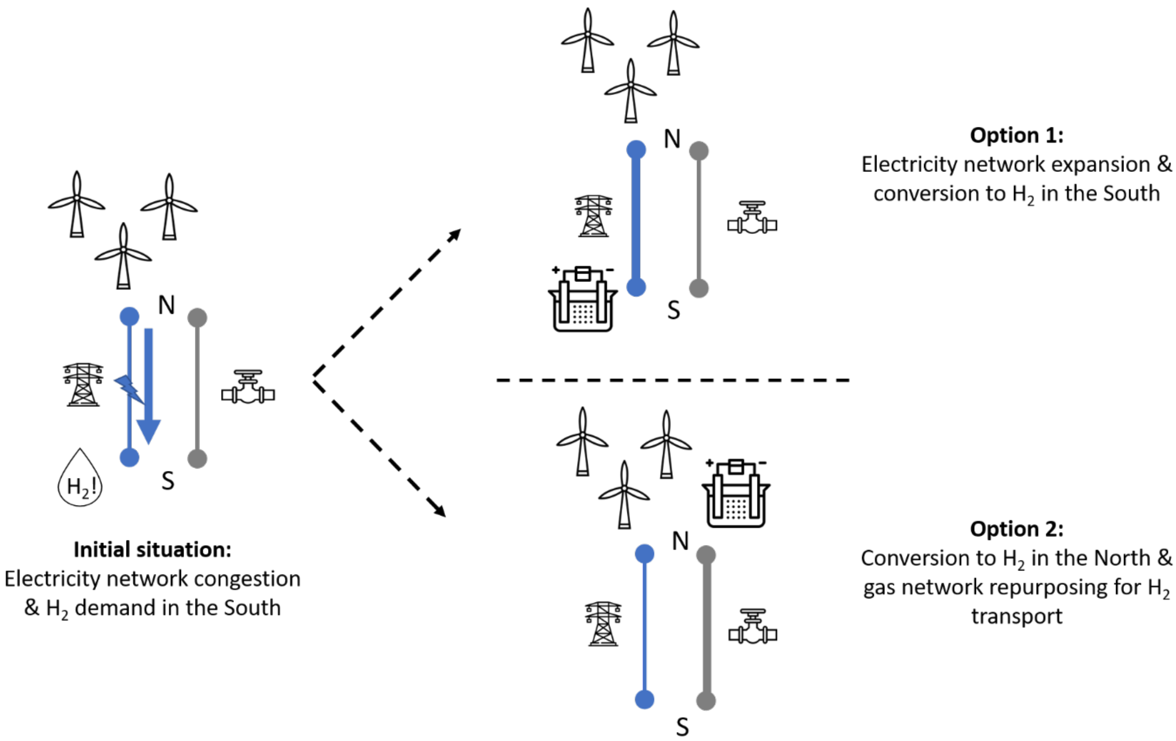

Figure 11: Illustration of the initial situation with structural bottlenecks in the electricity network and demand for H2 in the South (left-hand side) and two options to address them: Option 1 by expanding the electricity network (top right-hand side) and converting the electricity to H2 in the South and Option 2 by converting the electricity to H2 in the North and repurposing of the gas network for H2 transport (bottom right-hand side)

Source: Own figure, free icons from flaticon

We illustrate the coordination problem with a numerical example; the example is highly stylized in order to focus on the analysis of a coordination problem. We define the two options:

Option 1: the electricity TSO (henceforth: E-TSO) assumes electrolysis capacity to be built in the South addresses the congestion problem with network expansion of the electricity network. In this case, redispatch is no longer required, offshore wind in the North can produce, there is no need for the conversion of the gas network to transport H2 (in Figure 11 on the top right-hand side).

Option 2: congestion in the electricity network is addressed by electrolysis in the North, which requires conversion of the gas network to transport H2. This case requires an investor for the gas-H2-network, which we assume is the gas-TSO (henceforth G-TSO). In this case, the electricity network needs not to be expanded (in Figure 11 on the bottom right-hand side).

