nemesys

NEMESYS Subproject C:
Nordic Efficiency Model
FINAL REPORT

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Disclaimer

This is the final report for the subproject *Nordic Efficiency Model* within the Nordic Efficiency Model for Electricity distribution SYStems (NEMESYS) project commissioned by Nordenergi under coordination by SUMICSID AB. This report has been coordinated and edited by Helle Grønli, EC Group AS, with contributions from prof. Per Agrell and prof. Peter Bogetoft, SUMICSID AB and Pontus Roos, RR Institute of Applied Economics.

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Summary

This second interim report from the NEMESYS project on the Nordic Regulation Model is devoted to Nordic Efficiency Benchmarking. The subproject draws on a relatively long Nordic tradition in regulatory benchmarking within the energy sector to focus at the specifics of a potential harmonization of the efficiency modeling and data. The advantages of a harmonized model include improved reference material for the regulators, equal performance expectations for Nordic distribution operators and lower administrative costs for model development, maintenance and reporting.

Theoretical and practical support are given for the deployment of advanced benchmarking techniques, frontier analysis, using primarily input-oriented models with decomposition on the output side. The originality of the study with respect to methodology is a thorough discussion on the inclusion of quality factors in benchmarking, structuring the discussion on separate versus integrated assessment of service quality. A proposal is made to integrate reliability metrics in the benchmarking, an approach that is also illustrated using a new Nordic data set.

The implementation challenges for a joint Nordic Efficiency Model concern somewhat varying task definitions for distribution, national cost accounting systems, lack of comparable capital valuation standards and some differences in the technical definitions underlying the quality metrics. Harmonization of output data is most important in the proposed orientation, which may result from a phased development in which the model and data specification are adjusted sequentially. Four development strategies are available for a joint Nordic Efficiency Model. These strategies have been illustrated by Table 1.

Table 1. Model and data harmonization.

		Model specification	
		Joint	*Separate*
Data specification	*Joint*	Common Nordic model, operated on homogenous data	Separate models, drawing on a harmonized data base and definitions
	Separate	Common Nordic model, run separately on national data	Status quo, national models and databases

Benchmarking is inherently an information intensive exercise with great potential for both regulators and firms in terms of improvements in quality, cost efficiency and structure. The existing national models, facing limitations in the reference material, are forced to strike a narrow compromise between the risk of model *misspecification and the need for discriminatory results. This study shows for method, model and data how a Nordic coordination can address the national challenges with minimal impact on regulatory commitment.*

Findings and recommendations

A common Nordic Efficiency Model has several advantages and should be followed up on. This requires that the Nordic regulators initiate a harmonization process across national cost and reporting structures. Introducing a common Nordic Efficiency Model has to be a long-term target, which requires quite some work on the hands of the regulators before possibly becoming reality. The issues that have to be dealt with before getting closer to a common Nordic Efficiency Model include:

- *Principal discussions regarding the purpose*
- *In-dept analysis of the cost structures and tasks*
- *Harmonization of the cost and reporting structures*
- *Discussions regarding model design*
- *Discussions regarding data specifications*

The development strategy from a situation with separate national models and databases should be determined in order to introduce a step-wise process towards a joint Nordic Efficiency Model. By harmonizing the model specifications as the first step, the harmonization of cost and reporting structures can be focused on what is necessary for a joint Efficiency Model in the second step. Harmonization is anyhow necessary within several aspects before the Nordic companies are somewhat comparable in a Nordic Efficiency Model:

- *Cost accounting*
- *Capital valuation*
- *Technical definitions*

Due to the fact that the choice and design of the efficiency model depends on the regulatory framework in which it is to be applied, a recommendation with regards to the full scale design of the efficiency model is not being made at this point. Some recommendations with regards to principles for a common Nordic Efficiency Model can, however, be provided:

- *Simple input measures should be applied.*
- *Detailed output specification, including at least the measures customer service, transportation work and capacity provision.*
- *Quality aspects should be included.*

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1. Introduction

Since the 1990s many electricity regulators around the world have implemented incentive-based regulation models. The purpose of introducing this is to promote an optimization of social welfare related to distribution of electricity. The use of efficiency models (benchmarking) is most often an integrated part of these regulatory designs.

This report is part of the NEMESYS project initiated by Nordenergi. The goals of the NEMESYS study are to:

1) Evaluate the advantages and disadvantages of a pan-Nordic regulation model and benchmarking tools viewed in all perspectives of the stakeholders, i.e. customers, society, regulator, owner and distribution system operator.
2) Identify the most critical factors in cross-border regulation and benchmarking
3) Propose a common model for regulation and benchmarking of electricity distribution companies.

Subproject C, which was to develop a common model for evaluating the efficiency of the Nordic electricity distribution companies, has had its main focus on recommending the design and principles of a common Nordic efficiency model. The recommendation has been supported by a set of pilot runs. An important part of the project has been to investigate and point to required changes of national reporting structures in order to achieve a common efficiency model in the future.

There are several reasons why a common Nordic efficiency model would be beneficial:

4) A common model would imply that more companies are included. This secures comparativeness due to the fact that the chance of finding a similar company increases with a more extensive range of companies.
5) Companies estimated as efficient in one county might have an efficiency potential that appears when compared to companies of other countries.
6) Having a common Nordic efficiency model might improve on the regulatory efficiency.

There are, however, some challenges related to international efficiency models that have to be dealt with in one way or another:

7) Data might not be comparable with regards to technical definitions and accounting principles.
8) There might be structural differences, e.g. different technical standards and historically grown energy systems.
9) The legal and regulatory requirements may differ, e.g., the task description for the grid companies and taxation.
10) The operational conditions, such as climate and topology might differ, even to a larger extent than within a country.

Authorship

The editing of the report is coordinated by Helle Grønli (coordinator, EC Group AS) and includes contributions by prof. Per Agrell and Peter Bogetoft, **SUMICSID AB**, and Pontus Roos (RR Institute of Applied Economics) in alphabetic order.

Outline

Alternative model structures and estimation techniques are described and discussed in Chapter 2. Quality aspects related to a common efficiency model are discussed in Chapter 3. Chapter 4 analyses general differences between the countries having relevance for the efficiency model. Data availability, differences in data definitions and business context are covered in Chapter 4. The results of the pilot runs are shown and analyzed in Chapter 5, while Chapter 6 concludes with the recommendations from the project.

2. Model structures and estimation techniques

Benchmarking is the process whereby the performance of unit is compared to other performance data in view of determining the best practice and the potential improvement that the unit under evaluation could realize. Evidently, benchmarking is useful not only in regulated contexts, but widely applied in all industries, organization and processes. Since the comparative logic of benchmarking is analogous to economic competition, there is no contradiction between benchmarking and open markets. In this part, we will discuss the structure of the benchmarking model. We also discuss the main criteria for the regulatory choice of a benchmarking model.

Scope of benchmarking

In terms of its scope, benchmarking methods may the divided in three types: *strategic, process,* and *performance*. Strategic benchmarking is a global approach that compares firms across their competencies, products/services and market segments in order to determine long-term repositioning. Process benchmarking aims at particular processes (invoice management, disconnection, forest clearing, etc) to enable direct improvements. Performance benchmarking, finally, is a quantitative technique to determine the best practice cost at any given level of output or quality. The discussion in this report pertains uniquely to *performance* benchmarking in regulation, although some concluding comments will be made as to its applicability in other contexts.

There are many available methods for benchmarking, from direct compilation of accounting data (profit, ROI, cost, etc), to advanced econometric and technical models with hundreds of variables. The simple measures are effective as complements to a process benchmarking, but are incomplete for a global performance assessment, such as in regulation. The phenomenon is illustrated in Figure 2-1 below. Ignoring the most naïve, unscaled benchmarks, assume that the units in the figure are ranked according to capital intensity (CAPEX) and operating costs (OPEX) at a normalized service level (in the simplest case, per MWh delivered or per connection). Firm (decision making unit, DMU) A has invested heavily in automated operation, metering and connection, whereas firm B relies on less costly equipment and higher cost for interventions. If one would "benchmark" A and B on the two ratios CAPEX/service and OPEX/service, two problems would occur. First, the performance assessment is ambiguous, since A dominates B on OPEX and B dominates A on OPEX. Second, setting the partial ratios as performance targets would effectively create a potentially infeasible comparator (PHANTOM in Figure 2-1) that, if used for reimbursement, might drive both A and B to exit the business. To avoid these elementary problems, regulators use primarily two types of benchmarking models: frontier models and engineering norm models. This presentation is devoted to various types of frontier models, which are the most widespread in regulatory applications. Engineering norm models are analyzed in Agrell and Bogetoft (2003b).

