The potential application of reference network modelling to TenneT

A FEASIBILITY STUDY PREPARED FOR THE NMA

February 2012

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Executive Summary

Introduction

The NMa is in the process of preparing for the forthcoming review of TenneT's efficiency. Frontier and Consentec were commissioned by the NMa to undertake a study into the feasibility of applying reference model techniques in order to benchmark the efficiency of TenneT. This report summarises the work we have undertaken and sets out the guidance we have provided to the NMa.

We note that the NMa has not asked us to provide our opinion on whether the NMa should proceed with a reference network study or not. It is for the NMa to draw a final conclusion on whether to proceed with reference modelling or not.

What is reference modelling?

Reference modelling is an analytical cost model approach which is capable of designing concrete, optimal networks for real transport and supply tasks. Reference modelling should not be understood to refer to single, well defined model. It is better understood to be a general methodology to identify an optimal network design, within which the researcher has considerable freedom over the factors that are modelled explicitly.

The researcher identifies the key elements of the transport and supply task at hand, which is typically understood to be, at a minimum, the location and size of infeeds and offtakes of the network. The researcher can then decide to what extent existing aspects of the network should be treated as fixed, or potentially free to be optimised. For example, an application of reference modelling could choose to presume that the existing location of substations is fixed, but that any and all routes between those substantiations could be utilised. A more restrictive form of model, might presume that not only are substation locations fixed, but also that only existing routes can be used. Such an approach might be reasonable if it was felt that planning restrictions ensured that new routes could not be used by the transmission operator.

While there are many approaches to reference modelling, each will follow broadly the same process, which includes:

- defining and describing the transport and supply task unambiguously;
- calculation of the efficient network structure needed to fulfil this task by means of optimisation algorithms; and
- calculation of the costs of this optimal network structure.

The results of a reference model – specifically the optimal costs so derived – can in principle be used in a regulatory context to inform on the efficiency of an existing transmission system.

The limits of reference modelling

Reference modelling is best suited to assessing questions related to investment in the network, for example whether the current set of installed assets is optimal to meet today's needs, whether proposed investments will best meet future needs and so forth. Reference modelling is not able to inform reliably on operating costs in general, and in particular cannot be used to assess business support costs and/or system operation costs at all.

There is also an important question over the extent to which any gap between modelled costs and actual costs can be understood to be evidence of efficiency. For example, past investments might have been made under a different regulatory framework, or subject to a different planning standard. Similarly assets might have been installed to serve a need that existed in the past, but has now changed. Ideally reference modelling should seek to capture such effects, but where it does not the results of any study should be interpreted with caution.

How can reference modelling be used in a regulatory context?

There are three high level approaches that could be followed.

- **An absolute reference model**: the company in question is compared directly against the cost derived from a reference model.
- **A relative reference model**: a number of companies are modelled and for each the ratio of actual cost to modelled cost is constructed. Companies are then assessed on the basis of this ratio, e.g. requiring all companies in the sample to get "as close" to their optimal model as the best performing company.
- **An input to another technique**: in principle a reference model can be used as an approach to derive structural variables that capture the "scale" of the transport and supply task. Interpreted in this way, these variables can be used as an input to another benchmarking technique, for example a regression study.

In order to pursue an absolute approach, it would be necessary to have a highly sophisticated reference model that captures robustly all relevant cost drivers. Otherwise the approach would be open to the critique that any difference between modelled and absolute cost was simply arising as a consequence of limitations in the modelling, i.e. the inability of the model to capture fully all cost drivers and all relevant constraints. Developing an absolute model for use in a regulatory context should be understood to be highly challenging.

A relative application has the potential to reduce the need to capture all aspects of the transport and supply task, plus constraints, in such detail. This might follow if it is possible to demonstrate that certain excluded factors have the same cost impact on all companies in the study. Such factors could then be excluded from a relative study without giving rise to any bias. In practice however, it might be difficult to prove that the exclusion of some factor gives rise to no bias and a sophisticated level of modelling might still be required. With a relative approach, it is also clear that there is a potentially increased resource cost associated with modelling in detail several networks. However, we regard a relative application as the approach most likely to be pursued successfully, notwithstanding the challenges in application that then arise.

Challenges of application

The two main challenges relate to the availably of data and the standardisation of data (in the context of a relative model).

Data requirements

A large volume of data would need to be collected to facilitate a reference model. However, almost all of the required data would be available from TenneT, except for historic data that might be used to model in detail the evolution of the TenneT network over time.

Data required would include:

- Technical data
  - A complete list of substations and their voltage levels together with their geographical coordinates.
  - Aggregate values for load and generation connected to each substation.
  - The **technical rules** which have to be obeyed by system design algorithms.
  - A set of **standard assets** for each asset type (at least switchgears and overhead lines, potentially also cables and transformers) and their technical characteristics.
  - **Potential routes** for system design together with their length.
- Economic data

- standard cost and related information for each asset type; and
- actual cost for comparison with the derived standardised cost measure.

Where costs potentially differ significantly between areas (e.g. as a consequence of one area being more difficult/costly to construct in) then two standard asset types with identical technical properties, but different economic properties, could be defined.

Comparability in a relative study

There is a direct link between the comparability of peer group members and the necessary accuracy level of the reference model. The higher the comparability of companies within the peer group, the less aspects have to be modelled explicitly within reference modelling and the lower data/resource requirements tend to be. This is especially important as varying data availability in different jurisdictions might impose limits on the achievable accuracy of reference modelling. If reference modelling is to be pursued, we would therefore recommend that the NMa seeks a peer group which consists of TSOs that are as similar as possible to TenneT. As indicators for such similarity one could use e.g.:

- technical standards applied (which might e.g. differ in different synchronous systems);
- input costs (e.g. labour costs);
- population density;
- exposure to historical developments;
- load density; and
- transmission network length per peak load.

In addition, considerable effort will be required to ensure close comparability of actual cost data in a relative application, since differences in regulatory accounting rules and other related factors could result in otherwise similar companies reporting very different capital costs. Adjustments might be required to account for differences in at least the following elements:

- tax rates;
- interest rates/allowed returns;
- actual asset ages;
- currency fluctuations;
- input prices, e.g. labour rates (and differential costs of social/pension provisions);

- capitalisation policies (i.e. allocation of overheads to capex, including potentially differences in insourcing/outsourcing policies);
- assumed asset lifetimes;
- depreciation method (e.g. straight line, annuity); and
- inflation accounting.

It is worth noting, however, that the challenge of cost standardisation will be relevant to any international benchmarking approach, it is not an issue specific to reference modelling.

Critical success factors

It is possible to identify a range of circumstances each of which would need to be in place in order to be able to implement successfully a reference modelling study. The relevant factors will include:

- the reference model can capture most critical cost drivers accurately;
- anything excluded from the model is either not a significant cost driver; or
- has a similar effect for all companies;
- standard unit costs can be identified, objectively justified and are sufficiently stable over time to be used to assess historic investments;
- the actual cost data used to form the ratio compared can be adjusted to be highly comparable;
- the potential for an increase in the risk of asset stranding is mitigated by other elements of the regime or is considered reasonable and defendable; and
- the work required for a cross-jurisdictional study can be completed within the required timelines and budgets.

If each of these is in place, then the outcome of the reference study should be sufficiently robust and suitable for regulatory purposes. Where not all of these can be shown to hold, the resulting study could still be used in a regulatory context through a cautious application of the result, or simply in order to bring about a detailed exchange of information between company and regulator in order to close the gap in information available to each.

Key assumptions and justification

With regard to the critical assumptions that must be made these mostly pertain to the ability to demonstrate that:

- certain potential cost drivers can be excluded without biasing the analysis;
- standard prices can be identified and defended; and
- that any differences in accounting treatments between participating countries/companies can be addressed.

Of these three areas, the last two are most likely to be addressed successfully. However, the work involved in standardising capital costs and deriving defendable standard prices across an international peer group should not be underestimated – both of these tasks should be understood to be large undertakings in their own right, although as noted above, the standardisation of actual costs will be encountered if the NMa pursues any international comparison.

Potentially the most difficult area in which to demonstrate that assumptions are reasonable is likely to be the effect of excluded potential cost drivers. Where all firms can provide data on the factor in question, analysis might be possible to confirm the effect of the cost driver – although to do this robustly might require the construction of a reference model that includes the cost driver in question in full in any event. Alternatively, stylised engineering analysis might be able to provide an indication of the potential effect of the cost driver, allowing analysis to proceed in this way. The most significant difficulty will be in cases where the data necessary to model the potential cost driver in full is simply unavailable (for one or more company), the most obvious example of which is the historic data that we know TenneT cannot provide. In the absence of data on historical evolution, how can it be proved that no bias arises from not modelling this factor, one way or the other? We believe that it will be difficult to move much beyond potential high level arguments in this area and this could present an important drawback for the NMa.

In summary, significant work would need to be undertaken in each of the three main areas identified above. Each of these areas is likely to throw up difficult challenges and all of these would need to be addressed satisfactorily. To be more concrete we would need to consider a specific application, in order to understand more about the potential similarities and differences in the peer group and also to understand what data might be available or not.

1 Introduction

The NMa is in the process of preparing for the forthcoming review of TenneT's efficiency. Frontier and Consentec were commissioned by the NMa to undertake a study into the feasibility of applying reference model techniques in order to benchmark the efficiency of TenneT. This report summarises the work we have undertaken and sets out the guidance we have provided to the NMa.

The NMa has asked us to provide practical and clear insights into a number of areas, including:

- what reference modelling could tell the NMa about TenneT;
- equally, on which areas reference modelling would be unable to inform the NMa;
- what actions would be required by TenneT to facilitate a reference network model (e.g. what data would be required);
- what assumptions need to be made and whether those assumptions can be objectively justified;
- what the resource implications would be for all relevant parties;
- how long a reference study might take; and
- more generally, the critical factors that might determine the success or otherwise of a reference modelling study.

In this report we provide a review of what we believe will be the most relevant challenges of application. By so doing, we address all of the questions identified by the NMa. This includes discussion of how reference modelling might be used by the NMa in Method Decisions.

We note that the NMa has not asked us to provide our opinion on whether the NMa should proceed with a reference network study or not. It is for the NMa to draw a final conclusion on whether to proceed with reference modelling or not.

The remainder of our report is comprised of the following sections.

- Section 2 provides **background** on analytical cost models and reference modelling in particular.
- Section 3 reviews the **criteria** we have used to structure our thinking on the potential application of reference modelling.
- Section 4 provides an overview of the **key challenges** in applying reference modelling.

- Section 5 provides a **summary** of our views on the feasibility of applying reference modelling to TenneT.

2 Background - Analytical Cost Models and Reference Modelling

2.1 General Approach

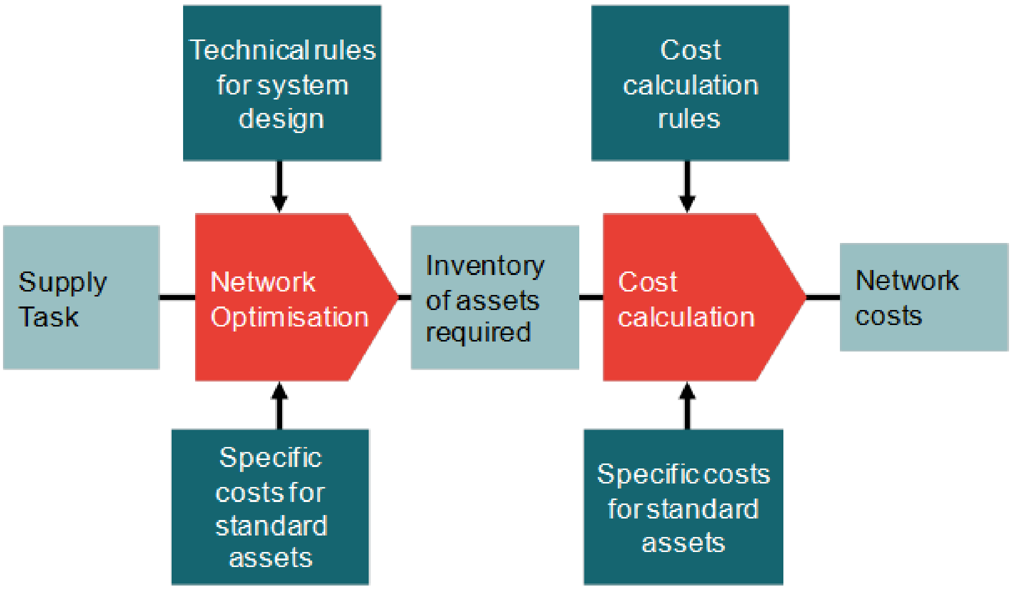
Together with the worldwide implementation of incentive schemes in regulation of electricity and gas networks a relatively new class of regulatory techniques, called analytical cost models, has been discussed for several years. Analytical cost models define a class of modelling approaches which generally aim at determining the efficient inventory of assets needed to fulfil the transport and supply tasks of gas and electricity network operators within a given supply or responsibility area. Based on the efficient inventory of assets needed, analytical cost models assess the necessary network costs to efficiently construct, maintain and operate these assets.