For the numerical illustration, we use the following costs and benefits:

Table 5: Numerical illustration for use case 3

Option 1: E-TSO		Option 2: G-TSO	
Saved redispatch cost	150	Saved redispatch cost	150
Cost of electricity network expansion	80	Cost of electrolysis in the North	20
Cost of electrolysis in the South	20	Cost of gas network repurposing	70
Welfare gain Option 1	50	Welfare gain Option 2	60

Source: own table

Both options fully address the congestion problem and cover the hydrogen demand, and thus save redispatch costs: cheaper offshore wind at low marginal costs in the North can be used, while generation capacity with high marginal costs in the South can be turned down, saving overall redispatch costs. We assume these savings to be 150 in both options.

Option 1 requires expanding the electricity network at a cost of 80 and investment in electrolysis in the South of 20. Net welfare benefit in option 1 compared to the initial situation would thus be 150 – 80 - 20 = 50.

Option 2 requires conversion of the gas network to transport H2 at a cost of 70 and investment in electrolysis in the North of 20. Net welfare benefit of option 2 compared to the initial situation would thus be 150 – 70 - 20 = 60.

In this stylized numerical example, option 2 has lower costs and thus higher net welfare benefits and is therefore more beneficial for society.[11] Therefore, the incentives for the investors should be such that option 2 is the outcome. Whether this actually happens, is a coordination problem. To see this, we distinguish three cases.

Case 1: Assume that network users, who pay for their respective networks, decide. Assume for this, as is actually the case in Germany, that redispatch costs, are passed through into the network charges of the electricity network. In option 1, the electricity network users have a net benefit of 70 (150-80), whereas the gas network users are unaffected and have a net

[11] Obviously, this holds only for this numerical example for analytical reasons; in real-world cases, the numbers may well be reverse.

benefit of 0. In option 2, the electricity users have a net benefit of 150, while the gas network users have a net cost of 70. Therefore, the electricity users would prefer option 2, but clearly the gas users would prefer option 1.

Case 2: Assume that the TSOs decide and their goal is to minimize own costs, following the incentive regulation. Assume furthermore, following the regulation, that redispatch costs are simply passed through into network charges. This case is straightforward. Both the E-TSO and G-TSO would not want to invest and would rather leave the problem to be resolved by the other side. If they do not cooperate, presumably, the E-TSO is responsible to resolve the problem in the electricity network and will expand the electricity network, which is the option with the lower welfare benefit.

Case 3: Assume again that the TSOs decide but that their goal is to maximize profits by capital expenditure. Depending on the details of the regulation, the TSOs may have incentives to increase rather than decrease capital expenditure, in which case, both TSOs would actually want to make the investment. The outcome of this case depends on who moves first. If the E-TSO is primarily responsible to resolve congestion in the electricity network, the E-TSO will expand the electricity network, even though converting the gas network instead would result in lower costs.

In all three cases of this admittedly highly stylized example, the non-cooperative outcome does not maximize overall welfare.

4.3.2 Policy measures for use case 3

For the coordination problem in use case 3, we suggest a core policy package with the two measures.

- B.2: Joint planning
    - Additional to B.2: B.1. Round table
- A.2: Cost-revenue-sharing
    - Additional to A.2: A.1. Incentive mechanisms

In section 3.1.7, we distinguished sector-specific network development plan (NDP) and cross-sectoral system development plan (SDP). The former sets out the investment plans for a specific sector only. The latter outlines and coordinates a development plan for several sectors. Clearly thus, in this case, with joint planning, we aim for a cross-sectoral development plan. This could be part of a larger SDP as suggested by dena (2020). Alternatively, it could be a bilateral agreement between electricity- and gas-NDPs. If these are developed individually, it would be necessary to coordinate the interfaces between the two. For few isolated cases, this ad-hoc coordination may suffice, but the question emerges, do the parties know the need for coordination and therefore the need for talks in the first place? One might consider the possibility of round tables to exchange the information to make sure that the need for coordination is apparent at all.

Still, even if the parties know the need for coordination, they might not have the incentive to cooperate, as was illustrated in the numerical example above. This sets the case for side-payments, or called differently, cost-revenue-sharing. As is well-known from the Coase theorem, it depends on initial property rights who will compensate whom to reach an efficient outcome. This also applies to the numerical example above, but it goes beyond the scope here to work this out in detail. Basically, we see that the electricity users gain from reduced redispatch, but not the gas users. Intuitively, we would expect that electricity users, possibly represented by the E-TSO, compensate the gas users, to convince the gas users, possibly represented by the G-TSO, to make the investment. This use case actually provides an argument for cross-sectoral cross-subsidies: electricity (network) users may have to pay for an investment in the gas network.