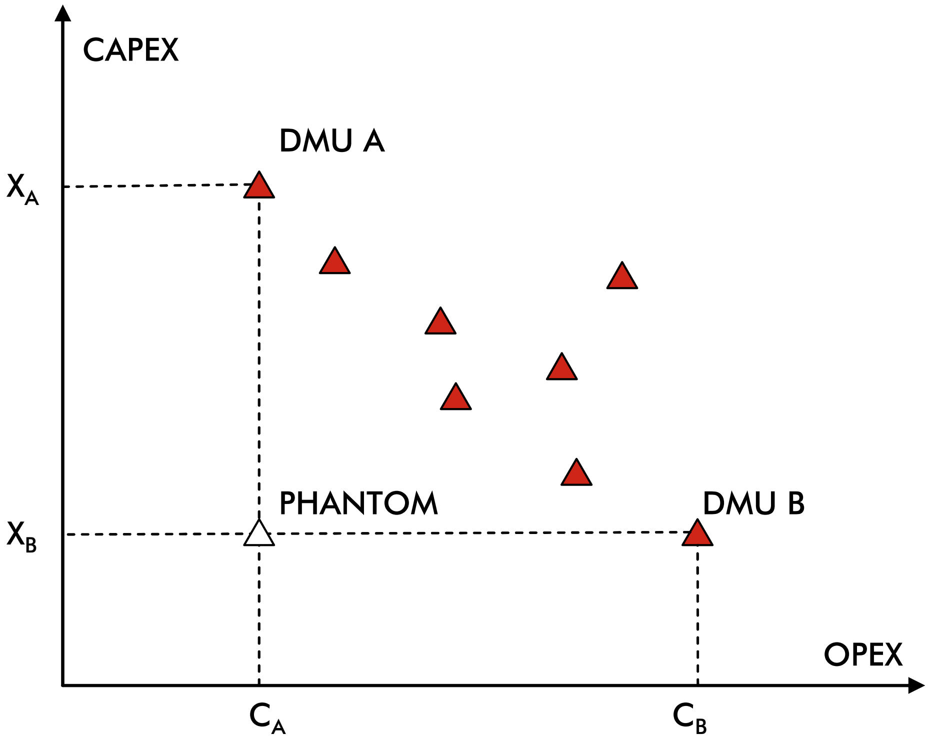

Figure 2-1 Benchmarking with partial measures.

Frontier analysis

Frontier analysis in general and DEA methods in particular are developing rapidly in theory as well as in practice. There are by now more than 1000 scientific papers and numerous text books focusing on frontier models, c.f. the bibliography on www.deazone.com. This prohibits a balanced and comprehensive coverage of benchmarking approaches within any project. Instead, we offer a discussion of some of the factors that we consider to be of particular importance in regulatory applications.

2.1 Steps in a regulatory benchmarking study

The value of benchmarking tools – as most tools – depend on how skillfully they are used. With the forthcoming of professional computer codes, the ease of efficiency analyses has increased – and hereby also the risk of un-reflected misuse of the frontier approaches. A particular problem in the business of frontier modeling is the lack of simple warning indicators and model specification tests. The risk increases when the modelers do not have rigorous methodological training. Textbooks seldom contain detailed guidelines for proper use of the tools they describe. A safeguard against misuse is to adhere to sound application procedures. We outline a series of relevant steps in such procedures.

The model development includes the following steps: 1) Analysis of regulatory interface with benchmarking (preference structure and application), 2) Choice of model structure, orientation and evaluation horizon, 3) Choice of production technology (returns to scale and disposability), 4) Choice of variables and environmental proxies, 5) Choice of estimation approach (parametric or non-parametric)

The steps are illustrated in Figure 2-2 below. We now comment on the individual steps.

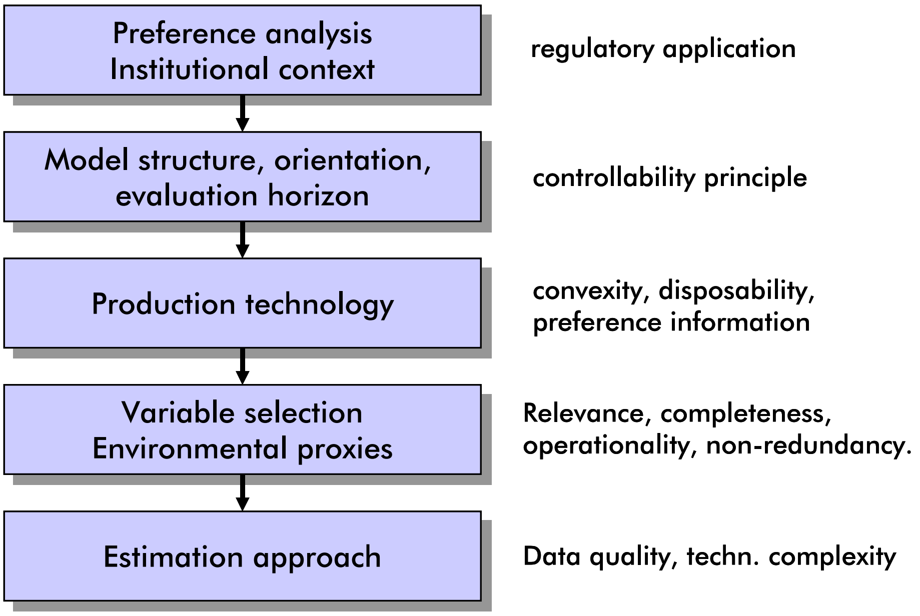

Figure 2-2 Model development steps

Regulatory interaction

Our development of a benchmarking model, e.g. cost model for electricity distribution and ways to measure excessive costs compared to this, can be guided by two perspectives. One is the purely *statistical perspective* of seeking a model that provides the best possible fit between realized and predicted (model based) costs levels. The other is the development of a model that is best suited for *regulatory applications*. The latter approach is similar to a decision theoretical approach to statistics, cf. e.g. Cox and Hinkley (1974). It uses the intended application, incentive regulation, to guide the choice of model structure and estimation technique. Early demonstrations of the optimality of the DEA estimation approach in the context regulatin with moral hazard and adverse selection issues, respectively, are Bogetoft(1994, 1997).

In this report we shall use both approaches. In practice, this means that a model assumption can not only be motivated by the argument of improving the "goodness of fit" of the model as reflected in typical significance test etc. It can also be motivated by paving the ground for reasonable regulatory incentives. To illustrate, a constant return to scale assumption may be motivated as a property of the technology or it may be imposed as a requirement to improve the structural efficiency by punishing DSO that are not operating at the most productive scale size, cf. below.

The scope, frequency and scale of the regulation regime shall ideally guide the choice of optimal benchmarking method. In repeated moderately incentivized settings with audited data collection, deterministic non-parametric methods, such as data envelopment analysis DEA, are often selected as primary benchmarking tools. In one-shot assessments of incumbent inefficiency and settings with high-powered regimes and potentially noisy data, parametric approaches, such as stochastic frontier analysis SFA or multi-output econometric models, are appropriate.

It is also important to adapt the benchmarking approach to the long-term vision of the regulator. The methodology for this sort of *dynamic regulatory trajectory* has been subject to study in Agrell and Bogetoft (2003a, 2004) and Estache and Martimort (1999).

We shall keep the regulatory application of the model in mind in the following discussion and we shall summarize the model and method recommendations from a regulatory perspective in the last section of this chapter.

Model structure and orientation

The modeling proceeds to investigate the activity under the *controllability principle*. In incentive applications, it is important that the measures are linked as directly as possible with what the evaluated units can affect. In this way, one can hopefully avoid "pure risk" in the regulatory contracts since such risks can only increase the risk premium to the regulated firms. One implication is that the limited influence on demand makes it more natural to focus on cost minimization than output expansions. Another implication is that one should tailor the evaluation horizon with the degree of controllability over the activity, if necessary splitting the comprehensive model in a long-run and a short-run model. In distribution regulation, this corresponds to the need to incentivize both efficient infrastructure investments in the long run and efficient grid operation in the short run.

The *orientation* is normally given by the controllability principle as well. That is, the discretionary (i.e. controllable) and non-discretionary variables are identified and discretionary inputs (or outputs) are reduced (or expanded). The recent development of directional distance functions offers a flexible approach that can take into account both the *controllability* of different resources and the preferences towards alternative directions.

The *preferences* for alternative improvement directions may reflect the regulator's trade-offs, say between economic and environmental concerns. In a multi-national application, different regulators may have different trade-offs. One harmonization strategy could involve the development of a common model of the production technology and different, country specific directional distance measures.

Production technology

The first thing to decide is of course which *production units* we are trying to model. They should ideally transform the same type of inputs into the same types of outputs and be influenced by the same types of non-controllable context variables. This is not to say that all units need to exhibit positive values for all variables. Some may be zero. A high degree of similarity between the units is however important to make the relative performance evaluation effective.