All analytical cost models typically applied in this context simulate network planning processes. The different approaches differ, however, in modelling accuracy and degrees of detail considered, with reference modelling at the more complex end of the spectrum.

Any analytical cost model is based on an appropriate representation of a network operator's "transport and supply task". With this term we describe any influencing factor relevant for a network operator's system layout, but not directly influenced by him. This includes especially properties of the responsibility and supply area (possible routes, possible sites for substations, terrain, spatial development etc.) as well as customer demands (connection points, power takeoff or injection, energy demand, etc.). Depending on the way analytical cost models are applied, real as well as stylised, field-relevant transport and supply tasks can be considered.

The generic steps involved in undertaking analytical cost modelling are set out in **Figure 1**.

Figure 1. Overview of analytical cost model approach



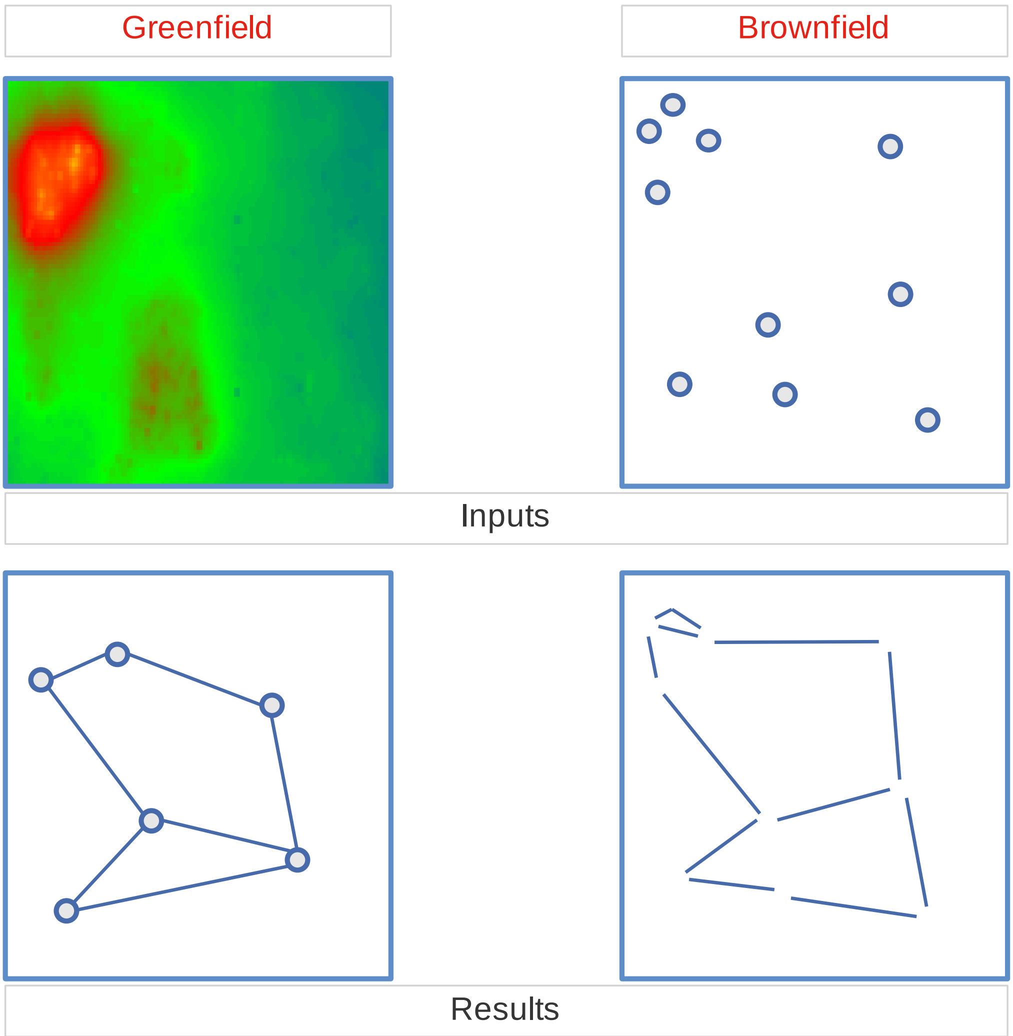
The process of cost modelling begins with gaining an understanding of the real transport and supply task. Typically, no account need be taken of existing system structures[1]. This is because they can be influenced by a network operator – at least in the long run – and therefore are not considered as part of the transport and supply task. Hence, analytical cost models can be understood to follow a "modified greenfield" approach. In contrast to typical, pure Greenfield methods, however, the position of substations as well as the allocated load and generation are taken as fixed boundary conditions. The approach described below might be more reasonably described as brownfield planning. **Figure 2** illustrates the difference between both approaches in some more detail. With a Greenfield approach no element of the existing network infrastructure is used as an input to the model. Consequently, the application of the model would produce an optimisation of every aspect of the network structure, using an optimal number and ideally located substations. In **Figure 2** this optimisation is illustrated on the left side by only defining a – stylised – load density distribution as input data whereas number and position of substations as well as the network structure itself are the result of the application. With a Brownfield approach instead, one would not question the position and number of substations, but only calculate the optimal network which is necessary to connect these existing substations and

1 As we explain below, it is, however, entirely possible to develop an approach to reference modelling that can presume that some elements of the existing network are fixed.

supply their load. Consequently, in **Figure 2** on the right side substations are shown as an input and only the network structure itself is an application result.

The analytical cost model has to consider technical boundary conditions and planning rules relevant in practice (such as network structures, substation layout, technical properties of assets). Furthermore specific costs for construction and operation of assets (and possibly other factors as losses) have to be taken into account in order to simulate the planning process for a given supply task adequately.

Figure 2. Inputs and Results with Greenfield and Brownfield approach



A typical application, however, will not consider historic influences. For example, a typical analytical cost model will not be able to decide whether any deviation between actual system and reference model are a consequence of any managerial inefficiency of the part of the network operator or due to historic development. For example, it is entirely possible that planning decisions were efficient at the time they were taken, but have proven to be inefficient ex-post, or have now become suboptimal as a result of changes in demands (injections/offtakes) on the network over time. In order to evaluate historic influences and their effects on assets and network costs, it is possible in principle to do a stepwise evaluation for different points in time, using the results from one point in time as a the fixed starting point for subsequent optimisations.

The core step of any analytical cost model, "network optimisation", delivers a cost optimal network for the analysed transport and supply task and subject to all boundary conditions provided. Typically, for regulatory purposes it is sufficient to consider the inventory of assets needed, separated by asset types, whereas topology, switching states[2] etc. can be neglected.

The derived inventory of assets allows the researcher to calculate the costs of the optimal network structure developed. Typically the costs calculated from the optimal asset register are based on annuities, i.e. long-term average costs per year calculated on the basis of today's reinvestment costs, using the assumption of a typical useful lifetime and a cyclic reinvestment after this useful lifetime. These annuities can be calculated on the basis of specific investment and operation costs for the asset types considered in the network optimisation step. Thus, the objective function for the optimisation core is the minimisation of the product of the inventory of assets (differentiated by asset types) and the respective specific costs (converted to annuities).

It is important to understand that for any analytical cost model, and also for reference modelling, there is no unique way how the method is applied. An analytical cost model has to be understood as a concept which allows the researcher to objectively assess the efficient costs for fulfilling a transmission or distribution task by

- defining and describing this task unambiguously;
- calculation of the efficient network structure needed to fulfil this task by means of optimisation algorithms; and
- calculation of the costs of this optimal network structure.

Any of these steps can be applied in various ways depending on the questions to be answered and the data available. The applicability and robustness of the approach will be determined by the details of the application chosen.

2 The electrical properties of a network, e. g. regarding actual load flows, are not only determined by the existence of lines, but also by the question where and how these lines are connected with each other. As a result of this connection (switching state) the electric topology of a network may deviate from the geographical structure.

2.2 Reference Modelling

Reference modelling defines an analytical cost model approach which is capable of designing concrete, optimal networks for real transport and supply tasks. The approach typically requires a significant volume of detailed input data. The results of an application of reference modelling can, in principle, be directly compared with real existing networks and particular effects e. g. of changes in the transport and supply task, can be evaluated.

Reference modelling uses a brownfield approach, assuming that at least the location of existing substations is fixed. From there an optimal system for the current transport and supply task is designed.

2.2.1 Regulatory precedent

The first applications of reference modelling approaches have not taken place in the regulatory context. Instead, such approaches were developed in an academic context mainly for high and medium voltage networks as tools to support long term network planning. Brownfield approaches are typical for long term network planning where they are applied in order to gain insights over the optimal development of the system without being overly restricted by existing network structures, but typically limited to existing routes. This kind of planning differs from that undertaken by most network planners since their work is typically more aimed at an evolution of the existing system. Network optimisation is performed in reference modelling using automated and objective software solutions based on optimisation algorithms.

The term "reference modelling" has been used previously in a regulatory context e.g. in the introduction of an incentive regulation scheme for German electricity and gas networks. One important issue for this implementation has been the problem of evaluating the efficiency of the four German electricity transmission system operators where:

- a sample of four operators was considered not sufficient for undertaking a national benchmarking; and
- doubts existed that an international benchmarking could be applied successfully due to comparability and data issues.

Hence, reference modelling was included in the German legislation on incentive regulation as one possible way to assess the efficiency of TSOs. Data was collected and the method was applied before the start of the first incentive regulation period. However, ultimately an international TSO benchmarking was applied and the results of this benchmarking were found to be sufficient and were used to determine efficiency scores. As reference modelling is only a substitute for other benchmarking methods according to the German legal framework there was therefore no need to use the reference modelling results.

Nevertheless, this demonstrates that reference modelling tools for transmission systems and extra high voltage levels are available and have been used in a similar context.

The tool used by the German regulator Bundesnetzagentur (BNetzA) is based on the heuristic optimisation approach of evolutionary algorithms. It uses:

- coordinates of substations together with information on load and generation connected to these substations (data for different loading situations can be provided);
- standard asset types used in EHV networks (which can be configured by the user); and
- possible routes between the substations where it is possible to specify the possible voltage levels and the minimum and maximum number of circuits on a particular route.

The model then creates one intermeshed transmission system that connects all substations. From a technical perspective the resulting networks are (n-1)-secure for all loading situations.

2.2.2 The treatment of certain electrical properties in reference modelling

Limits which can be monitored include thermal rating of branches, voltage ranges and short-circuit currents. For thermal rating, maximal allowable currents are specified for the different conductors as an asset type property. For voltage and short circuit current values, upper and lower boundaries can be defined per substation and voltage level. Typical applications are, however, often limited to consideration of thermal rating of branches. One reason for that is that branch currents are more or less fully influenced by network structure and asset (conductor/transformer) types, i.e. optimisation values of the reference modelling approach, whereas remedies to voltage and short circuit problems cannot typically be optimised within reference modelling only. Regarding these methodical limitations, it is important to understand that several assets or properties of assets (e.g. their consequences for load flow and short circuit currents) typically considered in planning of transmission networks can also be captured by reference modelling algorithms, like:

- compensators and coils;
- FACTS[3];
- phase-shifting transformers; and

3 The term FACTS (Flexible AC Transmission Systems) describes technologies based on power-electronics and used in transmission systems to flexibly control active and reactive power flows.

- generator layout.

The optimal layout of these assets is, however, not included in the optimisation problem dealt with by the reference modelling approach. The effect of predefined (existing or planned) assets can be evaluated, however. This means that for a given set of such assets, the reference modelling method will be able to calculate and take into account their effect on load flows in the system. Hence, the outcome of reference modelling will be optimal subject to the existence and layout of these predefined assets. Reference modelling will not be able to evaluate, however, whether a better solution might be possible with any other configuration of such predefined assets. If desired, these assets can also be considered in the calculation of cost.

2.2.3 Choice of route

Perhaps the most important element of any reference model is the extent to which the optimisation algorithm is permitted to choose routes, including where appropriate the optimal voltage level and number of circuits. In principle the researcher can allow the reference model to re-optimise routes completely, but such an application is likely to be of only academic interest since planning restrictions will usually make "ideal" routing impossible to achieve. A common alternative is to restrict the model to choosing between only existing routes, where the relevant planning permissions and permits are already held. Finally, it is possible to set up a reference model that also presumes that some assets are fixed in addition to the routes. Ultimately, it is for the researcher to establish which of this approaches is the most relevant and of most interest, given the question they seek to answer.