The third case above, where we assume that the TSOs decide and their goal is to maximize profits by capital expenditure, creates a challenging regulatory problem. In this case, the economic approach would be to compensate the E-TSO for not making the investment in the electricity network, but instead allow the gas side to make investments. For regulation this is difficult. Implementing such incentive scheme is challenging, because the counter-factual reference value has to be set. Quite possibly, the firms would have a perverse incentive to make up fake-projects. More importantly, as a rule, incentive schemes are within one and the same regulated firm. Not so here: the E-TSO receives compensation for leaving an investment to another company.

As a last point, we note that these two policy measures B.2 and A.2 are interdependent. If the governance structure for the design of the SDP is ideally such, that the participants (here, the TSOs) have an incentive for truth-telling, we might actually trust and use the information in the SDP. In that case, the cooperation problem following flawed incentives would actually not emerge. This requires careful design of the governance structure for the set-up of a SDP, which requires further research.

5 Summary and conclusions

Following liberalization and especially the energy transition, energy infrastructures are developing rapidly and significantly. Electricity networks are expanded to facilitate connection of renewable energies and new load such as heat pumps and electric mobility. Gas networks are preparing for a phase-out on the one hand and possibly repurposing for transportation of hydrogen on the other hand. At a communal level, the heat transition moves towards heat pumps and district heating, both in turn affecting electricity and gas infrastructure. Lastly, infrastructure for hydrogen and CO2 for CCS are being developed. These developments affect various stages within the sectors. These simultaneous and interactive developments require coordination between and within various energy infrastructures. Coordination of energy infrastructures has been coined Whole System Approach (WSA) (cf. CEER, 2020; CERRE, 2021).

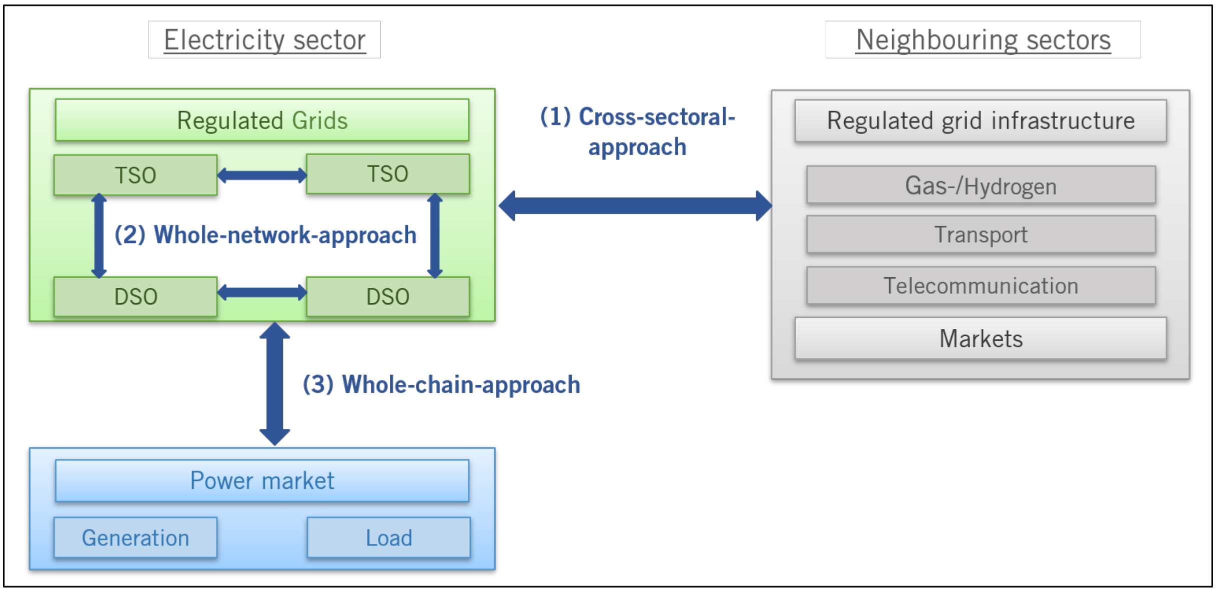

Figure 12: Three levels in the Whole System Approach

Source: own figure, based on CEER (2020)

As depicted in the Figure 11 above, following CEER, we can distinguish three levels of a Whole System Approach.