The definition of similar units may be complicated in practice. The units we seek to model may only represent some of the processes in a larger organization. The total cost of this organization must therefore be allocated on the benchmarked and the non-benchmarked processes. There is no ideal allocation approach, even theoretically, as soon as the benchmarked and non-benchmarked activities interacts – which they typically do since this is in fact the motivation for organizing them jointly in the first place. For practical purposes, however, it may be possible to identify similar units using common allocation keys, e.g. the employment levels in the different processes.

The interactions, the positive and negative synergies, may also be handled by redefining the outputs so that the full spectrum of products is accounted for. The comprehensive approach is advantageous from a theoretical point of view but it may require a larger data set in practice.

To illustrate, the above discussion, consider the transformation from 110kV to 22 or 24 kV. This transformation is considered a DSO task in Finland but not in Norway. This may lead to biased results since the cost of installing, operating and maintaining the corresponding transforms may inflate the Finnish costs levels. These transformer costs should therefore be excluded using the number of transformers as the allocation key. Alternatively, the output should be redefined by including these transformers in the output specification.

In the following we shall assumed that the all units have been delineated in a similar way. For a detailed discussion of ways to do so – and the nature of the problem – we refer to the detailed discussions in Agrell and Bogetoft (2003d, 2005a), where the definition of units in the transmission business is analyzed.

Having defined the similar units, we shall make more specific assumption about the technology- Non-parametric as well as parametric models usually invoke assumptions regarding *convexity, disposability* and *returns to scale*.

Most models use a global *convexity* assumption. That is they assume that any weighted average of any pair of feasible productions plans is a feasible production plan as well. Although it is widely used and can be motivated in some cases, it is fair to say that it is traditionally assumed for technical convenience to simplify the duality between the production and cost space. Also, in efficiency studies it is done to increase the discriminatory power by extending the production possibility set. On the other hand, there is by now a series of models invoking less comprehensive convexity assumptions, e.g. Agrell and Tind (2001), Bogetoft (1996), Bogetoft, et al. (2000), Borger and Kerstens (1996), Deprins, et al. (1984), Petersen (1990), Tulkens (1993). These models are theoretically appealing as they rely less on a priori assumptions and they are in general easier for the industry to accept as they rely less on the idea of mixed organizations – and of course tend to put everyone in a better light.

In terms of *disposability, i.e.* whether or not the production space is characterized by congestion constraints, rather strong assumptions are usually imposed, say strong free disposability where more inputs can always produce less outputs.

In terms of *return to scale*, the traditional models either make no assumptions or presume a – possibly local – version of the constant return to scale hypothesis. There are several common motivations to use a constant return to scale assumption, i.e. to assume that if we adjust inputs upwards or downwards with a given factor, we can do the same on the output side and vice versa. One is that one can always use multiples of smaller units. This prohibits decreasing return to scale where more inputs generates smaller and smaller increases in the output. A second is – as with convexity - to retain sufficient discriminatory power.

The model structure also depends on the possible use of *partial price (preference) information*. The idea is that we may know something about the range of substitution possibilities – e.g. that the total cost for one high voltage connection corresponds to at least 3 low voltage clients and fall short of that of 20 low voltage clients. The use of such information can reduce informational rents, but it also violates the endogeneity of the input-output weighting in the method in that it reduces the flexibility in an *ad hoc* manner.

The basic assumptions of an efficiency analysis model should ideally be tested. Validation with *statistical tools* allows the analyst to settle on the right model with arguments that withstand industry challenge. There is a growing literature on statistical test but an early approach by Banker (1996) can be used to test all of the above models, i.e. the validity of a constant return to scale assumption, a free disposability assumption and a convexity assumption.

In addition to statistical testing, convexity and constant return to scale may also be motivated by the incentive perspective. A DSO operating in a “convex hole” should alternatively be reorganized as two units with the convex dominating structures. Likewise, a DSOs operating below (above) optimal scale size should ideally be merged (split up) into fewer (more) and larger (smaller) units. Observe that such arguments presumes a long terms perspective, and that it – even in the long run is valid only if there are no other obstacles to the restructuring of the industry. In the case of electricity distribution, small isolated areas in valleys or on islands may have no way to adapt their scale and scope to the optimal ones. This suggests that some areas may be too small and work under increasing return to scale.

Variables and environmental proxies

The choice of variables for a given model structure is always the focus of considerable debate. Part of this is due to a lack of methodology in the delineating of relevant variables. In previous regulatory benchmarking studies, e.g. Agrell and Bogetoft(2000), a more systematic approach has been suggested. It involves looking for a set that is *relevant, complete, operational* and *non-redundant.*

Relevance means that the set of variables should reflect the industry’s and the authority’s comprehension of the system. The variables should be defined such that decision makers and legislators can relate to and refer to them in the regulation. In the modeling, a compromise is found in the interval between the industry’s process-oriented desire to capture the details of the process and the authority’s tendency to aggregate to increase comparability.

Completeness means that the set of variables fully capture the objectives (or regulated costs/revenues) of the decision making units. Non-modeled activities are to be explicitly acknowledged to avoid opportunistic action.

Operationality makes it preferable to use variables that are unambiguously defined and measurable. Qualitative indexes, subjective assessments of utility or service value are inadequate in this sense.

Non-redundancy is another word for Occam's razor, prescribing the least complicated means that achieves the end. Overlapping and partially redundant variables may interfere and introduce avoidable noise in the analysis.

The *model's degree of freedom* is a technical concept from the purely statistical approach to model choice. It relates the number of observations to the dimensionality of the model. The lower the dimensionality of the model, the higher it's discretionary ability. In the parametric, statistical model, the concept is related to the power of subsequent hypothesis tests. In the non-parametric models, heuristic upper limits on the number of variables have been proposed as well, cf. Cooper, Seiford and Tone (2000). They require that the number of observations must exceed 3*(p+r) or p*r, where p is the number of inputs and q the number of outputs. With a fair number of distribution companies, this allows for rather flexible non-parametric models. DEA scholars often find that these limits on data requirements are much too optimistic. Another heuristic rule – and it remains heuristic since the DEA model is intrinsically non-parametric – is to think of a corresponding translog specification – which is after all a very flexible parametric form - and to calculate the number of parameters to be estimated herein. In a cost function specification, we get for example $1+r+r*(r+1)/2$.

Regulatory benchmarking is the art of ensuring a fair treatment of all firms without leaving excessive rents. The proper use of *environmental variables* in the benchmarking models assures these two conflicting objectives. Categorical variables are related to climate, topology, density or other imposed regional heterogeneity in operating conditions. In particular mountainous regions such as Austria, Sweden and Norway are subject to such conditions, whereas models for the fairly homogenous countries in Western Europe have ignored this aspect. E.g., the final regulatory models for Sweden 2000 in Agrell and Bogetoft (2002), included four control variables (climate zone[1], transforming capacity/interconnection station, subscribed capacity in MW, minimal spanning network-length). However, we recommend that the final choice of environmental variables be made after exhaustive pilot-runs with alternative configurations and statistical tests like above. In this manner, the regulator has access to convincing evidence to various objections against the benchmarking results by the regulated firms.

The choice of variables for the model need not be unique. It can in many case be useful to have an *arsenal of complementary models*. First of all, it gives more credibility to the results if they are verified in a series of models. Secondly, to the extent that the different specifications lead to contradicting results, one can let the benefit of the doubt protect the evaluated – like it is done in a Norwegian context with respect to alternative capital measures, cf. Subproject A. The idea of picking the best result fits particularly nicely with the DEA idea of putting everyone in their best possible light. In fact, DEA results can be interpreted as the best results one can obtain using linear (or convex) cost functions, cf. Bogetoft (2000). Thirdly, using a spectrum of specification can be useful to understand the nature of the inefficiency

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[1] The climate zone was suppressed in 2002 after statistical tests to coordinate with the Network Performance Assessment Model, which does not control for climate.

and to decompose the differences among them. Again, this has a nice theoretical basis as several types of inefficiency, e.g. technical, scale and allocative inefficiencies are defined precisely from the effects of using one or another model assumption. The use of models with different variables is probably less common than the use of different model assumptions like return to scale assumptions. Still, it is routinely done in second stage analysis of the results. Also, in both a Swedish and a Norwegian context practioners have found it very useful to work with cost models that have either direct operating expenditure or direct consumer charges as inputs. By comparing the outcome of the two, one can identify if more efficient companies simply generates more profit to the owners and one can better identify possible strategic behavior.

Estimation approach

In the principal choice of an estimation method, a number of issues can be used to evaluate the appropriateness of a particular method. We shall discuss this in more detail in the next section of this chapter.