For systems with more than one voltage level the number, position, and size of coupling transformers can also be optimised. For substations a typical layout with two switchable busbars in coupled operation is assumed. There is no optimisation of substation layout or switching states.

2.2.4 Key determinants of solution time

For usual transmission systems (up to 100 substations, up to 2 voltage levels) computation times typically lie in a range between several hours and 3 to four days on a standard personal computer. Besides of the size of the system this computation time is mainly influenced by the following factors.

- The **technical boundary conditions** considered: If only the thermal limits of lines are considered, computation times are significantly lower than with consideration of voltage limits and short circuit currents. At the same time the amount of input data required is reduced.

- The **number of routes**: An optimisation which starts with existing routes and considers only selected possible routes is much faster than a consideration of more or less all possible connections between two substations. One might argue that only the latter approach guarantees an optimal solution as any limitation to existing routes will prevent the optimisation tool from selecting routes not used to today. With typical transmission systems, though, possible distances to an optimal solution should be very small. For a regulatory application it is typically necessary to reflect accurately planning/wayleaving constraints and this will lead to a restricted choice of routes.

- The **number of standard asset types**: If for one route the optimisation algorithm has to choose between a large number of possible asset types (e.g. conductors with different diameters), the complexity of the optimisation problem increases significantly. It is common to limit the number of possible asset types per route, therefore to reduce run times. It is important to understand that such an approach does not exclude the possibility to define different asset types for different routes. Instead, we consider such a possibility as an important measure to guarantee the practical relevance of reference modelling outputs. The reasons for such differentiation might lie in diverging possible line layouts resulting in technical or economic differences and motivated by pylon layouts usually used in different systems, area properties which require different layouts of lines (salty environment, mountains etc.) or diverging criteria for electromagnetic field compliance.

- Intended **simplifications and abstractions**: For several regulatory applications of reference modelling (cf. section 2.4) it might be desirable to simplify real transport and supply tasks. If costs or inventory of a reference model are not used as an absolute yardstick for the actual costs of the existing system it might be acceptable to neglect, for example, different voltage levels and calculate systems which only consist of one voltage level. A reference model so derived might be considered to be a reasonable long-run optimal solution (e. g. calculate reference models with only 380 kV level albeit from voltage levels existing in the actual network).

In reference modelling the consideration of historic developments often turns out to be important. Before discussing respective methodical possibilities in detail, it should be mentioned that the relevance of historic developments for reference modelling results depends on the regulatory approach to be taken, i.e. the reference model should be tailored to the context.

2.2.5 Accounting for historical network development

Actual networks are not planned using a brownfield approach. Instead they are influenced by historic developments of load and generation, previously existing system structures and the evolution of technical options and boundaries. Hence, even without any other simplification in modelling and calculations, actual networks tend to be more expensive than brownfield reference models. Such cost surplus should not necessarily be interpreted as evidence of inefficiency but more likely is an unavoidable consequence of an evolving transport and supply tasks. Neglecting historic developments therefore is especially crucial if the costs derived from a reference model are directly compared with actual network costs (c.f. section 2.4.1).

If results of a reference model are not directly compared with actual network costs, it might be acceptable not to model historic developments in detail. With a relative application of reference modelling (c.f. 2.4.2) the resulting optimal models will not be biased provided that the magnitude of historic influences on actual network costs is not significantly different among the TSOs compared. Consequently it is not necessarily the case that the most accurate (and sophisticated) reference model approach is essential to ensure that the results could be used in a regulatory context. However, the effect of the historical evolution of assets on the existing configuration is likely to be a contentious in such a context.

In certain cases it will not be possible to demonstrate that the exclusion of historical developments gives rise to no bias. In such situations, it is generally possible to further evaluate this point by:

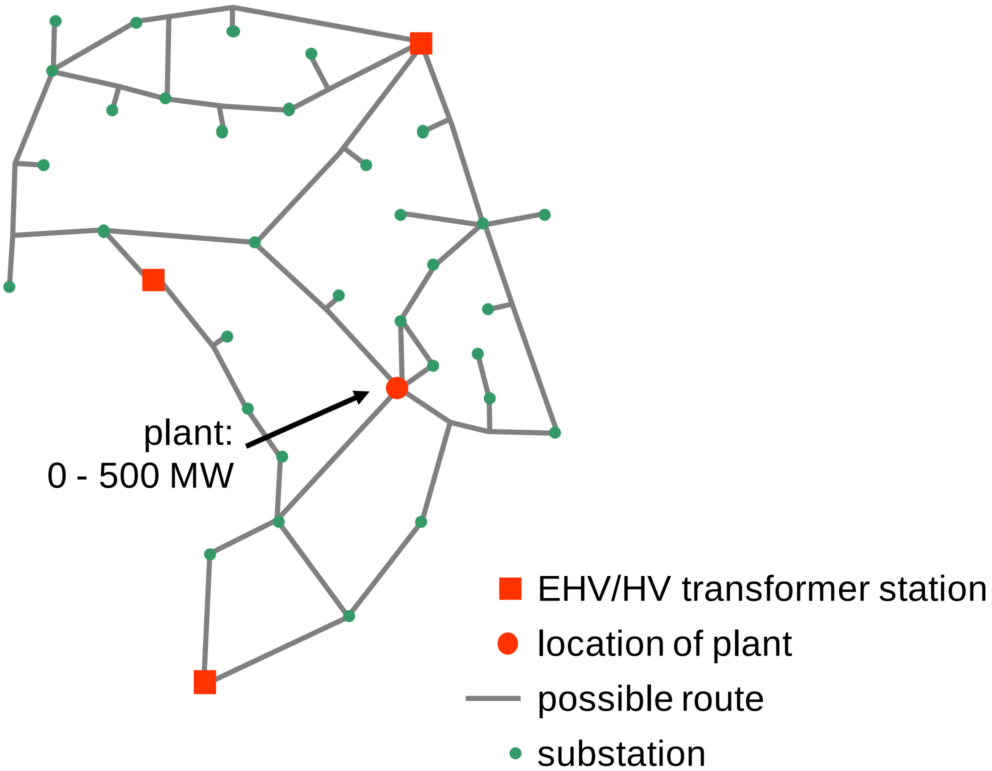
- collecting all relevant input data not only for the time of application but for selected times in the past (e.g. 5, 10, 20 and 40 years ago);
- applying reference modelling with a pure greenfield approach only for the first of these points in time; and
- then applying a brownfield approach at each subsequent point in time where planning decisions found to be optimal for previous points in time may not be revised again.

With such a sequential application of reference modelling it will be possible to determine a reference model which fulfils all relevant technical boundary conditions and defines an optimal solution subject to all historic influences included in the input data. It should be noted, however, that such a sophisticated way to apply reference modelling is not only a challenge in terms of computational efforts but also extremely data intensive since it requires a consistent description of past transport and supply tasks for all compared TSOs.

2.2.6 An example

The following example shows a typical application of reference modelling. This application aims at investigating the cost-driving effect of connecting a power plant to a subtransmission system[4].

Figure 3: Transmission and supply task for exemplary application of reference modelling



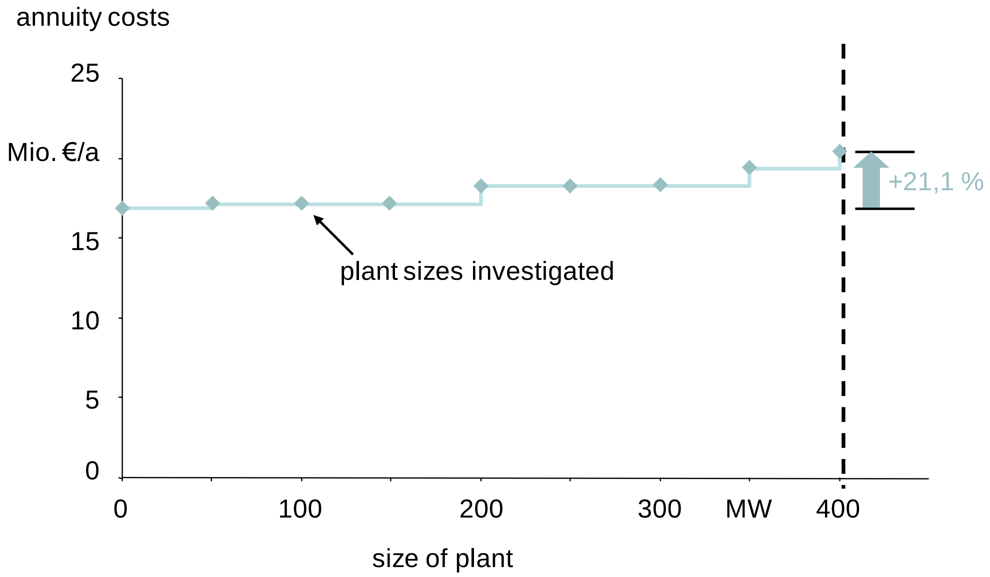
From the description of the transmission and supply task it can be seen that a power plant of varying size shall be connected to a typical subtransmission system with approximately 40 substations. The planning algorithm may choose between several possible routes none of which is obligatory.

Figure 4 shows the results as a relationship between size of the connected plant and annuity costs of the optimal network structure resulting from a reference modelling application for the respective plant sizes. Obviously, a plant of up to 50 MW would not cause additional network costs whereas plant sizes up to 400

4 The concrete example refers to a 110-kV-network. Such networks, however, tend to have a similar strucure as transmission networks. Therefore, also reference modelling tools for both voltage levels are comparable.

MW increase the network costs in discrete steps. For plant sizes above 400 MW no valid solution is possible with the degrees of freedom defined.

Figure 4: Results of reference modelling application – annuity costs of optimal solutions for different sizes of plant connected



2.3 Limits of Reference Modelling Approach

As explained in the previous section reference modelling should not be seen as one single and well-defined method but rather as a flexible approach which can be used to develop cost-efficient network structures for defined transport and supply tasks in order to assess the long-term average costs of these networks. Within that general approach models with varying degrees of sophistication can be developed and the optimal choice is not necessarily the most sophisticated but the one that is best suited for the context, for which sufficient input data is available and which delivers comparable results for all networks considered.

Nevertheless, the nature of reference modelling brings with it strengths and weaknesses when used in a regulatory context. In the following we will explain what reference modelling is useful for on the one hand and what cannot be derived from any application of the approach on the other hand.

2.3.1 Questions that can be addressed using reference modelling

Reference modelling is capable of thoroughly evaluating the effect of most cost-driving factors for infrastructure in transmission systems. For example, reference modelling:

- can be used to explain not only the costs of necessary infrastructure but the amount of necessary infrastructure itself;

- can compare and cost the effect of different technical solutions to transmission extensions;
- can evaluate effects of local changes in the transport and supply task (like locational shifts of load or generation) which might not be considered to be relevant when only considering aggregated values (typical for econometric benchmarking methods);
- can be used to verify objectively and quantify the cost effect of supposed or claimed cost-driving factors like unique area properties;
- can be applied in a way which delivers the most accurate yardstick for infrastructure demand among all practically relevant benchmarking tools;
- provides a well-documented method which can be modified and adapted in a way that best fits with individual requirements;
- from a technical perspective allows a comparatively high level of transparency (at least among suitably qualified engineering professionals) as all input and output data can be directly interpreted by the TSO's technical experts and results can be verified with typical network calculation software[5]; and
- does not suffer from comparability issues to the same extent as other benchmarking methods as the application of reference modelling on various TSOs allows the consideration of case-specific optimisation variables and boundary conditions (reflecting e. g. planning, decision making and licensing procedures or technical rules to be applied in different jurisdictions).

As a consequence, reference modelling has the potential to expand the range of questions that a regulatory office can evaluate.

2.3.2 Potential drawbacks

However the method also has some characteristics that give rise to potentially important drawbacks for practical regulatory application.

First there is the high effort for collection and validation of input data. This issue is discussed further in chapter 4. From a methodological perspective reference modelling approaches clearly focus on the assessment of the efficient infrastructure demand to fulfil a defined transport and supply task. This has several implications.

5 Transparency can be limited in real applications due to confidentiality reasons, however.

- There is a need to assess whether network operators may be blamed for the potential inefficiency of infrastructure investments which were made under a completely different regulatory framework. For the application of reference modelling it would at least be necessary to separate existing network infrastructure into two groups, consisting of pre-liberalisation investments (fixed for reference modelling) and post-liberalisation investments (degree of freedom for reference modelling).