- Between different sectors (*cross-sectoral-approach*). The cross-sectoral-approach concerns the coordination between actors from different sectors (sector coupling).
- Between the networks in a sector (*whole-network-approach*). The whole-network-approach addresses the optimization of the network levels (network operator coordination) within one sector.
- Between the network area and the market in a sector (*whole-chain-approach*). The whole-chain-approach aims at the interface between the regulated networks on the one hand and the competitive markets on the other.

In this report, we examine approaches for applying a Whole System Approach. Sometimes these approaches are spontaneous, voluntary actions from within the sectors: actors may realize that coordination and cooperation will be beneficial and may set up coordination devices. Often, however, applying a WSA may require an explicit policy, possibly supported by state action. For ease of notation, we decided to call all approaches policy measures; these may or may not require state intervention.

This study is part of a research project on Whole System Approach.[12] Another part of the research project analyzes (misaligned) incentives between different actors and incentives for coordination and cooperation in a game-theoretical setting, using real-world use cases; results can be found in Flachsbarth et al 2024 (forthcoming).

The policy measures to apply a WSA examined in this study are summarized in Table 6 below. We should note that this list of options is not intended to be exhaustive; surely, the reader may find that options are missing. We nevertheless find that this list provides a thorough impression of measures to deal with whole system coordination problems. Moreover, as we noted during the analysis, the borderline between different options is not always sharp; there may be quite a big overlap. We also note that these options are not "new", but sometimes are used in practice. The list provides options of what can be done; we do not claim that nothing is done momentarily. Lastly, we note that these options are not necessarily substitutes. In fact, we found in the use cases in section 4, that many options are actually complements. Certain problems may require combinations of options rather than a single option.

Table 6: Overview of policy options to apply a WSA

A. Monetary incentives	B. Cooperation	C. Hierarchies
A.1 Incentive mechanism	B.1 Round tables	C.1 Rules
A.2 Ex-ante cost-revenue-sharing	B.2 Joint planning	C.2 Arbitration board
A.3 Ex-post financial compensation	B.3. Information sharing	C.3 Competence hierarchy
A.4 Auction		C.4 Joint ventures
A.5 Differentiated tariff-structures		C.5 IESO
		C.6 Horizontal or vertical integration

Source: own table

We grouped the policy options in three main categories.

- Monetary incentives, which aim to reallocate costs and revenues to align incentives.
- Cooperation, which refers to the voluntary collaboration among individuals or groups within an organization.
- Hierarchies, which in one way or another requires the installation of an institution or entity, associated with roles and responsibilities. Usually, decision-making involves some kind of mandate.

[12] „Whole System Approach: Anpassung der Anreizregulierung zur Verbesserung der Gesamtsystemoptimierung", funded by Stiftung Energieforschung Baden-Württemberg (346-22).

Section 3 of the study presents and assesses these policy measures. This assessment relies on different criteria, of which two turned out to be most important and distinguishing features. First, effectiveness: does the policy option address whole system coordination problems effectively? Second, ease of implementation: how easy or complex is it to implement the option in practice. We have tried to classify the options in Figure 13 below according to these two criteria.