2.2 Estimation approach

We now give an introduction to state-of-the-art in estimation of benchmarking models. At a general level, one can distinguish between parametric and non-parametric models on the one hand and between stochastic and non-stochastic models on the other.

Parametric versus non-parametric

In the modern benchmarking literature, parametric models are characterized by being defined a priori except for a finite set of unknown parameters that are estimated from data. The parameters may refer to the relative importance of different cost drivers or to the parameters in the possibly random noise and efficiency distributions. Non-parametric models are characterized by being much less restricted a priori. Only a broad class of functions – or even production sets – is fixed a priori and data is used to estimate one of these. The classes are so broad as to prohibit a parameterization in terms of a limited number of parameters.

Deterministic versus stochastic models

In stochastic models, one make a priori allowance for the fact that the individual observation may be somewhat affected by random noise, and tries to identify the underlying mean structure stripped from the impact of the random elements. In non-stochastic elements, the possible noise is suppressed and any variation in data is considered to contain significant information about the performance of the unit and the shape of the technology.

Taxonomy

The two dimensions leads to a 2x2 taxonomy of methods as illustrated in Table 2-1. A few original key references are included.

Table 2-1 Model taxonomy.

	Deterministic	Stochastic
Parametric	**Corrected Ordinary Least Square (COLS)** Greene(1997), Lovell(1993), Aigner and Chu (1968)	**Stochastic Frontier Analysis (SFA)** Aigner, Lovel and Schmidt (1977), Battese and Coelli (1992), Coelli, Rao and Battese (1998)
Non-Parametric	**Data Envelopment Analysis (DEA)** Charnes, Cooper and Rhodes(1978), Deprins, Simar and Tulkens(1984)	**Stochastic Data Envelopment Analysis (SDEA)** Land, Lovell and Thore (1993), Olesen and Petersen (1995), Weyman-Jones (2001)

We emphasize that for each class of model, there exist a large set of model variants corresponding to different assumptions about the production technology, the distribution of the noise terms etc., cf. above. Here, we simply stress that the non-parametric models are the most flexible in terms of the production economic properties that can be invoked while the stochastic models of course are the most flexible in terms of the assumptions one can make about data quality etc.

We presume a basic knowledge of these models here and are not going to explain them in any details. We simply recall the differences in a simple cost modeling context. The setting is that we seek to model the costs that results when best practice is used to produce one or more outputs. We have data from a set of production units as indicated in Figure 2-3 below. Now, COLS corresponds to estimating an ordinary regression model and then making a parallel shift to make all units be above the minimal cost line. SFA on the other hand recognizes that some of the variation will be noise and only shift the line – in case of a linear mean structure – part of the way towards the COLS line. DEA estimates the technology using the so-called minimal extrapolation principle. It finds the sample production set (i.e. the set over the cost curve) containing data and satisfying a minimum of production economic regularities. Assuming free disposability and convexity, we get the DEA model illustrated in Figure 2-3. Like COLS, it is located below all cost-output points, but the functional form is more flexible and the model therefore adapts closer to the data. Finally, SDEA combines the flexible structure with a realization, that some of the variations may be due to noise and only requires most of the points to be enveloped.

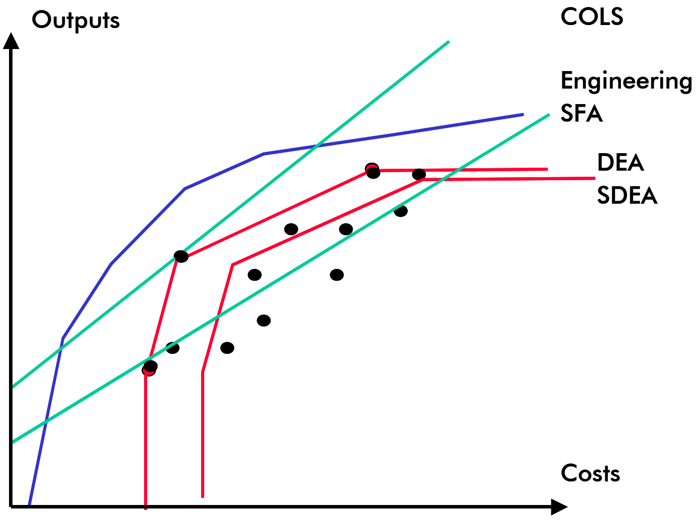

Figure 2-3 Benchmarking methods (example)

In Figure 2-3 we have included a fifth frontier, for the engineering norm models mentioned in 0. The idea is to base the modeling on data from engineers about best possible performance, perhaps in idealized settings. The Swedish Network Performance Assessment Model is an example of such an approach, cf. Subproject A. Engineering norm models in Spain and Chile are discussed in Agrell and Bogetoft (2003b).

Pros and cons

We will now focus on the pros and cons of these methods in general, and in particular their relative merits in a regulatory context. Again, it goes beyond the scope of this project to explain and prove the pros and cons in any details. In the cases where there may be different opinions among the specialists in these methods, we will give a few more explanations.

Some of the strengths of non-parametric methods like DEA include

- Requires no or little preference, price or priority information
- Requires no or little technological information
- Makes weak *a priori* assumptions
- Handles multiple inputs and multiple outputs
- Provides reel peers
- Identifies best practice
- Cautious or conservative evaluations (minimal extrapolation)
- Supports learning and in some cases planning and motivation
- Game theoretical foundation of the industry-regulator relation

Some of the strengths of parametric methods like SFA are

- Strong theory of significance testing (sensitivity, re-sampling, bootstrapping, asymptotic theory)
- Separates noise and efficiency
- Smoothes out some dynamic differences
- May leave lower rents when functional form known
- Creates anonymous peers, may be relevant in regulation

Basic trade-offs

As indicated, the different approaches have different advantages and disadvantages. From a regulator's viewpoint, the relative importance of these merits depends on the overall regulatory approach (cf. Agrell and Bogetoft, 2003a), i.e., the role assigned to the model among the regulatory instruments.

In our view, however, a fundamental difference from a general methodological perspective and from regulatory viewpoint is the relative importance of *flexibility* in the mean structure vs *precision* in the noise separation. The inevitable tradeoff is illustrated in Figure 2-4 below.

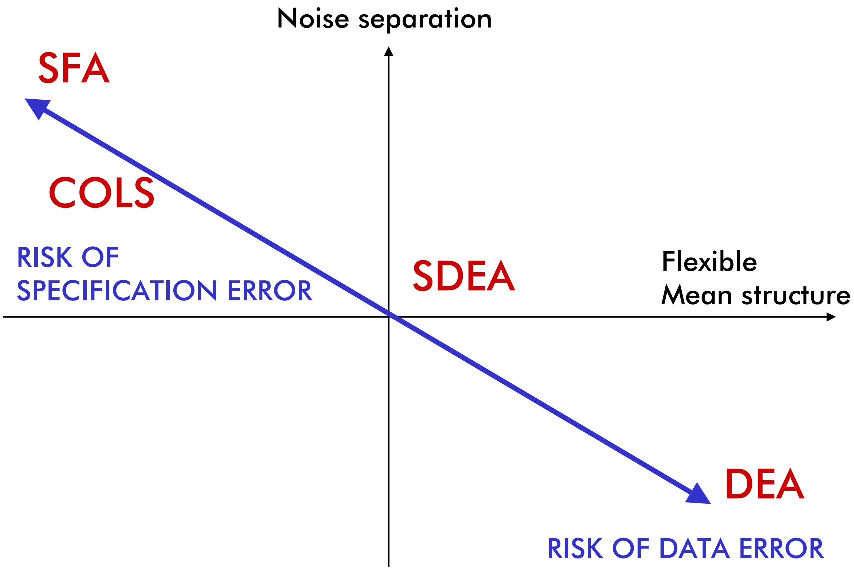

Figure 2-4 Tradeoffs in technology and noise specification, respectively

An important property of a benchmarking approach is its ability to reflect and respect the characteristics of the industry. This requires a *flexible* model in the wide sense that its shape (or its mean structure to use statistical terms) is able to adapt to data instead of relying excessively on arbitrary assumptions. This is particularly important in attempts to support learning, individual motivation and coordination. It is probably less important in models aimed at evaluating system wide shifts, e.g. in aggregate motivation and incentive provision. The non-parametric models are by nature superior in terms of flexibility.

Another important property of a benchmarking approach is its ability to cope with noisy data. A *robust* estimation method gives results that are not too sensitive to random variations in data. This is particularly important in individual benchmarking and perhaps learning – and probably less important in industry wide motivation and coordination studies. The stochastic models are particularly useful in this respect.