- Furthermore, it can be argued that today transmission investments are not subject to entrepreneurial discretion of the respective TSOs but are a consequence of political and regulatory decisions and public consultation processes. This would make it at least questionable whether it makes sense to thoroughly evaluate the efficiency of such investments by reference modelling, since reference modelling might presume greater freedom of choice than exists to the transmission operator in practice.

- While capex (and the financing of capex) are significant contributors to the total cost of any transmission system, opex for maintenance, system operation and administration and costs for ancillary services (which have to be provided by system operators in order to guarantee system stability and security) are also a very substantial part of the cost base. TenneT has confirmed the share of each in its cost base with compensation for capital investments (i.e. depreciation of and return on it's the regulatory asset base (RAB)) amounting to approximately one third of their total costs. Reference modelling can only help to explain certain elements of these costs.
  - As reference modelling is focused on assessing efficiency of network infrastructure it will be best suited for explaining the related amount of capex (usually defined as annual depreciation plus annual return).
  - However, the costs which result from reference modelling are long-term average costs or annuities, whereas in a regulatory context costs are typically the result of the prevailing regulatory accounting arrangements. These costs are aggregated in the RAB. The RAB invariably does take account of the age structure of the inventory of assets on the one hand and the individual accounting policy of a TSO on the other hand. The age structure of assets may be very different between TSOs and this could give rise to a bias in comparison (at least it might be necessary to demonstrate that there is no such bias as a result of asset age). Similarly, otherwise identical companies could have different costs as a result of different depreciation policies (e.g. assumed asset lifetimes). We return to this concern in Section 4.4.3 below.
  - Reference modelling determines the efficient amounts of infrastructure based on specific costs for certain types of assets provided as an input

data. Hence, the validity and comparability of these specific cost data is of critical importance in reference modelling. In particular in the context of an international comparison, assumptions on standard asset prices for different companies will be a key driver of the eventual estimation of relative efficiency. However, reference modelling itself does not provide a basis for testing the reasonableness of assumed standard prices and external evaluation is necessary.

- Reference modelling considers operational expenditure on the network only very roughly. As is typical for planning purposes, operating cost for maintenance of the required assets is estimated based on the inventory of assets and on assumed data on typical operating costs for each type of asset. Such a way of modelling allows a rough comparison between different solutions that might consist of assets with high investment - low maintenance costs on the one hand, and other assets with comparably low investment - higher maintenance costs on the other hand. A typical example would be the evaluation of cable and overhead solutions for a line project. However, the level of detail of opex modelling within reference modelling is not typically sufficient to evaluate the efficient level of total maintenance opex for a TSO's business.
- Reference modelling cannot be used to inform on other opex costs, such as business support costs (i.e. head office costs). To gain an assessment of the entire cost base, these costs would need to be assessed using a different approach.
- Similarly, reference modelling cannot provide guidance on the efficient cost of system operation, market facilitation, TSO cooperation etc.
- Finally, reference modelling provides no scope for the assessment of the efficient cost level for ancillary services. The relevance of this issue depends on the individual regulatory regime. Within many regimes applied in Europe, ancillary service costs are excluded from incentive regulation and more or less directly passed through to costumers or at least handled by specified regulatory methods. In such situation, there would be no need for a reference modelling approach to give further insight to ancillary services costs.

The discussion of the points above shows that reference modelling is able to assess a certain share of a TSOs costs in a potentially accurate and detailed way and might be superior to other approaches for that particular purpose. Other important shares of costs are not considered at all, however. If these cost elements are to be incentivised additional methods would be necessary.

2.4 Application for Regulatory Purposes

Once a reference model has been implemented, there are three broad ways in which it could be applied for regulatory purposes. We provide a review of each potential approach in the subsections below.

We note that analytical cost models have been successfully applied in other sectors, in particular for example the telecoms sector. While this reveals that approaches of this kind can be successfully applied to regulated networks, we note that there are a number of important differences between electricity transmission and telecoms (e.g. in the rate of technological progress, the technical lifetime of assets, the divisibility of assets, the locational specificity of assets, the predictability of demand, the impact of planning restrictions etc.). The successful application of this general approach elsewhere does not, therefore, in our view ensure that the approach can be applied in electricity transmission with equal success.

2.4.1 Absolute Benchmark

The simplest way in which reference modelling can be used in a regulatory context is as a direct benchmark for the actual costs of the company, i.e. the modelled costs derived from the reference model are used to set the target level of cost that should be allowed to the regulated company.

While a fuller review of the properties of this approach is provided below, a number of properties of this approach are immediately apparent:

- if the reference model is to be used as a direct target for the company, the reference model needs to be able to capture all relevant detail (at least all potential drivers of network planning and hence cost);
- this approach can be applied in cases where there is no peer data available, i.e. where comparative efficiency techniques cannot be applied;
- since the company is compared against some optimised network, it has good incentive properties (i.e. the company subject to this technique will know that it needs to plan and deliver capex as efficiently as possible); and
- however, the strong application of a reference model can have the effect of requiring the regulated company to write off already sunk capital, increasing materially regulatory risk.

An absolute application of reference modelling is open to a simple critique, that the reason for actual costs exceeding modelled costs is always as a result of important cost drivers that are not captured (hence the observed difference arises as a consequence of model weakness, not managerial inefficiency). In a regulatory context where legal challenge is possible and the burden of proof falls on the regulatory office, this critique can significantly limit the potential for a successful application.

The counterargument to this critique is that regulating unique transmission companies is difficult and any approach that yields helpful information could have a high value. An absolute reference model could provide sufficient information to be used indicatively in a regulatory determination and could drive significant savings for customers. Essentially, the reference modelling would provide a foundation for engagement with the company, with debate over the materiality of factors not captured in the modelling.

Similarly, an absolute reference model can also be used cautiously by the regulatory office. For example if the reference model suggests the modelled company's capital costs are 20% higher than the optimal model, the regulator could require the company to make reductions of only some proportion of this amount, thereby allowing a margin for error. The regulator could also make use of a "glide path" where the company is allowed time to reach the efficient level, again allowing for some potential margin of error in the model. This approach could increase the robustness of the approach to challenge.

2.4.2 Relative Benchmark

Reference modelling can be used to facilitate a relative, rather than absolute, benchmark in cases where reference modelling is undertaken for a number of companies. Under this application, the company is not compared directly to a cost measure derived from the reference model. Instead, for each company in the sample the ratio of its actual cost to modelled cost is formed. Companies are then compared against one another on the basis of this ratio. This approach has the effect of identifying the company that is closest to its reference model and requiring that other companies in the sample achieve a similar level against their own reference model. We note that the German directive on incentive regulation includes the use of a relative reference model (although as discussed this model is not being used to determine directly an efficiency score at present).

In a regulatory context, a relative application has a significant benefit when compared to an absolute application because it reduces the imperative to capture every potentially significant detail within the reference model. This follows if it can be agreed that factors not captured will have a similar effect on all companies (i.e. the ratio actual:modelled for each company will move in a similar fashion as a result of the simplification). This can reduce the complexity of the modelling and hence the volume/depth of data required, making the application of reference modelling more feasible and potentially more defensible.

However, there are also some potential drawbacks of a relative approach. The most obvious relate to resources. A relative approach requires a reference model to be built for all companies in the sample, multiplying the work involved (although this is potentially mitigated by the ability to simplify the reference model relative to an absolute application). It also gives rise to a range of questions over comparability including:

- are all companies in the sample able to provide the same set of data, in order to allow all elements considered critical to be modelled?
- to what extent can it be shown that non-modelled factors do not bias the analysis?
- are the actual cost data for the different companies comparable, or can they be made comparable[6]?

We note that the last of these points is not actually a concern specifically for reference modelling, but a more general concern with regard to any benchmarking exercise.

When considering the merits of a relative application, it is also important to consider the question of sample size. For example, would a relative application with a sample size of 2 be any more easily justifiable than an absolute application? This is clearly a question of judgement, but it would be necessary to consider the potential cost drivers of the two companies very carefully indeed. This could be contrasted with a case where very many companies were modelled and used in comparison with the efficient level of cost identified as the average level of actual:modelled cost in the whole sample. Such an approach might be considered entirely reasonable and defendable in a regulatory context, but is unlikely to be implementable as a consequence of the very large cost involved.

2.4.3 Input to another benchmarking technique

Reference modelling can be used to produce metrics that can feed into another benchmarking technique. For example, reference modelling can be used to produce structural variables (e.g. modelled network length at different voltage levels) that could be used as explanatory variables in a regression analysis of relative efficiency. The most obvious application here, is that the European TSO benchmarking project could adopt the use of reference modelling, with structural variables so derived used as inputs to this study.

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6 With a relative application, issues of the comparability of data are critical. A relative application focuses on a comparison of the ratio of actual to modelled cost and for a robust application this comparison must be reasonable. Modelled cost, which will result from the application of a common technique/process, can be relied upon to be comparable (subject to the question of whether all critical cost drivers have been captured). However, unadjusted actual data could be far less comparable as they will have been prepared by each member of the sample in accordance with the accounting rules that prevail in their jurisdiction. Differences in key assumptions, such as depreciation lifetimes and capitalisation policy can lead to material distortions.

This approach has the benefit of reducing further the importance of any single modelling assumption/parameter. Since the results of the model will only be used as structural inputs to another technique, alongside a set of other potential cost drivers, then relatively minor difference in modelling approach are unlikely to be seen as barriers to implementation. Technically, the derived/modelled structural variables might be considered to be highly correlated with the difficult to measure concept of the "size of the task" undertaken by the network operator. Where the ultimate technique adopted is a regression technique, then it is also possible to test statistically whether there is evidence to support the use of reference model outputs. This approach has been adopted, for example, in Austria as part of a package of analysis to assess the relative efficiency of distribution companies.

The main drawbacks to this approach again relate to the cost of implementation. As with the relative application, this approach requires a reference model for each company in the sample and this can quickly become costly. In particular if regression analysis is to be undertaken then it would be necessary to prepare a reference model for many companies on a broadly similar basis – at an absolute minimum we would suggest 10 and ideally many more.

2.4.4 Concrete proposals for assessment

In order to facilitate our review, we have chosen to develop a number of potential applications, which capture the different ways in reference modelling might be implemented. This allows us (and the reader) to consider the properties in the context of a specific example, rather than a more generic, conceptually application only.

The potential applications we review are:

- an absolute application, where only TenneT is modelled;
- a relative application versus a peer group of Dutch DSOs;
- a relative application versus a peer group of international TSOs; and
- reference modelling to facilitate the use of modelled, structural variables in the European TSO benchmark study.

We will return to these potential applications in Section 5.

3 Criteria for assessment

To draw a judgement on the potential of the technique, we need criteria against which to make an assessment. This section provides a discussion of the criteria we have applied in this assignment.

The scope of our work is an assessment of the feasibility of applying reference modelling in the Dutch context. It is not to compare reference modelling against all possible benchmarking techniques in order to identify whether the approach is "best". Our assessment, as set out in Section 5 below, is therefore absolute, rather than relative. We also note that our remit is not to reach a definitive conclusion on whether reference modelling should be applied. It is for the NMa to decide whether to proceed with reference modelling, or not.

A number of these criteria are in conflict with one another, creating cases where it will be necessary to make trade offs. One approach to identifying the preferred balance is to create a ranking of criteria. Given that it is not within our scope of work to draw conclusions over whether to proceed with reference modelling, we have not done so here. However, the commentary we provide in the following sections provides a summary of our assessment of reference modelling against these criteria. Others might make different judgements of the merits of the approach and consequently draw different conclusions from the detail of our review.

3.1 Robustness

A critical property of any benchmarking process and the resulting performance assessment is that it must be regarded as robust by the operators and peer reviewers. Ultimately a technique that produces results that are not sufficiently robust will be of little use in a regulatory context. The results would not be credible to the sector and the basis of the regulatory settlement would be weakened, opening up the prospect of the decision needing to be adjusted or being overturned on appeal. A regulator developing a technique to assess efficiency will therefore wish to ensure that it can use the results of the technique in its decisions (i.e. that the use will be robust to the relevant appeal procedures) and that this use will be regarded as reasonable.

There are a number of dimensions in which robustness should ideally be demonstrated. The technique should ideally be robust to "noisy" data with results that are not inappropriately volatile, nor driven in apparently inappropriate ways by variation in data. Results should be also verifiable, in the sense that the ranking of operator performance should be consistent with other forms of assessment and other performance metrics.