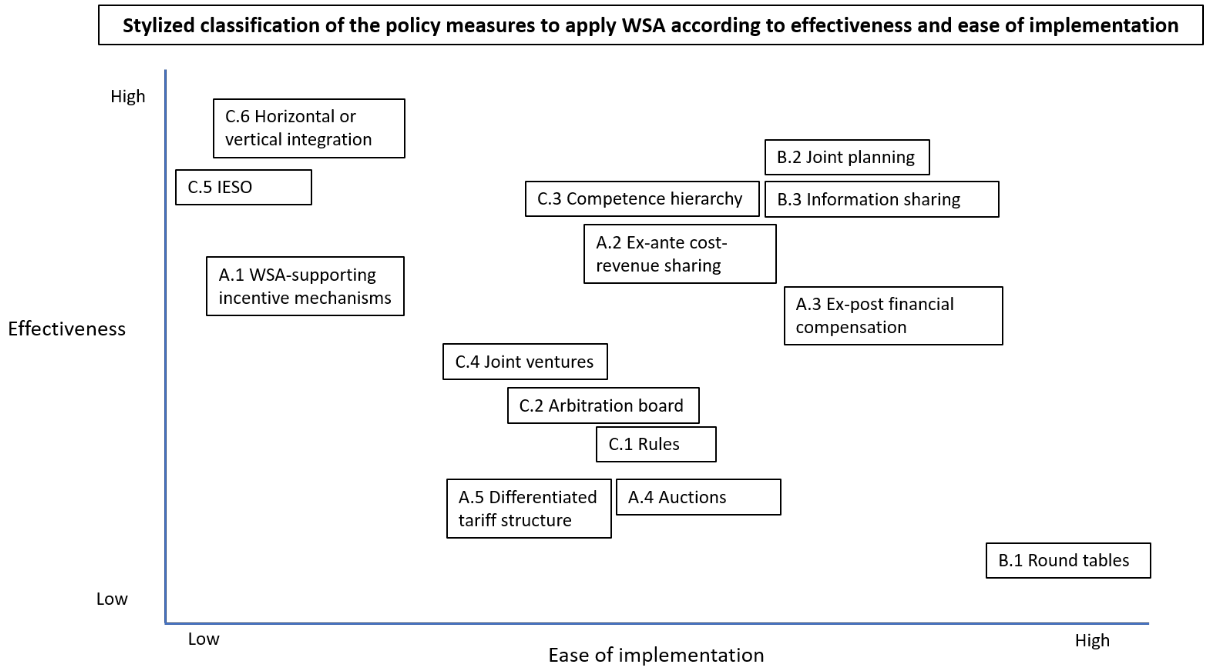

Figure 13: Classification of policy measures to address whole system coordination problems according to effectiveness and ease of implementation

Source: own illustration

The figure has been constructed such that the measures in the top-right corner are most promising, while the measures in the bottom-left are difficult on both accounts and are, therefore, not promising. To make the figure intuitive, we have used the criterion of "ease of implementation", such that high is on the right side and low on the left side, meaning that measures on the right side are relatively easy to implement. The scales are relative; "low" and "high" have no absolute meaning; the figure merely intends to make a relative comparison.

In the top-right corner, we find a small group of particularly promising policy measures.

Foremost, we find B.2 Joint planning and B.3 Information sharing in the top-right corner, indicating high effectiveness and high ease of implementation. Joint planning and information sharing explicitly aim at coordination; this is the main idea. Therefore, we would assume high effectiveness. The difference between the two is basically that joint planning would be most useful for the investment phase, and information sharing for the operational phase. Joint planning and information sharing are already widely used in business in general and in energy infrastructure specifically, such that we can rely on experience. For very specific coordination problems, both will have to be adapted though, which may be challenging at times.

Also in the right top corner, we find A.2. Ex-ante cost-revenue sharing and A.3. ex-post financial compensation. Both are well suited to deal with cooperation problems and to realign incentives; in fact, at least partly, this is the main aim of such measures. In our view, in one way or another these measures will be necessary to address many coordination problems in the WSA context. Effectiveness of these two measures is likely slightly less than B.2. and B.3 above for the following reasons. First, precise calculation of external cost and benefits can be challenging and may impede effectiveness, if they are not accurately included. Second, especially for B.3, ex-post sharing may have a limited effect on previous decisions. Lastly, the coordination problem is not always monetary, or cannot always be addressed with side-payments. Implementation seems challenging, but then again, there exists wide experience with cost-revenue-sharing approaches and negotiations in business in general; therefore, in our view, implementation seems manageable.

Lastly, C.3 competence hierarchy is also located in the top-right corner. This is clearly an important option. In case of doubt, and where processes are technically critical, one party has a mandate to decide and others follow. This is clearly effective and is applied in practice. In our view, however, it is a measure of last resort for selected cases, as it limits the freedom of choice of the stakeholders. Practical implementation will be straightforward, but it may require legal changes; presumably, the mandate will have to be laid down in a formal agreement or ordinance. Legal changes may impede the ease of implementation.

In the bottom-right corner (i.e. high ease of implementation with low effectiveness), we placed B.1. round tables. We actually value the round tables highly, especially as they are easy to implement. Stakeholders agree to meet and talk in an informal setting; this can be done any time in any way. The downside is that they are non-binding talks in which no decisions are made; no stakeholder has to agree to anything. In that sense, in our view, round tables, as useful as they may be, are not effective in addressing whole system coordination problems. The role of the round table is building trust and we would expect to see round tables on a voluntary basis to prepare for more formal meetings.