Ideally, then, we would like to use flexible models that are robust to random noise. The problem however is that all of this comes at a cost. The estimation task becomes bigger, the data need larger and still we cannot avoid a series of strong assumptions about the distributions of the noise terms. Coping with uncertainty requires us to dispense somewhat with flexibility and vice versa.

We furthermore argue that a lack of stochasticity can be partly compensated by a flexible mean structure – and a restricted mean structure can be somewhat compensated by allowing for random elements. This means that DEA and SFA may be very useful methods in combination and that we do not necessarily need to move to SDEA.

We will continue our discussion of the pros and cons of parametric versus non-parametric and between stochastic and non-stochastic models below.

2.3 Incentive based selection criteria

Practical selection criteria

Continuity. In considering the specification of the models, some consideration must be made to the continuity of previous models in the interest of learning and administrative costs for both regulators and firms. In this context, this condition has been expressed as sensitivity analyses on similar panel datasets to assess the relative benefits from including new information.

Robustness. The model specification and results must be robust to foreseeable cost, technology and institutional changes to guarantee stable incentive provision and minimization of the regulatory risk. Specifications that rely heavily on specific process information, e.g., may become obsolete with technological progress.

Verifiability. An efficiency measurement model used in incentive regulation must be based on verifiable information. Use of poorly defined or private information is directly encouraging opportunistic action. Worse, in yardstick regulation, distorted information may directly affect the incentives of complying firms.

Unambiguous. The model's definitions have to be unambiguous to withstand challenges related to conflicting interpretations, e.g. over time and organizational levels.

Feasibility. A regulatory model must show feasible results for any imaginable outcome to limit regulatory discretion. In incentive regulation, we note the problem of super-efficiency, where the DEA program may fail to find an efficiency estimate for certain production profiles. This may call for regulatory discretion or the reliance on an alternative model specification for such units. It should be noted however that this problem is smaller in the multi-national application with more DSOs in the dataset.

Output focus

As discussed at length in Agrell and Bogetoft (2003a) on *Dynamic Regulation* as well as in Subproject B, the most robust and least long-run costly regulation regime will be implemented with close definition at the output side and high aggregation on the input side. That is, in the long run, the emphasis should ideally be on the definition of the outputs, the products and services that the DSO provides. The elements on the inputs side, i.e. the costs elements, require a less detailed delineation.

This is not to say the efficiency should be measure on the output side. To the contrary, one can argue that with electricity demand quite insensitive to price levels the outputs is less discretionary than the outputs. This suggests the use of a model with minimization of total costs.

This is not to say that it is impossible to impact the output. The most obvious examples involve the merging of concession areas or the decomposition of a given area into two or more sub-areas. The impact of such structural changes, and in particular the effect on efficiency, scale and scope, can be analyzed directly using the analytical approach of Bogetoft and Wang (2005). This approach is however more involved and as a practical substitute it may be interesting to supplement the typical cost minimization models with output expansions models – or a hybrid corresponding to a profit maximization strategy and involving simultaneous cost savings and revenue increases

The output focus, i.e. the use of a detailed output description as opposed to an aggregate input description, follows from market logic – a market defines a price of a possibly complicated product and the market is in principle indifferent to the motivations behind the price. E.g., when buying a PC we are not interested in the capital structure and operational costs of the manufacturer but only the price. In particular, we do not accept to pay a higher price to compensate potentially heavy past development or equipment investments by the manufacturer. Likewise, in comparing two similar products from two firms, it would be nonsense to take into account the age and investment value of the equipment when evaluating the offer. The output focused strategy is the only viable in a long-run horizon, and thus we will allocate more effort to the output specification. On the input side we will generally believe that a single total cost measure will do.

The output focus enables direct integration of the model in a high incentive power model. The output orientation also yields a process independent model, which strengthens the robustness condition above and creates clear signals of regulatory non-involvement in the operations.

Although we strongly suggest that the output should be the focus of must attention also in the future model developments, we also realize that a more full input specification may be needed in a transitional period to make the change of regulation more continues. Likewise, we note that the regulator may not always be indifferent to the different cost elements. An information rent, for example, carries less social costs than a real production costs since the former is simply a transfer that has little impact on social welfare while the latter has a direct effect.

Minimal structural impact

Unless there is a clear and well-founded regulatory agenda related to industrial structure, the model should not give bias to any specific industrial organizational form. The stake-holder analysis, Subproject A, also supports the idea of the regulation being neutral to organizational form. Of course the exact interpretation of this is not clear, but assuming some willingness to change concession areas and allow mergers, this would in the long run point towards a constant return to scale assumption. If we want to allow for very special geographical conditions (islands etc), we might relax that and use a non-decreasing return to scale specification.

Variable choice: Endogeneity

Given an input-oriented model, it is essential that the outputs are exogenously defined. To be complete, we will comment on two issues that are traditionally discussed in electricity distribution regulation.

Network length. Usually treated as a proxy for capital and/or task complexity, the total network length in km is in reality a decision variable. By treating it as an output, inefficiency related to excessive construction of network lines and cables will not be detected, but rather promoted. However, the problem is of somewhat hypothetical character as the investment is associated with business and regulatory risks related to OPEX. We argue that the risk of opportunistic action related to network investments is plausibly lower than the risk of underinvestment due to sub-optimal regulation. We can therefore include network length as a proxy for capital requirement. In other models, and in particular in a long run model, the network length can be though of as in input.

Delivered energy HV/LV. Although only a limited part of the electricity bill for the final consumer, the analysis in Hope et al. (2003) concerning price elasticity on the tariff elements may have a bearing on the demand profile between high and low voltage. In particular the composition of the two-part tariff into a fixed and variable part may signal the operator's interest to expand output (underutilized capacity in rural areas) or to avoid costly investments (urban electricity distribution in central locations)

Environmental or context factors

Electricity distribution, as any process, is subject to exogenous cost drivers, i.e. factors that affect costs but are outside the control of the individual firm's management. All obligations to install, operate and maintain installations with higher than planned quality for example incur extra operating expenditure that are related to the universal service obligation. Thus, care should be taken to reflect these factors when increasing the incentive power on the model to ensure feasibility.

However, statistical tests of single candidate factors against observed cost are not adequate to conclude whether or not to include a specific control factor. High construction cost in a coastal region, for example, is plausible due to salt and wind, but there are other effects related to the model construction that may counterbalance the increases. Certain economies of scale in the operating cost per line and client may not be detected in a linear model. Aggregation of client types may also interact to the advantage of an otherwise disadvantaged firm. Hence, all tests for environmental variables have to be made in a systematic and integrated fashion.

The systematic screening validates whether a particular factor is truly *exogenous* (imposed), and if it has a *significant* and *durable* impact on the relevant cost. Many factors that correlate with asset base and operating standards that are decided by the firms meets this criterion.

In terms of practical implementation, the context factors will typically be modeled as either input if they contribute in a positive way to the production of output or as output if they necessitates the introduction of additional inputs. To reflect that they are beyond the control of the DSO they will be simply be dealt with as non-discretionary inputs or outputs.

Environmental variable can also be measured on an ordinal scale, say low, medium and high political pressure. Model wise, such variables can be handled by subdivision of the data set. The access to a larger data set in a Pan-nordic study makes this a more attractive strategy since there will be more data point in each category when the sample gets larger. That is, one advantage of a joint study is actually that it makes is easier to include ordinal varables.

Sample size and bias

The DEA cost structures are in general biased towards higher costs – and more so the smaller the data sets. This hold also for local areas less dense in observations. The bias can be non-trivial as illustrated in Agrell and Bogetoft (2005b), and should ideally be dealt with in a regulatory application, cf. the discussion of a neutral benchmarking model that do not explicitly or implicitly favors particular scale or scopes. Bootstrapping may be useful here but this shall not be a focus of this study since our aim is not to provide a turn-key model. Moreover, we note that the larger number of units in a Nordic sample compared to the national efficiency analyses carried through so far will alleviate the problem somewhat.

2.4 International standards

To guide the specification of the benchmarking model, it may also be useful to take a look at some international models of electricity distribution. As it is clear from cf. Table 2-2 below, they witness of a multitude of specifications. These specifications may even seem contradictory since some variables may in different models function as input, exogenous and output variables. It is clear that this reflects in part availability of data. In part, it also reflects the differences in intended application of the models, the time horizon etc. This means that all the seemingly conflicting specifications may all be perfectly sensible. Lines for example can be inputs in some model, since they work to transport electricity, exogenous in others, since they proxy for the extension of the area and hereby the task complexity, and as outputs since they proxy for the capacity provided.

Despite of these discrepancies, we suggest that the scientific as well as the technical literature converges on an output specification that reflects three dimensions:

- customer service
- transportation work
- capacity provision.

The first dimension is usually covered by the total number of clients, potentially divided into voltage levels or market segments. The second corresponds to total delivered energy, if needed differentiated by voltage level. The third dimension is covered by proxies for capacity such as installed transformer power or peak power.