Given the inevitable limitations of benchmarking, the ideal of a model that perfectly captures and balances all relevant factors is unattainable in any practical context. In this regard it should be understood that robustness is a relative concept. We might classify a number of points along a spectrum of robustness, where results might be regarded as:

- **definitive**: the results of applying the technique can be demonstrated to be highly robust along all relevant dimensions and can therefore be regarded as providing evidence on which allowances could be set with a high degree of confidence;
- **informative**: applying the technique produces results that capture most aspects of performance, but imperfectly. For example, proxy variables might be used to capture certain exogenous environmental differences between firms, implying that care should be taken when drawing conclusions on relative efficiency. The results are likely to be useful as part of a wider body of evidence with which to challenge operator forecasts and arrive at final cost allowances; and
- **unreliable**: in extreme circumstances there might be insufficient data with which to capture the salient features of the production process with confidence. While benchmarking results might provide a very broad indication of relative performance, important drivers of performance might be weakly captured making inferences difficult to draw from these results alone.

Of course, there are many intermediate points along this spectrum and the descriptions above should be regarded as illustrations of how outcomes might vary. We note that even comparatively unreliable benchmarking results might still be of use to the regulator. Suppose an operator is shown as being highly inefficient on the basis of an unreliable technique, yet after taking account of all of the factors missing from the model it was still not possible to close the gap between some operator's performance and the level predicted by the model. Even unreliable results, appropriately interpreted and supported by additional analysis in this way, might be regarded as useful evidence of inefficiency and a helpful ingredient to setting cost allowances.

3.2 Transparency

Transparent benchmarking models and processes should be preferred over those that are less transparent. If benchmarking methodologies are clear it will aid the ability of all stakeholders to understand the rationale for the selected approach, e.g. the why certain data has been used in the model and why other data has not. Similarly, it will be clear to the operators what conduct is being encouraged, how they have been rewarded for cost reductions, for enhanced quality etc., providing stronger signals on what the regulator (acting on behalf of customers) values.

Criteria for assessment

Although it is not the only dimension of transparency, simplicity is an important element. More complex techniques are likely to be more difficult for stakeholders to replicate, which might limit understanding and hence the extent to which operators and others are willing to engage in debate on performance. Stakeholders will be better able to replicate a simple benchmarking method, further increasing their ability to understand the key drivers of their proposed cost allowances. For example, while Ofgem published extensive details of the approach it adopted to benchmark operators at DPCR5, the process was highly detailed, based on very many different regression models. It is likely that few of the interested stakeholders will have been able to replicate the approach and many will therefore lack an intuitive understanding of the final results.

In the context of the Dutch regulatory system, an important element of transparency is likely to be the extent to which it might be possible to demonstrate the reasonableness of the approach to the relevant appeal body, or not.

3.3 Promotion of efficiency

In principle, the choice of benchmarking technique can be a critical driver of the behaviour of regulated companies. Benchmarking techniques should, ideally, promote not just efficient cost management, but also striking the appropriate balance between low costs and desired outputs. Consistent with this, benchmarking methodologies should ideally minimise the extent to which they distort incentives to favour one cost type over another. Ideally all competing costs should be exposed to benchmarking of a similar "strength".

Finally, it is likely to become increasingly important that benchmarking does not unduly encourage operators to avoid early action, innovation and investment that might be required to foster a transition to a low carbon economy. Benchmarking has traditionally involved taking "snapshots" of performance at points in time and it is possible that these techniques discourage operators from acting early, as there is a risk that those costs will be assessed as inefficient in comparison with other operators yet to act. Benchmarking processes might therefore be adopted that give rise to some institutional memory of past conduct, in order to ensure that appropriate and efficient early action is rewarded appropriately.

3.4 Adaptability

Given the likelihood of significant changes in the available data, there may be merit in pursuing a benchmarking technique that could evolve over time. This would be consistent with the view that there is merit in ensuring stability in any regulatory regime. An approach that is able to adapt over time should therefore be preferred over one that is not, all other things being equal.

It is becoming clear that the activities we will ask networks to undertake in the future might be different from those undertaken now. For example, it is anticipated that there will be the need for distribution networks to serve an increasing fleet of electric vehicles in future. It is unclear how this additional network activity might be best encouraged and delivered. Similarly, it is likely that the focus of certain outputs might change over time. The definition of some output measures can change, making some outputs more or less measureable as a consequence, and inevitably leading to breaks and/or gaps in the available data.

3.5 Reasonable data requirements

It is possible to develop highly sophisticated approaches to benchmarking. However, these techniques will only have merit if data exists with which to populate them. An ideal benchmarking model might include numerous explanatory factors, outputs and variables capturing regional differences, together with squared and interaction variables, leading to a rich description of the activity of each business. The availability (or unavailability) of data will inevitably limit the extent to which ideal models might be implemented and will rule out certain proposed models that would be impossible to make operational.

3.6 Proportionate resource cost

Finally, it is important to consider the resource cost of implementing a benchmarking methodology. All relevant resource costs should be considered, including the cost of time spent by the NMa, TenneT and external advisors in gathering and processing the data. If a technique requires only modest resource input and yet is found to be fit for purpose, this is clearly to be preferred to other techniques that might require a larger resource commitment. Similarly, it might be prudent to not pursue modest or uncertain benefits that could arise only following a significant resource investment. The counter-argument to this line is that, in comparison with the aggregate cost allowances of the sector, the resource cost of benchmarking is likely to be small. Therefore even small improvements in the accuracy of results might be worth paying for.

In summary therefore, all other things being equal, a less resource intensive approach should be preferred to a more resource intensive approach.

4 Challenges of Application

This chapter is focused on the practical challenges of an application of reference modelling in order to determine an efficiency value for TenneT. As far as possible we have sought to take account of our understanding of the data that TenneT has available. We have also considered the wider regulatory environment into which reference modelling would input.

4.1 Data Demand

As discussed in section 2.2, reference modelling approaches originate from software tools designed to support network planning tasks. Hence, the input data required for the application of reference modelling typically is a part of the data used by network planners for their daily work. While there would still be a need to ensure the efficient transfer of data in an appropriate format, the necessary data needed to apply reference modelling to a standard level of sophistication should be available for any network operator reasonably readily.

Data requirements can be split into technical and economic input data.

4.1.1 Technical data

The technical input data mainly defines the transmission and supply task of a network operator as well as degrees of freedom and boundary conditions for the optimisation problem to be solved by reference modelling. System design decisions are typically not only based on the current transmission and supply task but on its expected development for the foreseeable future. Thus, it might be sensible to consider these expected developments also within the reference model. The provision of such information should be straightforward for TSOs, since they are typically required to publish forecast documents as part of their licence requirements.

- As **substations** are not questioned by reference modelling, a complete list of substations and their voltage levels together with their geographical coordinates should be provided. In order to model connections with neighbouring transmission systems, we recommend to model the connection points (on the border) as virtual substations. Any devices important for load flow characteristics within the transmission system, but not optimised by reference modelling, such as var compensators and phase-shifting transformers, have to be provided as input data together with their technical characteristics.

- For each substation the respective network usage has to be provided. These are mainly **aggregate values for load and generation connected** to the substation. It depends on the exact application of reference modelling (see below) whether one or more scenarios for load and generation are considered. Where voltage restrictions are considered then both active and reactive power balances will need to be provided (including the reactive power control capabilities of generators).

- The **technical rules** which have to be obeyed by system design algorithms within reference modelling have to be agreed on. Typically, such rules can be derived from grid codes or written planning standards. However, it should be checked whether such standards can be interpreted in a unique and unambiguous manner. The conversion of all relevant codes into elements of the reference modelling algorithm is an important step in the modelling process.

- A set of **standard assets** for each asset type (at least switchgears and overhead lines, potentially also cables and transformers) and their technical characteristics has to be provided. Where different standard assets have to be used for different areas there will need to be a mapping of which assets may be used in which locations.

- **Potential routes** for system design together with their length should be defined. Several approaches are possible here. For routes already existing in the actual system the actual length of that route should be used. For any additional route the length can only be approximated as no detailed spatial development planning is likely to be available (i.e. the exact route that would need to be followed by new build would probably be unknown). Typically, aerial distances are multiplied with factors between 1.2 and 1.5 for overhead lines in order to achieve sensible route lengths. If new routes are allowed, then the choice of scaling parameter is likely to be important as a low scaling parameter will increase the likelihood of use of an as yet not constructed route.

Where a stepwise, historical application of reference modelling is pursued, the data outlined above would need to be provided for each period analysed.

4.1.2 Economic data

There are two types of economic data required for reference modelling. These are:

- standard cost and related information for each asset type; and
- actual cost for comparison with the derived standardised cost measure.

Standard asset costs

The set of data required for each defined standard asset are as follows:

- investment costs (per piece or per km)[7];
- useful lifetime;
- yearly operating expenditure (per piece or km), typically as a share of investment costs.

These costs are typically defined to be average costs with respect to influencing factors like layout of towers, ratio between suspension and angle towers etc.

Where these costs differ significantly between several areas (e.g. as a consequence of one area being more difficult/costly to construct in) then two standard asset types with identical technical properties, but different economic properties, should be defined.

Not all data necessarily have to be provided by the TSOs. Sections of the input data, such as specific costs, can be set by the relevant regulatory authorities (e. g. based on literature or separate additional studies) or can be substituted by assumptions. However, imposing assumptions that are not supported by the TSO would require careful justification. The higher the standard costs applied to each TSO, the more efficient that TSO will appear to be in the benchmark (all other things held equal). Consequently, the TSO can be expected to devote considerable attention to arguing for higher standard unit costs.

Actual capital costs

There will be a need to collect the actual capital costs of each TSO. Such information should be readily available for each company on the basis of prevailing regulatory accounting rules. However, as we discuss below, considerable further work might be needed to standardise such cost measures, in particular in cases where companies operate in different countries.

As discussed above one of the practical challenges for reference modelling is the comparison between long-term average costs of reference models and regulatory accounting costs. One approach to address this difficulty is to convert the costs of existing systems also into long-term average costs. If this approach is taken, additional data will be required. This additional data demand covers

- the inventory of assets within the existing system;
- specific costs for the assets within the existing system. These specific costs have to be comparable with the specific costs of standard assets.

7 In this context, investment cost should be understood to be an installed cost. It will therefore embody not only the cost of electrical kit, but also direct labour and the cost of any civil engineering work required. If the reference model application spans several countries then it will be necessary to ensure a common definition of what should be included in these standard costs. This will principally require a common view over what opex like costs should be capitalised.

> This can be especially challenging for older assets as today's reinvestment costs (not historic investment costs) would have to be provided which is often not possible (e.g. if such assets are not produced any longer).

The resulting ratio of standardised actual capital costs to standardised, optimised costs could be used as a basis for comparison.

4.1.3 Data validation

The technical data supplied by the TSO should be available and verifiable from a variety of existing documents (such as generation/demand reports and forecasts and detailed planning applications).

Actual cost data should also be readily available, at least on the basis of prevailing accounting rules, and should therefore require little validation.

Standardised cost data are unlikely to be available in the first instance in the required form, but can be readily derived. Significant work is likely to be required to derive a set of unit costs on a completely comparable basis however and the regulatory office will need to be prepared to defend any assumptions made. The TSO should be invited to submit its own estimates and should be asked to provide a detailed overview of the methodology it has adopted (including assumptions over capitalisation policy).

Transparency should be provided to the utmost extent possible. This will include e.g. allowing different TSOs to check and validate input data of peer group members which would significantly increase the trust in reference modelling results. However, it is possible that confidentiality might limit the extent of any data sharing.

4.1.4 Level of sophistication

Generally, the accuracy of a reference model (in terms of comparability with the existing system) for a given TSO is increased if the particular boundary conditions applicable for this TSO are modelled in a very detailed manner. On the other hand, an application relying to a high extent on general input data and assumptions will deliver less accurate models but might allow an investigation of specific issues at an acceptable level of complexity and administrative burden. Consequently there is a trade-off between accuracy and administrative burden.

In order to demonstrate the possible bandwidths for an application of reference modelling, we will explain two extreme applications in the following. The first application described can be considered an application with minimum data requirements, whereas the second aims at maximising accuracy.

Minimum data application

An application designed for minimum data requirements would require TSO-specific input data on only:

- substation locations;
- and one value for load and generation per substation (only active power balance, e.g. maximum value of last complete year).