In the top-left corner, which indicates high effectiveness and low ease of implementation, we placed two measures: C.6 Horizontal and vertical integration, C.5 IESO. In our view, horizontal and vertical integration and the IESO are highly effective to address whole system coordination problems: information, incentives and decisions are aligned by definition within one and the same hierarchy. There are limitations, however, where private end-users are involved in the coordination problem. In these cases, (ownership) integration would not be possible. Moreover, vertical integration may reach the limits of network unbundling. Notwithstanding high effectiveness, implementation may be a hurdle. Transaction costs of these measures to make the organizational changes will be high. It depends very strongly on the severity of the coordination problems whether the benefits outweigh the cost. Moreover, depending on the specific country, the measures may require legal changes.

Somewhat lower in the top-left corner, we find A.1 WSA-supporting incentive mechanisms. We stress that for the figure we explicitly limit ourselves to incentive mechanisms which are used to address coordination problems, and exclude more general incentive mechanisms. As explained above in section 3.1.1, general incentive mechanisms, which tend to strengthen profit-motives, can actually worsen the coordination problems. Therefore, we limit the figure to WSA-supporting incentive mechanisms. Effectiveness is relatively high because realigning incentives is precisely what WSA-supporting incentive mechanisms are designed for. On the other hand, it seems unrealistic to include all external effects in a systematic set of WSA-supporting incentive mechanisms; the measure will inevitably be incomplete, which limits effectiveness. Moreover, to our knowledge, there is almost no experience, neither theoretical, nor practical, with WSA-supporting incentive mechanisms. Therefore, implementation will be highly challenging.

In the middle, where both effectiveness and ease of implementation are moderate, we placed a group of five measures, which can be subdivided into two subgroups.

The first group comprises A.5 differentiated tariff structures and A.4 auctions. We have placed these two measures relatively low in the figure, indicating relatively low effectiveness. This may be somewhat surprising, as these mechanisms are well-established market-based instruments to guide incentives. We fully agree to this as a general principle. However, the application in our context of quite specific coordination problems is limited. In many cases, neither differentiated tariff structures nor auctions can actually be used. Effectiveness is limited to those whole system coordination problems, where the measures can be applied at all. We see that this is the case in whole-chain coordination problems. Moreover, even if experience with differentiated tariff structures and auction design is really wide in general, practical implementation for our WSA-cases is not always straightforward and, in fact, in some cases really challenging. And especially innovative network tariffs may face public and political opposition.

The second group consists of C.1 rules, C.2. arbitration board and C.4 joint ventures. In our view, context-dependent and at an ad-hoc basis, these measures can contribute usefully to addressing individual coordination problems. Yet, their scope will be limited. Despite this, the ease of implementation seems moderate, so it seems worthwhile to consider these measures. The role of these measures is complementary to other measures. Of the three, joint ventures may be the most promising to address very specific cases.

In this study, we illustrate the use of the policy measures with selected use cases, which cover the three WSA-levels, set out above.

Table *7* summarizes our recommended measures for each use case.

Table 7: Overview of use cases and recommended measures to apply a WSA

WSA-level	Use Case	Recommended measures
Whole-network-approach	1A: network operator coordination in the investment phase (example: investment in a DC-corridor	• A.2: Ex-ante cost-revenue-sharing. • B.2. Joint planning

	to decrease network congestion)	
	1B: network operator coordination in operation (example: operation of a DC-corridor)	• A.3: Ex-post financial compensation • C.3: Competence hierarchy
Whole-chain-approach	2: coordination problem between regulated network operators and network users (example: location decision of an electrolysis plant)	• A.5: Differentiated tariff-structures • B.3: Information sharing
Cross-sectoral-approach	3: coordination problem between network operators of different infrastructures (example: network development coordination between electricity and gas network operators)	• B.2: Joint planning • A.2: Ex-ante cost-revenue-sharing

Source: own table

To summarize the big picture. As suggested in Figure 13 above, especially A.2. Ex-ante cost-revenue sharing and A.3. Ex-post financial compensation from the group of monetary incentives and B.2 Joint planning and B.3 Information sharing from the group cooperation are most promising. The differentiation between A.2 and A.3, on the one hand, and B.2 and B.3, on the other hand, depends on the context. These options appear effective and relatively easy to implement.

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