In terms of input, most studies focus at the operating costs, either in terms of physical (labor) or monetary units, while using proxies for capital in terms of line length and/or installed transformers.

A second observation from the international studies is that the overall dimensionality of the specifications usually is very modest, especially seen from a Nordic viewpoints. Very aggregated models with 3-4 variables are used to benchmark integrated firms with large service areas and 100,000s of customers in e.g. South America and Australia.

Table 2-2 Variables for selected benchmarking models.

Model	Inputs	Outputs	Environmental factors
Dte 1[2] DTe (2000)	OpEx[3]	Delivered energy No of connections[4]	
Dte2 DTe (2000)	OpEx	Delivered energy No of connections	
Dte3 DTe (2000)	OpEx	Delivered energy No of connections HV No of connections LV Network size[5] No of transformers	
Dte4 DTe (2000)	OpEx	Delivered energy No of connections HV No of connections LV No of transformers Network length/customer	
Dte DTe (2000)	Total Operating Cost (TOC)[6]	Delivered energy No of connections Small No of connections Large Maximum demand LV Maximum demand HV	Network length
NordDEA model Edvardsen – Førsund (2003)	Operating cost Labor (kh) Capital (physical) Distribution losses (GWh)	Delivered energy No of connections Network size	
STEM SR-Agrell Bogetoft(2000)[7]	OpEx[8]	Delivered energy HV Delivered energy LV No of connections HV No of connections LV Maximum demand (MW)	Network length Transformers/installed capacity (MW) [Installed capacity MW[9]] Climate index[10]
STEM LR-Agrell Bogetoft(2000)[11]	OpEx Net losses (MWh) Capital (kkr)	Delivered energy HV Delivered energy LV No of connections HV No of connections LV Maximum demand (MW)	Network length[12] (GIS) Climate index[13]
NUTEK 1993[14]	Labor (kh) Network length HV Network length LV	Delivered energy HV Delivered energy LV No of connections HV	

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[2] Netherlands Electricity Regulatory Service

[3] OpEx (Operating Expenditure) = Variable costs = Materials + services+ staff + other costs

[4] Connections or invoiced customers, depending on available information.

[5] Interpretation for input efficiency with given networks, not maximization of network size. The most important outputs are delivery quality, delivered energy and installation of capacity to meet peak demand.

[6] Total operating cost = OpEx + depreciation on material assets, using a recalculated RAB.

[7] Short run benchmarking model for managerial cost efficiency.

[8] Net of activated labor, depreciation and transmission fees, including actual cost of netlosses – standardized cost using average NordPool price.

[9] Not used in actual runs 1997, 2000 and 2001.

[10] Suppressed in 2001.

[11] Long run benchmarking model for technical efficiency.

[12] Defined as GIS proxy from Network Performance Assessment Model in Agrell and Bogetoft (2000), actual length used in runs 1997, 2000, 2001 and 2002.

[13] Suppressed in 2001.

	Transformer capacity (MVA)	No of connections LV Utilization time for assets Peak demand (MW)	
Hjalmarsson and Veiderpass (1992)	Labor (kh) Network length HV Network length LV Transformer capacity (MVA)	Delivered energy HV Delivered energy LV No of connections HV No of connections LV	
Hjalmarsson and Veiderpass (1992)	Labor (kh) Network length HV Network length LV Transformer capacity (MVA)	Delivered energy HV Delivered energy LV No of connections HV No of connections LV	
Hougaard (1994) (Four models)	Labor (kh) Operating cost (ex labor) Total Operating cost Net losses Capital	Delivered energy No of connections Network size	
Kittelsen (1994)	Labor (kh) Net losses (MWh) Transformers Lines (kkr) Material and services (kkr)	Delivered energy No of connections	Network size
Kittelsen – alt. modeller	Labor (kh) Net losses (MWh) Transformers Lines (kkr) Material and services (kkr)	Maximum demand(kW) Industrial demand Commercial demand Residential demand	Distance indicator[15] Corrosion index[16] Climate index
STEM 2, Ek (1998)	OpEx or TOC[17]	Delivered energy HV Delivered energy LV No of connections HV No of connections LV	Network HV (km) Network LV (km) Installed transformers (MVA)
NVE	Labor (fte) Net losses (MWh) Capital (kkr) (net assets) Material and services (kkr)V	Delivered energy No of connections	Network size
Sydkraft	Network HV (km) Network LV (km) Installed transformers (MVA) Net losses (MWh) OAMC[18]	Delivered energy HV Delivered energy LV No of connections HV No of connections LV	Lines LV per customer LV
Roos and Färe (Etapp 1)	Network HV (km) Network LV (km) Installed transformers (MVA) Net losses (MWh) OAMMC[19]	Delivered energy HV Delivered energy LV	Population density No of connections
ELTA (Workshop 22.5.2000)	Labor (fte) Network LV (km) Installed transformers (kVA)	Delivered energy No of connections	Road length
HKKK (Helsinki School of Economics and Business Administration)	OpEx Investments	Delivered energy (weighted) Average interruption length	Average snow depth Share of forest No customers (weighted) Customer density Change in delivered energy
Network Utility Model. (STEM)	TOC	Netlength LV[20] Netlength HV	

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[14] Variable with a significant impact on the production result.

[15] Traveling time in minutes to regional center.

[16] Scale 1,0 to 4,0

[17] Real annuity of replacement value. OpEX from annual reports and the capital costs are calculated as an annual annuity from the replacement value given a normalized depreciation period (30 years, real interest 4%). Replacement values calculated using the EBR component catalogue and the firms' asset registers.

[18] Costs for administration, operation and measurement excl fixed costs.

[19] Costs for administration, operation, measurement and asset maintenance.

		Installed power	
Weyman-Johnes (1985)	Labor (fte)	No of connections	Network size Installed transformers (MVA) Del energy Max demand Customer density Share industrial customers

2.5 Summing up

To sum up, over discussion of the benchmarking models and estimation techniques suggests that the analysis data analysis should focus on

1) Simple input measures like total costs
2) More detailed output specification with measures capturing customer service, transportation work, and capacity provision
3) The inclusion, one way or the other, of quality aspects
4) The reliance on simple, possibly even linear models
5) Gains and losses from a joint benchmarking model for the Nordic countries.

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[20] Calculated from GIS data using a minimal spanning tree algorithm.

3. Introduction to Benchmarking and Quality

3.1 Quality and incentive regulation

Introducing high-powered incentive regulation without taking quality of service into consideration might lead to a drop of quality of service below what is socially optimal. High quality of service comes at a cost, at the same time as the companies are receiving strong incentives to cut costs through the regulation. Comparing the performance of the electric grid companies without taking differences in quality of service into consideration will benefit the companies with a low quality of service and punish the companies with a high quality of service.

This can be illustrated by the following example: Two companies are totally equal with the exception of costs and quality of service. Company A, which provides a relatively low quality of service, has total costs of 100. Company B, which provides a relatively high quality of service, has total costs of 110. If these two companies were compared without taking the differences in quality of service into consideration, company A would be measured as efficient and company B would not. However, assume that the costs of the consumers related to an inferior quality of service in area A and B totals respectively 20 and 10. In order to reflect the real performance of these two companies, the costs of the customers facing underperformance on their quality of service have to be included in the efficiency model. By including quality of service in the efficiency model the two companies would achieve the same score. The implications for the customers would be that the customers of company A would face lower charges and lower quality, and the customers of company B higher charges and higher quality. However, the total welfare of the customers of companies A and B would be the same.

The challenge of some of the above mentioned approaches for promoting quality of service through the regulation design is to define the "optimal" level. If the efficiency model over-compensates quality of service, there is a danger that the quality of service becomes too good relatively to the costs for providing it. By including compensatory allowances reflecting the costs of the customers related to quality aspects, the companies would be given financial incentives to move towards the socio-economic "optimal". This can be illustrated by Figure 3-1 below.