One could assume that any route between two substations will be possible (with a route length of 1.4 times the aerial distance) and that the reference model should consist of one voltage level only (e. g. 380 kV). As a technical rule for system layout a typical (n-1)-criterion would be applied but only with respect to thermal rating of lines. The set of standard assets to be used would be provided by the applying regulatory agency e.g. on the basis of available research reports on best practice in Europe. Reference models resulting from such minimum application will not be directly comparable with the actual system of a TSO. They could not be used as an absolute benchmark (see section 2.4.1). The usability for other purposes like a relative application (see section 2.4.2), however, cannot be assessed in a definitive way for a general case. Instead, the assessment would depend on the specifics of the selected peer group. As long as all compared TSOs do not differ significantly with respect to the effect of any cost drivers neglected in the reference modelling, the results might be valid for a relative benchmark. Where this is not the case, it is possible that neglected cost drivers could lead to a set of results subject to systematic bias. If TSOs from different countries with varying technical and legal framework conditions are to be compared, there would be a need to defend a simple application as reasonable on the basis of the underlying comparability of the TSOs.

Maximum sophistication application

A reference modelling application designed for maximum accuracy reduces the number of assumptions and standard values to the greatest extent possible. To support such modelling a case-specific data and detailed set of data will be needed from each TSO. This would mean that the TSOs would not only have to provide the above mentioned input data for the minimal approach but also detailed information on:

- installed devices for voltage control;
- several scenarios for load and generation per substation (preferably not only for today and the foreseeable future
- for historic points in time;
- a TSO-specific (and possibly regionally differentiated) list of standard assets together with their costs;

- individual planning standards; and
- a thorough assessment of possible routes and their lengths.

Additional routes not realised in the existing system would have to be evaluated on a whitelist (additional routes possible and their lengths are explicitly named) or blacklist basis (impossible routes are excluded, for possible routes a country-specific ratio between length and aerial distance is applied). All TSO-specific data would have to be validated by the respective regulatory agencies. This is important for the specific costs of assets in order to discriminate between explainable differences in specific costs and inefficiencies.

The reference model optimisation algorithm itself would become more complex as the amount of input data would increase, several scenarios for network usage would have to be considered and more complex calculation methods (AC instead of DC load flow, short circuit calculation etc.) would have to be applied. The results, however, particularly if historic influences are captured by a stepwise application as described in section 2.2, should be closely comparable to actual systems. Such an application would also facilitate the comparison of the systems of TSOs with potential very different boundary conditions (e.g. regarding planning standards, minimum requirements for quality of supply, specific costs etc.) as such differences would be considered within the reference modelling application itself.

We would expect that any real applications will lie in between the bandwidth defined by these extreme minimum and maximum specifications, based on the underlying comparability of the companies in the peer group and the availability of data.

4.1.5 Data Availability at TenneT

In our discussions with TenneT we have reviewed the availability of data for both above mentioned specifications. TenneT confirmed to us that they will be able to deliver any data needed for a reference modelling application aside from information on historical network development usage which is not available. Based on our experience also other TSOs don't typically have accurate representations of past network usage cases. This is to be expected given the long lived nature of transmission infrastructure and hence the age of some installed assets. Hence, even if such data would be available for TenneT it is unlikely to be usable in the context of a relative benchmark, as we anticipate the same data would not be available for potential peers.

In the absence of historical data, it will of course still be possible to apply reference modelling as described in Section 2. However, this will leave open the question of whether an application that ignores the development path that has arisen as a result of the historic evolution of demands on the grid might give rise to a bias.

Challenges of Application

4.2 Peer Data

If reference modelling is to be used to compare TenneT to other TSOs a peer group has to be selected. Within this chapter we will focus on general requirements regarding peer data. The necessary sample size is addressed below.

In order to achieve sensible results from reference modelling, the network operators within the peer group should ideally be as comparable to TenneT as possible. This affects technical as well as economic aspects of the comparison. Nevertheless, most likely it will not be possible to define a peer group among which there are no significant differences in cost-driving factors. Such differences have to be explicitly considered by the reference modelling approach itself. In our discussions TenneT[8] has highlighted what it believes to be a number of important technical considerations for inclusion in a reference model, including:

- high costs for permit procedures (i.e. the increased cost of securing access to new routes or upgrading existing routes);
- high technical standards of construction (in particular the amount of steel used in towers);
- high ratio of angle to suspension towers;
- the salty environment near the seaside;
- the need for undergrounding parts of the system; and
- the high number of water crossings.

It lies beyond the scope of this study to assess these supposed cost-driving factors in detail, but any subsequent application of reference modelling would need to consider carefully whether these factors should be taken into account. We would nevertheless recommend that in advance of any reference modelling application it is secured that these factors:

- either affect all compared network operators to a more or less identical extent; or
- are modelled explicitly e.g. when setting the specific costs for standard assets.

Generally, comparability within the peer group is one of the major issues when assessing the efficiency of a TSO. One important reason is that most countries only have one TSO so that there is no natural peer group which is exposed to an identical legislative framework and very similar technical challenges. As a remedy

8 TenneT has also indicated that it does not regard this list as necessarily exhaustive and it could raise additional factors in due course should reference modelling be pursued by the NMa.

to that problem the TSO could be compared to DSOs from the same country or to TSOs from another country(ies). We discuss both possibilities in the following sections.

4.2.1 Potential comparison of TenneT with Dutch DSOs

Comparing a TSO and domestic DSOs is potentially appealing since DSOs operate in the same country and hence share a very similar legislative framework, although energy laws might define different rights and tasks for each. Nevertheless, differences regarding the historic development of the regulatory framework, rules on accounting and depreciation and technical standards, which often are difficult to handle within international benchmarking applications, should be minimised by such comparison. We would consider it challenging to compare TenneT against a set of Dutch DSOs for several reasons.

- TenneT as the Dutch TSO not only operates 380 kV and 220 kV networks but also most parts of the 150 kV network within the Netherlands. However, DSOs operate networks at voltage levels of 50 kV or even lower. Where 150 kV networks (typically designed for subtransmission tasks) are structurally comparable with EHV systems to some extent, network structures and network planning methods, security and quality of supply requirements, typical assets, maintenance methods and licensing procedures are very different between transmission systems and distribution systems at lower voltage levels. Consequently, it would be hard to draw any valid conclusions from a direct comparison. In particular, we would consider it difficult to distinguish between real inefficiency and differences due to varying framework conditions.

- While the development of distribution systems is typically driven by a continuous evolution of influencing factors (e.g. load, connections), single discrete decisions like the connection or retirement of a new plant will have major effect on the efficient layout of a transmission system. Furthermore, the extension of transmission systems has to be done in discrete steps taking into account possible developments that are uncertain by nature. Hence, we would expect transmission systems to be much more exposed to historic developments leading to a suboptimal solution from today's perspective, but also to inefficiency risks due to more uncertain boundary conditions than any distribution system. This is especially relevant as smoothing effects are also limited due to the low number but high economic value of individual assets.

As a consequence of these factors, we do not believe that a relative application using Dutch DSOs provides a fruitful way forward for the NMa.

4.2.2 Potential comparison with other TSOs

In contrast with a comparison with Dutch DSOs, the most relevant challenges for comparing TenneT with TSOs from different countries are the differences in regulatory and legislative framework, in particular regarding:

- the duties of the respective TSOs; and
- accounting and depreciation policy.

Any differences within these fields will lead to a situation where actual costs of the compared TSOs are not directly comparable. It should be noted that these problems do not only apply specifically to reference modelling but generically to any international TSO benchmarking. Thus, they do not set up specific obstacles for an application of reference modelling.

There is a direct link between the comparability of peer group members and the necessary accuracy level of the reference model. The higher the comparability of the TSOs within the peer group, the less aspects have to be modelled explicitly within reference modelling and the lower data requirements tend to be. This is especially important as varying data availability in different jurisdictions might impose limits on the achievable accuracy of reference modelling. If reference modelling is to be pursued, we would therefore recommend that the NMa seeks for a peer group which consists of TSOs that are as similar as possible to TenneT. As indicators for such similarity one could use e.g.:

- technical standards applied (which might e.g. differ in different synchronous systems);
- input costs (e.g. labour costs);
- population density;
- exposure to historical developments;
- load density; and
- transmission network length per peak load

Furthermore, it would be preferable for compared TSOs to be exposed to similar challenges in general. For instance, a TSO with assets to a large extent depreciated, but significant network extension requirements (e. g. due to changing location of generation) and high constraint costs might turn out to be more efficient in reference modelling applications than another TSO where extension plans have already been realised, constraint costs are consequently low but infrastructure costs of non-depreciated assets significantly higher than in the former case. TSOs at similar points in their investment cycle should therefore provide a more comparable peer group[9].

It is not clear that it is possible to provide a general recommendation regarding which TSOs are most comparable to TenneT. We would recommend that the NMa investigates particular cost drivers for each potential peer group member and decide whether these cost drivers have to be modelled explicitly by the reference model. In order to undertake such an assessment collaboration with at least one other regulator is likely to be required. This follows since we are unaware of any public source of data on TSOs that would provide the information needed to undertake such an assessment.

4.3 Time Demand

The NMa has asked us to consider the time that would be needed for reference modelling. This time demand should more or less directly correlate with the costs of applying a reference modelling approach as there are no significant costs other than the time commitments of NMa (and other involved regulatory authorities), TenneT (and other involved TSOs) and the appointed consultant.

As noted above, the administrative burden of applying reference modelling and therefore also the time demand will change depending on the level of complexity of the reference modelling. In the following we will again identify a spectrum of possible time requirements depending on the level of sophistication. For our estimations on time demand we will distinguish between the preparatory phase including data collection, the actual application and any post-processing including the discussion with the involved TSOs.

- During the preparatory phase a peer group has to be selected and an arrangement among the involved regulatory authorities on principle guidelines has to be agreed.

- Initial work needs to be undertaken to reduce the relevant network codes of each participating country/company to the point where they can be included within an optimisation algorithm.

- As a second step, data requests have to be drafted and co-ordinated among regulators. We would expect that these data requests have to be consulted on with (at least) the affected TSOs before a final decision on necessary data

9 It is worth noting, however, that among the German TSOs investment cycles obviously differ. One relevant example is the 380 kV voltage level, the construction of which started in the late 1960s (especially in the western and south western parts of the country), which was however more or less completely reconstructed or newly constructed in the eastern parts of the country after 1990.

provision can be taken. In the likely case of comments from TSOs' side an arrangement among regulators on whether and how data requests should be revised has to be found. We would furthermore recommend to co-ordinate the data request with the selected consultant for the later application of reference modelling. We would expect that it will take at least six to nine months from establishing a first contact among regulatory authorities until a final data request can be sent out given the length of consultation typically required.

- Depending on the intended accuracy level appropriate response times for TSOs might lie between eight weeks and six months (see explanations above).

- After having received the TSOs responses, the regulatory authorities will have to check the validity of the data provided. We would assume a time demand of another two months for such validity check. During the whole preparatory phase, however, only intermittent workload (due to pending co-ordination etc.) is likely to occur.

- The application of reference modelling itself consists of preparing the input data sets for the respective software tools, the (most likely iterative) application of these tools and intensive quality assurance measures where the validity of results has to be checked, models have to be revised, findings have to be documented etc. We would estimate the necessary time-demand for such application to amount to roughly 20-25 man-days per TSO. Total time demand will depend on the possibility of a parallel application (personnel and technical resources of the selected consultant). As normal personal computers typically fulfil computational requirements for applying reference modelling software, at least a partially parallel application should be possible.

- If there is a need for significant scenario/sensitivity testing the modelling phase could be further extended, perhaps by an additional 5-10 man days depending on the extent of analysis required.

- During the post-processing step, the results of the reference modelling application should be presented to the modelled TSOs. At least they should be provided with the input data and disaggregated results to validate the findings for their own system. Full transparency for all compared systems is recommended if no confidentiality requirements prohibit that. We would expect that TSOs will need at least four weeks to cross-check and validate the concrete results of reference modelling application. Depending on the outcome of that check models might need to be revised. Such revision should, however, only occur under rare circumstances. The expected additional effort is therefore considered to be low (a few days) on the consultant side.

The necessary time demand for data provision by TenneT obviously depends on the amount of data to be provided and possible effort due to format conversions and similar issues. TenneT, however, agreed with our tentative findings that the necessary time demand after final definition of data requirements could lie in between eight weeks (minimum application) and six months (accuracy-optimised application, excluding historical data).

Given these estimations above, the total process of applying a reference model in order to assess TenneT's efficiency is estimated to last approximately one year. Neither NMa, nor TenneT, nor commissioned consultants will have to work continuously on such project, however.

4.4 Use in Method Decisions

In this subsection we consider how the regulatory approach to using reference modelling might give rise to certain challenges and, if that is the case, what factors might determine whether those challenges could be overcome. However, we begin with an initial discussion of the rationale for benchmarking in a regulatory setting and the Dutch regulatory system, both of which provide important context.

4.4.1 Using efficiency analysis in regulatory reviews

It is helpful to begin with a review of the usual role of efficiency analysis in regulatory review.