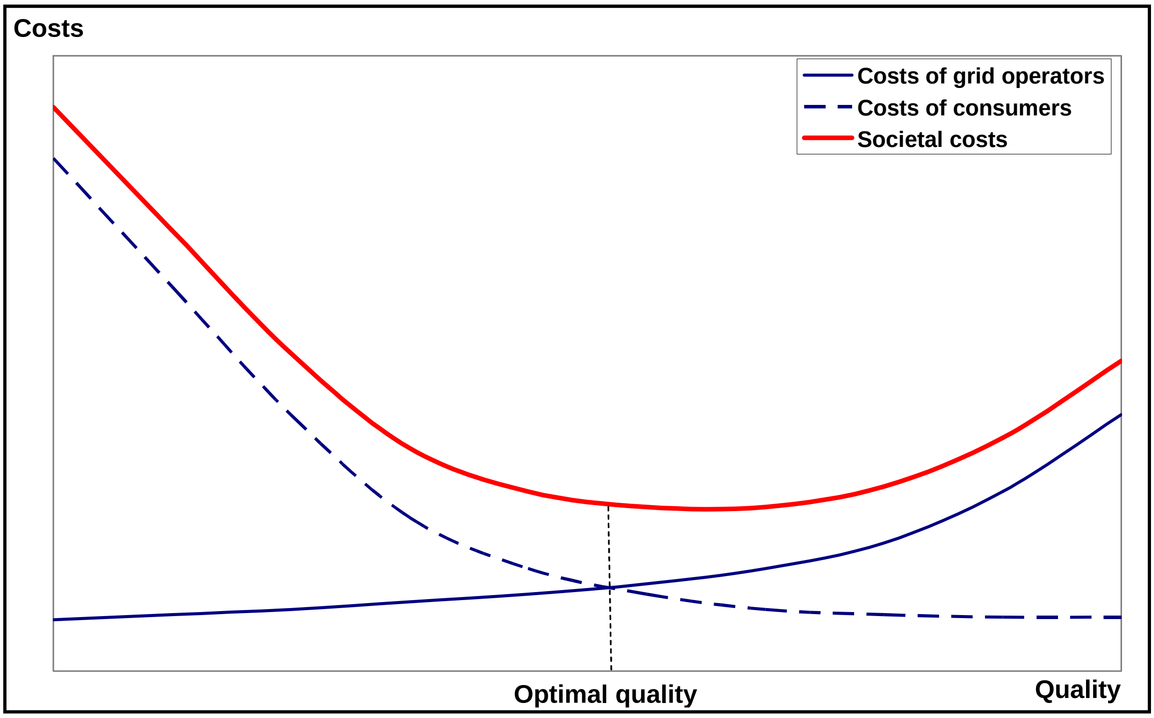

Figure 3-1 Optimal level of quality from a socio-economic perspective.

The level of quality should be increased as long as the marginal benefits to the consumers (costs savings due to improved quality of service) exceed the marginal costs of the grid companies providing it.

For more one the importance of coping with quality in the design of cost incentives, see Subproject B.

In subproject B, we also describe different ways that the quality aspects can be included in the regulation. This include, cf. also Frontier Economics (2003),

1) Marginal rewards and penalties: Companies receive a reward or penalty per unit of quality improvement (degradation) that reflects the marginal value that customers attribute to quality.
2) Absolute fines or quality requirement: Companies are required to pay a pre-specified amount if quality drops below a threshold.
3) Quality-incorporated benchmarking: Similar to marginal rewards and penalties. Provides additional incentives due to the fact that the company's quality of service is compared to others.
4) A combination of different approaches, like for instance in Norway where marginal rewards/penalties have been combined with quality-incorporated benchmarking, is possible. It is important that the design of the efficiency model is well adapted to the regulatory design.

3.2 Quality dimensions

The quality property is seldom single dimensional. Rather, quality has several dimensions and numerous indicators can be used to measure these quality dimensions. cf also CEER(2001).

Security of supply
1) number of interruptions
2) duration of interruption
3) energy not supplied / lost load

Quality of supply
4) voltage stability (voltage dips and peaks)
5) flicker (over harmonic)
6) over/under voltage

Customer service
7) friendliness of customer consultants
8) waiting time (phone, email, complaints)
9) complaints

Quality of service has been included in a few benchmarking approaches around the world. The specification of quality of service in these studies and benchmarking models is summarized by Table 3-1.

Table 3-1. Including quality of service in benchmarking

	Input	Output
Finnish regulatory efficiency model (DEA)	Moving average of customers' total interruption time as a non-controllable input	
Norwegian regulatory efficiency model (DEA)	Actual costs of energy not supplied	Projected costs of energy not supplied (proxy for environmental factors)
Swedish regulatory efficiency model (NPAM)	Total number of interruptions and total duration of interruptions	
Giannakis et. al (2005) (DEA)	Total number of interruptions and total duration of interruptions	

Three general criteria

The service quality measures to be used in the efficiency model have to satisfy a set of criteria (Robert, 2001). The measure has to be

10) of importance to consumers,
11) controllable by network operators, and
12) measurable by regulators.

Relevance for final clients

The importance of the above mentioned aspects of quality of to the consumers depends on type of customer that is hit, time of day, duration, frequency, notified or not, country etc. Industrial customers often have high costs related to restarting the machines after interruptions, meaning that the number of interruptions is of importance with regards to representing these consumers' costs related to quality. Should a household customer be exposed to frequent interruptions at night, it would probably be of little costs or annoyance to this customer, unless the interruption lasts long enough to destroy for instance the content of the freezer. The importance of a longer-lasting interruption during winter time would probably be higher for a Norwegian household customer with electric heating than Danish with district heating. Disturbances such as voltage dips harm a limited number of industrial processes, meaning that such disturbances would have cost impacts for a limited number of customers. This means that the valuation of quality of service ideally should be differentiated with regards to:

13) Type of customer
14) Time of day
15) Country
16) Notified, not notified
17) Duration
18) Type of disturbance

SINTEF Energy Research (Samdal and Kjølle, 2003) has estimated the costs of Norwegian consumers related to long- and short-term interruptions to a total of respectively NOK 850 million and NOK 600 million pr year. The costs related to voltage dips have been estimated to NOK 170-330 million pr year. These cost estimates have been based on questionnaires to the consumers, requesting their willingness to pay in order to avoid interruptions and voltage problems. The results have been used as a basis for determining the rates for energy not supplied used in the Norwegian regulatory design.

Controllability

The grid companies should be able to control the quality measures being included in the regulatory system. This means, that the grid companies are able to influence on the aspects that the measure represents through some kind of actions. If the quality measure is not controllable by the grid company, the company can not adapt to the regulatory incentives that are introduced. Controllability might, for instance, be an issue related to some definitions of customer service. Assume that a customer service indicator is introduced that is based on asking the customers of the different grid companies. Such an indicator would not necessarily be controllable by the grid companies, as the customer's opinion might be influenced by issues out of the control of the grid companies.

Measurability

While the customer's costs related to reliability of service have been estimated, this is to a limited extent the case for the costs related to quality of service and customer service.

Network operators do track and collect several quality measures, such as the number and duration of interruptions, the number and duration of disturbances such as voltage dips etc. The regulator measures several of these quality measures on a regular basis. However, quality measures related to customer service might be difficult to control for the network operators, as well as to measure for the regulator.

The discussion above can be summarized by Table 3-2.

Table 3-2. Quality dimensions

	Customer relevance	Controllability	Measurability
Security of supply	Important to most customers. Importance varies with customer group, time of day and duration. Costs have been estimated.	Yes	Yes
Quality of supply	Important to some customers. Costs to a lesser extent estimated. Harder to estimate customer costs than for security?	Yes	Yes
Customer service	Important to customers, but to a lesser extent than security and quality of service. Customer costs have not been estimated, and are hard to estimate.	Controllable when objectively defined.	Hard to measure in a consistent manner across companies

The regulator defines and collects a set of quality measures, which might differ from country to country. The definition aspects related to quality of service that might differ and which might define the criteria for measures to be reported or not include:

- Planned and unplanned interruptions,
- The definition of short vs long-term interruptions,
- Point of measurement, e.g. grid station, customer, voltage levels

The reporting of security of service measures differs across the Nordic countries (Mogstad, 2003).

- Norway is the only country to focus on Energy Not Supplied (ENS) and the costs related to ENS.

- Interruptions are reported per "point of reporting" (transformer or point of exchange with the customers of high voltage grid) in Norway, Denmark and Finland. In Sweden interruptions are reported per customer.
- All interruptions are reported in Finland. In Denmark interruptions lasting longer than 1 minute, and in Norway and Sweden interruptions lasting longer than 3 minutes are reported.
- In Denmark, component defects are reported thoroughly.
- The reporting of reliability and quality of service measures is to a variable degree voluntary.

Quality as input or output

Radial efficiency models can be input or output oriented. An input oriented model implies that input factors are minimized for a given level of output. An output oriented model implies that outputs are maximized for a given quantity of input factors. Dealing with quality in radial efficiency models implies that the quality measures should be handled as outputs when the quality indicator leads to higher costs, and as inputs when leading to lower costs.

Newer model development has introduced ways to include both good (desired) and bad (undesired) outputs of electricity distribution through so-called directional distance functions. An output based model based on the directional distance function approach is able to simultaneously increase desirable outputs, such as transferred energy, and decrease undesirable outputs, such as the number of interruptions.

3.3 Quality and the benchmarking model

We will now formalize the discussion on how quality can included in the a benchmarking model used for regulation.