Benchmarking, if applied appropriately, is an effective tool for overcoming the asymmetry of information between the regulator and the regulated operators. In principle, in the absence of benchmarking, the regulator must judge whether or not a regulated operator is performing at the maximum possible level of efficiency on the basis of information revealed by the operator itself. If there are penalties for inefficient behaviour, the operator is unlikely to reveal information that makes it appear inefficient. Therefore, in order to provide an incentive for the operator to reveal this information, the regulator must offer some sort of reward. Ultimately, the cost of that necessary reward is borne by customers.

If benchmarking is possible, the regulator will be able to compare operators to retrieve information on the possible level of performance 'independently' of the information revealed by the operator itself. Benchmarking can therefore be used to reduce the size of the reward offered to operators, without necessarily reducing the strength of incentives.

However, no benchmarking can perfectly capture all differences between companies. Consequently, when a benchmarking model identifies a gap between actual performance and the level that the model predicts should be achieved, this could be as a result of something other than managerial inefficiency. Differences in perceived performance can arise from a number of potential sources including underlying differences in:

- operating environment (e.g. geography, topography, soil properties, and the urban/rural nature of certain areas);
- past configuration decisions and planning constraints;
- differences in the relevant legislation (e.g. planning, health and safety, employment, pension etc.) and tax/accounting standard;
- input costs (e.g. labour rates, local taxes);
- past managerial efficiency in planning and delivering capex; and
- current managerial and operating efficiency.

Where the outputs of the benchmarked companies are difficult to measure completely and unambiguously, observed differences in performance could also be a consequence of omitting an important cost driver from the analysis (or at least failing to capture it completely).

Debates over the meaning, and hence appropriate use, of efficiency studies in regulatory determinations are inevitable and will focus on the extent to which the results can be understood to be primarily driven by managerial inefficiency or by one of the other factors identified above.

4.4.2 The role of the Ministry in approving important investments

We understand that as a consequence of recent changes to legislation, from 1st July 2011 any significant investments undertaken by TenneT will be sanctioned by the Ministry.

We do not believe that this gives rise to any concerns with regard to reference modelling since it is entirely feasible to identify a set of existing infrastructure (and associated costs) that the model will take as given. Should the NMa wish to treat Ministry sanctioned investments as efficient by default, such a treatment can therefore be accommodated within the reference model.

4.4.3 Cost standardisation

As with any benchmarking technique, it is essential that the actual cost data used are appropriately standardised to ensure comparability. Otherwise, there is no way of confirming that the results of the benchmark are not confounded by a lack of comparable input data, making them consequently unsuitable for regulatory application. The standardisation of capital costs is particularly challenging and since reference modelling's main focus is capital costs, this issue requires careful consideration.

Absolute application

In the context of an absolute benchmark, the issue of standardisation arises as a result of the need to consider how the results could be applied to determine an efficiency "catch up" factor for the company scrutinised. Since reference modelling does not inform on the age structure of assets installed, while any typical regulatory cost measure does, there is likely to be a need to consider how to convert the standardised annuity cost from reference modelling into something that can be compared with regulatory measures of capital consumption. For example, the age of actual investments on each route could be used to calculate the age adjusted standard cost of that piece of infrastructure. However, this might require a significant level of detail over the actual installed assets, and where lines have been refurbished a number of times it might not be possible to identify its age unambiguously. Similarly/additionally, the scrutinised company is likely to argue that the standard cost of assets installed today is too low for use in valuing older assets, as a result of technical progress. Significant effort is likely to be required to address these questions.

Relative application

For a relative application in this context, the issue of cost standardisation will be even more important as there will be the need to gather data for companies operating in other countries. Again, this issue is not specific to reference modelling but is a generic point that applies to any benchmarking technique. However, in this case the task at hand will be to ensure the comparability of capital costs across international boundaries.

Considerable effort will therefore be required to ensure close comparability, drawing on a range of necessary data. Adjustments might be required to account for differences in at least the following elements:

- tax rates;
- interest rates/allowed returns;
- actual asset ages[10];
- currency fluctuations;

[10] It might be necessary to make an adjustment to take account of differences in investment cycles, since in a capital cost only assessment companies with older assets could appear more efficient than companies with newer assets. This follows since older assets will be more fully depreciated than newer assets and consequently the "old" company will have lower regulatory capital costs than the "new" company under the most commonly used regulatory accounting rules. Under a total cost assessment any benefit for the "old" company will be likely to be offset by increases in inspection and maintenance costs associated with older assets.

- input prices, e.g. labour rates (and differential costs of social/pension provisions);
- capitalisation policies (i.e. allocation of overheads to capex, including potentially differences in insourcing/outsourcing policies);
- assumed asset lifetimes;
- depreciation method (e.g. straight line, annuity); and
- inflation accounting.

The task will be to develop a methodology in which as similar as possible a method has been adopted to develop a standardised actual cost measure for each company. We envisage the task of standardisation entailing significant work from the NMa and any other collaborating office, and also in identifying how efficiency scores derived from standardised cost measures could be "mapped" back to costs on a regulatory basis for us in Method Decisions.

If it were possible to gather data for a relative application from companies operating under essentially the same regulatory regime then many of these issues would be immediately addressed. For example, if all companies in a relative sample used precisely the same accounting rules and operated in the same country, there would be considerable confidence that actual cost measures calculated for regulatory purposes would already be highly comparable. However, since TenneT is the only operator of an electrical transmission grid in the Netherlands, the only other possible source of such comparable data is the Dutch distribution companies and as we discuss in section 4.2.1, we foresee difficulty in achieving a successful application of a relative approach on this basis.

4.4.4 Modelling historical developments

For the absolute application of reference modelling, there would appear to be limited scope for reference modelling that does not take account of historical developments, unless it can be demonstrated that demands on the network have been consistent and have grown uniformly over time. If demands on the grid have changed over time then it is entirely likely that the resident transmission operator will be found to have assets that are not optimal (e.g. excess capacity on some routes), where those assets were originally installed to serve needs that have changed. A regulated company faced with a reference model that did not take account of historical developments would be likely to mount a detailed defence of the rationale for the original installation of their assets.

In the event historical effects are captured and modelled appropriately, then in principle the resulting reference model will only identify assets that have been installed in the past without an obvious need case. Since there are likely to be few such assets (at least few examples of very significant unjustified schemes), it is reasonable to predict that the model will produce an optimal reference that is very close to the actual grid. In this case, there is an argument that reference modelling decomposes down to a unit cost benchmark, where there is close agreement over the assets that should be installed but potential differences over what they should have cost. If NMa has no reason to suppose that TenneT's grid is suboptimal (or at least not optimal given the changing demands it has served over time) then it might be better to proceed directly to an examination of TenneT's unit investment costs, which would involve significantly less resource.

In the context of a relative benchmark, there is the potential for reference modelling to take no account of history, provided that there are reasonable grounds to believe that each network in the sample will have faced a similar degree of additional cost (versus the present optimum) from meeting historic demands. However, given the locational specificity of assets and the lumpiness of investments there is no *prima facie* reason why the effect of the evolution of demands over time on a grid's costs can be expected to be similar for each TSO in the sample. Consequently, if the burden of proof falls on the regulator it is likely to find itself needing to justify the reasonableness of this assumption with detailed analysis, while the data to do so are unlikely to be readily available for any TSO.

4.4.5 Sample size

Intuitively it would seem reasonable to presume that the larger the sample of companies involved in a relative study, the more robust the results of that study might be perceived to be. If very many companies were modelled using the same reasonably detailed approach it is likely that the resulting efficiency results could be highly informative. A regulatory regime that required a given company to match the average (or median) performance in the sample (i.e. to be as close to its optimised model network as the average/median level in the sample) might be considered highly defendable, even in the context of a regime where the burden of proof falls primarily on the regulator, provided the key cost driving factors of the resident TSO were captured sufficiently well by the reference model.

However, even with a large sample a regime that imposed the ratio of the most efficient firm in the same sample might be regarded as significantly less defendable. In this case, the regulated company is still effectively being compared to a single firm, where that firm has the most extreme positive result. It is possible (perhaps even likely) that this best performing firm is particularly favoured by the methodology and this would be likely to be the basis of a critique of the approach.

This discussion reveals that, as a general proposition, relative reference modelling should typically become more robust as more firms are included in the sample, provided the frontier level of performance is not applied. In this context, we can consider absolute reference modelling as a unique case application, with a sample size of one.

The obvious question then, is how many companies are needed in the sample to produce a robust result. The answer will vary on a case by case basis. In circumstances where it can be shown that the included networks share many similarities (in operating conditions, legal environment, evolution path etc.) and/or that any differences in cost drivers have been fully modelled, a small sample might be considered sufficient.

4.4.6 Incentive properties

The choice of benchmarking technique applied by regulators can have important consequences for the incentives faced by companies. Since companies can be expected to respond rationally to the effective incentive structure created by the regulator, it is necessary to consider how TenneT's behaviour might be influenced by the application of a reference model, absent any other countervailing change to the regulatory regime.

The first order incentives of a reference modelling style benchmark, whether absolute or relative, would appear to be likely to deliver sound public policy outcomes. A company benchmarked in this way – and having the reasonable expectation that it will continue to be benchmarked in this way – will know that its choice over which assets to build and when will be subject to review, as will the cost of installing those assets. Consequently, it should rationally seek to deliver the right investments at the right time at the least cost.

However, reference modelling could have further incentive effects since it might reduce the certainty that the scrutinised company might have over capital recovery. Unless certain assets are identified as "given" in the development of the reference model, the need or otherwise for all installed assets is subject to question. From the company's perspective, this gives rise to the risk that a future reference modelling exercise might find a certain past investment unnecessary and hence it could be disallowed by the regulator. This would cause a significant increase in regulatory risk, as absent any other adjustment it creates the possibility that past investments (including those that have previously been scrutinised by the regulator) could now be stranded. Similarly, the use of standard asset prices to examine costs creates the risk that, even if the need for assets remains and is validated by the model, the cost of installing those assets might be deemed excessive at some future review.

Stranding risk of this kind could be deemed to increase TenneT's regulatory risk and as a consequence their cost of capital. It could also have the effect of discouraging TenneT from making investments without seeking to have them "certified" as necessary in advance by the regulator, i.e. TenneT could become more risk averse in deciding whether to proceed with an investment.

Furthermore, since reference modelling scrutinises only capex costs in detail, without any countervailing changes to regulation TenneT might rationally choose to adopt high opex – low capex network solutions, if it believed that capex was subject to a tougher test than opex. If not addressed, then over time this could lead to a system with higher constraint costs and outages than is optimal.

The NMa will need to consider whether other elements of its regulatory regime might have the effect of mitigating this possible increase in risk. This will be particularly relevant given the wider context of the electrification of economic activity across Europe and the drive for the connection of increased renewable generation, both of which have the potential to require very significant increases in transmission investment. The NMa will wish to ensure it strikes the appropriate balance between encouraging efficiency in capital deliver and securing needed transmission infrastructure investment in a timely manner.

5 Summary

In Section 2 we provided background on reference modelling and its potential uses. Building on this background, in Section 4 we have provided an analysis of reference modelling in general and under the specific circumstances that might be envisaged by the NMa. In this concluding Section we draw together the key messages and themes from those sections into a summary, structured using the criteria set out in Section 3. We provide:

- an assessment of a relative application of reference modelling using a sample of international TSOs;
- using this assessment as a base, we then assess:
  - a relative application against a sample of Dutch DSOs;
  - an absolute application; and
  - using reference modelling as an input to the European TSO benchmarking project.

We also provide specific answers to the questions identified in the original terms of reference for this study, listed in Section 1. In particular, our report concludes with a review of the critical success factors that together determine whether there is scope for the successful application of reference modelling.

5.1 Assessment of the regulatory use of reference modelling

Below we provide a summary of our views on the potential use of reference modelling. We begin with a full assessment of the merits of a relative application against an international sample of TSOs. Subsequent assessments of the alternative regulatory approaches are made relative to this first assessment.

5.1.1 Relative application – using International TSOs as a peer group

Below is our summary assessment of the possible relative application against a peer group of International TSOs. For this we have presumed that a reasonably sophisticated reference model would be needed, although some factors that might need to be modelled in full in an absolute application could be dropped.

Table 1. Summary assessment of the application of an relative reference model to TenneT – International TSO peer group

Criteria	Assessment
Robustness	• Heavy burden on the detail of the modelling given the need to capture all factors that potentially have a differential impact on companies in the peer group. • Modelling that captures historic developments not possible • Need to demonstrate that ignoring historical developments does not bias the results – which could be difficult to prove (note, equally hard to disprove, although there are in principle arguments that suggest modelling history could be important) • Need to standardise actual cost data for other companies to ensure comparability of the ratio of actual to modelled cost – although this challenge will arise in almost all benchmarking approaches • Need to develop standardised cost assumptions for modelled asset components for each company • NMa would therefore need to be able to defend a significant number of assumptions in its Method Decisions and subsequently on potential appeal • Can only inform reliably on capital costs – unlikely to be sufficiently robust on network opex, business support costs, system operation etc., implying that additional techniques will be needed to assess TenneT's complete cost base • Robustness could potentially be improved by making use of glide paths, not setting the benchmark at the frontier etc.
Transparency	• Each company in the sample would have a good understanding of its own model and the process of modelling applied to all • But it would not be possible to replicate the reference model of another company • Confidentiality could further limit data exchange • Would be almost impossible for "outsiders" to replicate however – in particular could be hard to demonstrate the clearly the reasonableness of the model in court
Promotion of efficiency	• Strong incentives on the regulated company to plan and deliver capex efficiently • But could significantly increase regulatory risk by potentially disallowing existing capital costs – care needed to ensure incentives to invest are preserved • Limited incentives on network opex and cannot inform on business support costs, system operation • Need to ensure no incentive to substitute into opex and away from capex through the use of additional measures
Adaptability	• In principle the reference model can be updated at each review to reflect developments and new policy goals • There would be a resource cost associated with the need to

	develop further the reference model • If collaborating regulators did not wish to continue the co-operation, there would be no way to repeat the study at subsequent reviews
Availability of data	• Slightly reduced data work required to facilitate a reference model for use in an relative context (compared to absolute) – but significant data still required • Data required for the more robust version of modelling, that accounts for historical developments, not available • Additional work involved in gathering data from TSOs but this effort would be incurred by co-operating offices. Absent this co-operation NMa has no ability to access data for peers
Resource Cost	• Significant time required by NMa, external consultants and TenneT to agree data, collect data, construct and test model - could be ~6 months of work, ~1 year of elapsed time • High cost as many companies will need to be engaged – but mitigated by potentially reduced complexity of the reference model and the fact that some costs would be borne by other offices • More project management required to ensure all reference models completed to same standard by the required timetable – and the management of this process could be largely beyond NMa's control (highly dependent on co-operating offices) giving rise to the risk that key deadlines might not be met • Cost likely to exceed other traditional forms of assessment very materially • Given limited cost base coverage, must be used in conjunction with other techniques to ensure complete cost coverage

5.1.2 Relative application – using Dutch DSOs as a peer group

Below we set out our assessment of a relative application using Dutch DSOs as a peer group. As noted above, we report only the key differences to the assessment of a relative application versus an international TSO sample, presented in **Table 1**.

Table 2. Summary assessment of the application of an relative reference model to TenneT – Dutch DSO peer group

Criteria	Assessment
Robustness	• Data required for a fully historic analysis unavailable. • We do not anticipate that it would be possible to demonstrate that TenneT and DSOs have been subject to similar historical effects, calling into question the validity of comparing TenneT to ratios of actual:modelled cost derived from DSOs • Hence we foresee a significant risk that the model does not withstand challenge when used in a regulatory context under any circumstances • Reduces the extent of data standardisation as all companies will operate within the same legislative framework • Otherwise, as above
Transparency	• As above
Promotion of efficiency	• As above
Adaptability	• In principle the reference model can be updated at each review to reflect developments and new policy goals • There would be no dependency on other offices as NMa would have the ability to collect all relevant data from Dutch DSOs
Availability of data	• Additional work involved in gathering data from DSOs, but NMa has the ability to compel DSOs to supply the required information • Otherwise as above
Resource Cost	• Many companies will need to be engaged – the entire cost would be borne by Dutch society given no outside collaborators • Otherwise as above

5.1.3 Absolute application

Below we provide a summary of our views on the potential use of an absolute benchmark. Given the characteristics of an absolute study, for the purposes of populating the table we have presumed that a sophisticated reference model would need to be applied in order for the approach to have any prospect of being sufficiently robust.

Summary

Table 3. Summary assessment of the application of an absolute reference model

Criteria	Assessment
Robustness	• Heavy burden on the detail of the modelling – the model would need to capture all potential cost drivers unlike in a relative application • In the context of TenneT we know that an application that models the historical evolution of the network will not be possible – and the context of an absolute study this is likely to leave the modelling results vulnerable to the critique that the model is simply failing to recognise that "inefficient" assets were originally installed efficiently to meet a need that has now changed • We foresee a risk that the model would not withstand challenge, even if the model is used in a cautious manner (e.g. glide paths and not requiring frontier performance be achieved) • Reduces the need to standardise actual costs, although there will be a need to map the output of the reference model to actual costs, so some work still required
Transparency	• As above, although the concerns over verifying the modelling of other companies fall away
Promotion of efficiency	• As above
Adaptability	• Largely as above, but the need to study only one company in detail removes some of the co-ordination concerns associated with the relative study
Availability of data	• Intensive data work required to populate a most sophisticated reference model • Data required for the more robust version of modelling, that accounts for historical developments, not available.
Resource Cost	• Largely as above, although the resource cost implications of absolute versus relative are potentially ambiguous. The need to study only one company reduces the resource cost compared to a relative application, but the need to study that company in more depth will increase resource costs.

5.1.4 Input to European TSO study

We conclude this subsection with an assessment of the merits of undertaking reference modelling for use as an additional cost driver in the existing (or subsequent) European TSO benchmark.

Summary

Table 4. Summary assessment of the application of an reference model to enhance the existing European TSO benchmark

Criteria	Assessment
Robustness	• Possible to justify modelling more in line with the minimum data requirements model outlined in this report given the intended use as an input to another technique • Still the potential need to demonstrate that neglected factors do not give rise to a systematic bias, although a lower burden of proof might be accepted • Need to standardise actual cost data for other companies, but considerable work has already been done on this in the context of the European TSO benchmark • Ultimately, the robustness would remain broadly consistent with the perceived robustness of the existing benchmark, although the application of reference modelling might provide some improvement in validity • Can only inform reliably on capital costs not other costs – but used in this way could be accepted as a broad measure of "scale" and hence used as a potential explanator of opex
Transparency	• Largely as above, but the large number of participating countries would make it difficult for any one entity to have a reliable overview of the models and validity of those models for all companies/countries
Promotion of efficiency	• Governed by the cost coverage of the European TSO benchmark and the proposed application of the results in Method Decisions, so not assessed here in detail • However, the potential for the approach to also operating costs could remove a potential distortion, or the need to address that distortion with an additional incentive
Adaptability	• In principle the reference model can be updated at each review to reflect developments and new policy goals • There would be a very large resource cost associated with the need to develop further the reference model however, given the number of countries participating • If collaborating regulators did not wish to continue the co-operation, there would be no way to repeat the study at subsequent reviews – the approach might remain applicable is sufficiently many regulators/companies remained as participants
Availability of data	• As above
Resource Cost	• Cost likely to exceed other traditional forms of assessment very materially – but the costs borne by the NMa would be reduced relative to other reference model applications considered here as only simple modelling would be applied to TenneT

Summary

5.2 Answers to specific research questions

Our terms of reference posed a number of specific questions to which the NMa were seeking answers. We address each in turn here.

5.2.1 What can reference modelling tell the NMa about TenneT?

Reference modelling develops an optimised grid layout to serve a specified transmission task. There is a wide range of factors that could potentially be included within a reference model study, allowing the researcher to take account of more or less potential cost drivers, depending on the data and resources available and the nature of the question they wish to answer.

Given this, reference modelling can potentially answer questions around the optimal level of the installed asset base, including potentially the efficiency of proposed incremental investments. The critical question will then be whether the reference model can be made sufficiently robust that the results can be used in a regulatory context.

5.2.2 On which areas will reference modelling not be informative?

Reference modelling is less well suited to addressing the level of opex incurred. The optimised network can be used to assess at a high level whether direct network operating costs are broadly reasonable, but the assessment would not, in our view, be sufficiently detailed for use in a regulatory context. Furthermore, reference modelling cannot inform on the efficiency of business support costs and other indirect engineering support, nor can it inform on the reasonableness of system operation costs. It is unlikely that the NMa would wish to use reference modelling alone therefore, as there will be a need to determine opex allowances in addition to the level of reasonable capital costs.

5.2.3 What would TenneT need to do?

At a minimum, TenneT would need to provide the data necessary to facilitate reference modelling (see Section 4.1). From discussion with TenneT we understand that almost all of the data that might be useful would be available. NMa has the authority to request formally all relevant data.

TenneT has confirmed that it would not be able to provide the data needed to populate a model that took account of the historic evolution of the network and the supply task.

In addition to providing the data, any reference study would benefit from constructive engagement with TenneT. This would help to ensure that, for example, the relevant codes and planning conditions had been appropriately codified within the reference model itself and also that all relevant potential cost drivers (as viewed by TenneT) had been analysed.

5.2.4 What are the resource implications of pursuing reference modelling and how long might a study take?

The only significant costs are the time inputs of the NMa, TenneT and the consultant that might be appointed to undertake the reference modelling. We anticipate that it might take up to one year to complete a reference model study, accounting for data collection, model construction, model testing, model running, sensitivity analysis and reporting, with the need for consultation at a number of stages. While nobody would need to work on reference modelling continuously during this period, it is still reasonable to presume there would be a significant time commitment involved from all parties. In the absence of more specific proposals over the depth of the reference model and the number of participating countries/companies, it is difficult to be more precise over the potential cost of these time inputs. However, it is clear that reference modelling is likely to be considerably more resource intensive than many other benchmarking techniques.

5.2.5 What are the critical success factors?

It is possible to identify a range of circumstances each of which would need to be in place in order to be able to implement successfully a reference modelling study. The relevant factors will include:

- the reference model can capture most critical cost drivers accurately;
- anything excluded from the model is either not a significant cost driver; or
- has a similar effect for all companies;
- standard unit costs can be identified, objectively justified and are sufficiently stable over time to be used to assess historic investments;
- the actual cost data used to form the ratio compared can be adjusted to be highly comparable;
- the potential for an increase in the risk of asset stranding is mitigated by other elements of the regime or is considered reasonable and defendable; and
- the work required for a cross-jurisdictional study can be completed within the required timelines and budgets.

If each of these is in place, then the outcome of the reference study should be sufficiently robust and suitable for regulatory purposes. Where not all of these can be shown to hold, the resulting study could still be used in a regulatory context through a cautious application of the result, or simply in order to bring about a detailed exchange of information between company and regulator in order to close the gap in information available to each.

5.2.6 What assumptions need to be made and can they be justified?

With regard to the critical assumptions that must be made these mostly pertain to the ability to demonstrate that:

- certain potential cost drivers can be excluded without biasing the analysis;
- standard prices can be identified and defended; and
- that any differences in accounting treatments between participating countries/companies can be addressed.

Of these three areas, the last two are most likely to be addressed successfully. However, the work involved in standardising capital costs and deriving defendable standard prices across an international peer group should not be underestimated – both of these tasks should be understood to be large undertakings in their own right. Significant work is likely to be required, including substantial sensitivity analysis, and this might result in potentially reasonable ranges rather than a single point estimate. As with any implementation phase, there is always a risk that these topics might not be addressed to the satisfaction of the NMa and/or the relevant appeal bodies, reducing the robustness of the results of the study. For example, given the long lived nature of transmission investments, standardisation of actual capital costs might require the availability of a great deal of data on historic investments, not all of which might be available. Data shortages might be overcome by making assumptions, but every assumption made has the potential to weaken the analysis and it is possible that the result might not be regarded as sufficiently robust.

Potentially the most difficult area in which to demonstrate that assumptions are reasonable is likely to be the effect of excluded potential cost drivers. Where all firms can provide data on the factor in question, analysis might be possible to confirm the effect of the cost driver – although to do this robustly might require the construction of a reference model that includes the cost driver in question in full in any event. Alternatively, stylised engineering analysis might be able to provide an indication of the potential effect of the cost driver, allowing analysis to proceed in this way. The most significant difficulty will be in cases where the data necessary to model the potential cost driver in full is simply unavailable (for one or more company), the most obvious example of which is the historic data that we know TenneT cannot provide. In the absence of data on historical evolution, how can it be proved that no bias arises from not modelling this factor, one way or the other? We believe that it will be difficult to move much beyond potential high level arguments in this area and this could present an important drawback for the NMa.

In summary, significant work would need to be undertaken in each of the three main areas identified above. Each of these areas is likely to throw up difficult challenges and all of these would need to be addressed satisfactorily. To be more concrete we would need to consider a specific application, in order to understand more about the potential similarities and differences in the peer group and also to understand what data might be available or not.

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