In fact, the discussion here is not only relevant for quality. It can be extended also to cope with other complicating factors and properties, i.e. local conditions for, and local properties of, the DSO activities that should ideally be taken into account. It hereby illustrates ways to account for environmental and context variables as discussed in Chapter 2. The challenge is to account for these refinements without having too many dimensions in the model to prohibit comparisons.

Set-Up

Let there be n DSOs using p inputs to produce q outputs. Let the actual inputs be $x^i = (x^i_1,..,x^i_p)$ and outputs be $y^i = (y^i_1,..,y^i_q)$ for DSO i, $i = 1,..,n$. Also, let

$$T = \{(x,y) \in \Re^{p+q}_+ \mid x \text{ can produce } y\}$$

be the underlying true production possibility set.

The Farell based input efficiency of DSO *i* can therefore be measured as

$$E^i = \min\{E \mid (Ex, y) \in T\}$$

All of what is said below can be repeated on the output side.

Let z be a r-dimensional vector of complicating factors or properties with possible values Z.

One way to distinguish between the different ways to include z below is to think of factors that affect the transformation of inputs into outputs in an integrated or in a separate manner. In the case of quality, the question is if we can think of quality improvements as being done in a separate process or whether it is intimately integrated with the core processes such that the products we get out are really different products. Is high quality high voltage deliveries just a particular form of high voltage deliveries or are high quality high voltage deliveries as distinct from low quality high voltage as it is from other variables, say number of costumers ?

Quasi inputs and outputs

The usual way to handle complicating factors is as quasi inputs (if they facilitate the outputs) or outputs (if they require resource to cope with).

If they are furthermore non-controllable, as with complicating factors but not complicating properties, this is handled by avoiding contractions (or expansions) in the direction of these factors. The modified input-based measure becomes

$$E^i = \min\{E \mid (Ex, z, y) \in T\}$$

The advantage of this approach is that the dimensionality of the problem does prohibit comparisons. Of course, the new variables may still be enough to significantly limit the ability to discriminate between DSO.

The primary disadvantages of this approach is that several factors affect multiple inputs or multiple outputs but are not inputs or outputs in the usual sense.

Contingent inputs and outputs

Complicating factors affecting the nature of the inputs or outputs shall ideally be dealt with by redefining the inputs and outputs according to the z values. That is, one distinguishes between for example costs in regions with strict regulation of working conditions and costs in regions with less strict regulation. Similarly, one may distinguish between capacity produced in mild and cold climates, respectively. Formally, this approach means that we use $(x_z, z \in Z)$ as inputs and $(y_z, z \in Z)$ as outputs where x_z and y_z are the number of the inputs and outputs with properties z.

The advantage of this approach is that it is theoretically well-established as it corresponds to the idea of state-contingent goods etc.

The disadvantage is that the dimensionality explodes as the number of inputs and outputs increases from p+q to |Z|(p+q) where |Z| is the cardinality of Z.

Adjustment coefficients

One way to deal with the complications as properties while at the same time avoiding the explosion of dimensionality is by the use of adjustment coefficients on the input and output side. This is similar to the familiar correction for variation in salaries or currencies.

Formally, we simply redefine the input and output vectors into W(z)x and P(z)y where W(z) and P(z) are pxp and qxq diagonal matrices, respectively.

If for example there is a general increase in construction costs by a% because of the harder climate conditions in a country, one can adjust the outputs using P(z) with (1+a) in all diagonal cells or one can adjust the inputs using W(z) with 1/(1+a) in all diagonal cells.

The correction factors can be derived from experts like in the in ECOM+ models. Or from firms supplying turn-key equipment. Or from underlying models.

The advantage of the adjustment factor approach is that it does not increase the dimensionality of the problem. Of course, this is accomplished by hiding the problems of determining the aggregate impact of the complicating properties inside an expert or a sub-model.

Factorized impacts

Between the extremes of using aggregate impact coefficients and full scale contingent input-output models, one can consider the use of factorized impacts by assuming one of the following regularities

$$E((x_z, z \in Z), (y_z, z \in Z)) = E(x, z)G(z)$$

$$E(x, y, z) = E(x, z)G(z)$$

Two Stage Approaches

The most common approach is probably to leave out most complicating factors in a first analysis and then to examine in a second stage if the complicating factors and properties may contribute to explaining the variation in efficiency. The second stage may involve regressing the first stage results on the multiple complicating factors and properties. Also, it may involve building a non-parametric (DEA-like) model linking the factors and properties to the first stage efficiency scores.

The second stage models can then be used to correct the first efficiency measures by using a corrected efficiency measure:

$$\text{Efficiency}^{\text{FIRST STAGE}} / \text{E(Efficiency,z)}$$

where $\text{Efficiency}^{\text{FIRST STAGE}}$ is the efficiency of the DSO in the first stage model and E(Efficiency,z) is the predicted first stage efficiency of a unit with complicating factors and properties z. This prediction is determined by the modeled estimated in the second stage.

The advantage of this approach compared to a direct inclusion of the complicating factors in the first stage is once again to save degrees of freedom.

3.4 Summing up

Both reliability and quality of service measures are considered important to consumers, controllable and measurable. However, reliability aspects are more important to more customers than quality of service. Therefore, including reliability measures should be prioritized in the first place. Quality of service measures can be considered included at a later point, while customer service measures should be left out unless a totally objective measure can be found.

The costs of the consumers related to inferior quality could be included as an input variable in the efficiency model. One can also include the savings compared to expected costs of inferior quality as an output. Again this can be done either explicitly in the model or via a two-stage-analysis, where the impacts of quality or quality provision complications are handled in the second stage. Determining the costs related to inferior quality might, however, be difficult.

A combination of number of interruptions and the duration of interruptions is expected to provide a good representation of the costs to the customers from inferior reliability. To a large extent the customer costs related to interruptions are connected to the fact that an interruption occurs rather than the fact that energy goes lost. The customer costs will be a function of number of interruptions and duration of these interruptions. One interruption with 10 kWh lost will probably be less costly/disturbing for the customers than 10 interruptions with the same quantity lost due to the fact that there are some start-up costs involved. This is supported by a study done in the Netherlands by Baarsma et. al (2004).

4. Differences in data and business context

4.1 General differences

In order to provide a rough overview of the differences between the four countries, general statistics have been compared.

Table 4-1 provides an overview of general statistics of the Nordic countries.

Table 4-1. General statistics, [CEER (2005) and Nordel (2005)]

	Denmark	Finland	Norway	Sweden
Total electricity consumption (GWh)	35 210	84 702	115 008	145 476
Share of household consumption	29 %	25 %	35 %	31 %
Share of industrial consumption	29 %	55 %	42 %	44 %
Share of commercial consumptions	34 %	19 %	22 %	20 %
Share of other consumption (incl. agriculture)	8 %	1 %	1 %	5 %
Number of distribution companies	125	104	150	180
Average grid charge (€/MWh)	42	40	30	44
Population (million)	5,387	5,220	4,565	8,976
Total consumption per capita (kWh)	6 536	16 226	25 193	16 207

As can be seen from Table 4-1, the industry structure differs somewhat between the countries. The share of electricity delivered to industrial customers is particularly low in Denmark. However, an explanation to this can be the categorization between industrial consumption and commercial consumption. Commercial consumption is, as can be seen from Table 4-1, higher in Denmark than in the other Nordic countries.

Household consumption is particularly high in Norway, what can be seen both from the relatively high share of household consumption, but particularly from the total consumption per capita. A consequence of this is relatively low average grid charges in Norway compared to the other Nordic countries. There can be several explanations for the high electricity consumption in Norway, of which the most important is that a large proportion of the heating consumption comes from electricity. District heating and gas distribution is not very well developed in Norway. Having less "competition" to electricity distribution should imply higher efficiency scores of Norwegian distribution grid companies.

The proportion of industrial consumption is higher in Finland than in the other countries. This should indicate that the grid has a higher proportion of higher voltage assets than in the other countries, which would imply higher capital costs per km grid.

Denmark has the highest share of underground cables among the Nordic countries, with a cable share of 84 % in 2002. Norway has the lowest with a cable share of 39 %, Sweden's cable share lies at 54 % while the lower voltage cable share in Finland is not reported. A higher share of cables should indicate higher costs pr. km grid related to capital costs. On the other hand, operational costs are normally higher for lines than for underground cables.

Norway apparently has smaller distribution companies than the other Nordic countries, with an average company size which was at least 30 % smaller than the other countries in 2002. Assuming economies of scale, this would indicate that the Norwegian grid companies are less efficient than the distribution companies of the other countries. The distribution of the company size of the different Nordic countries is shown by Figure 4-1, which is based on the dataset used for the pilot runs.

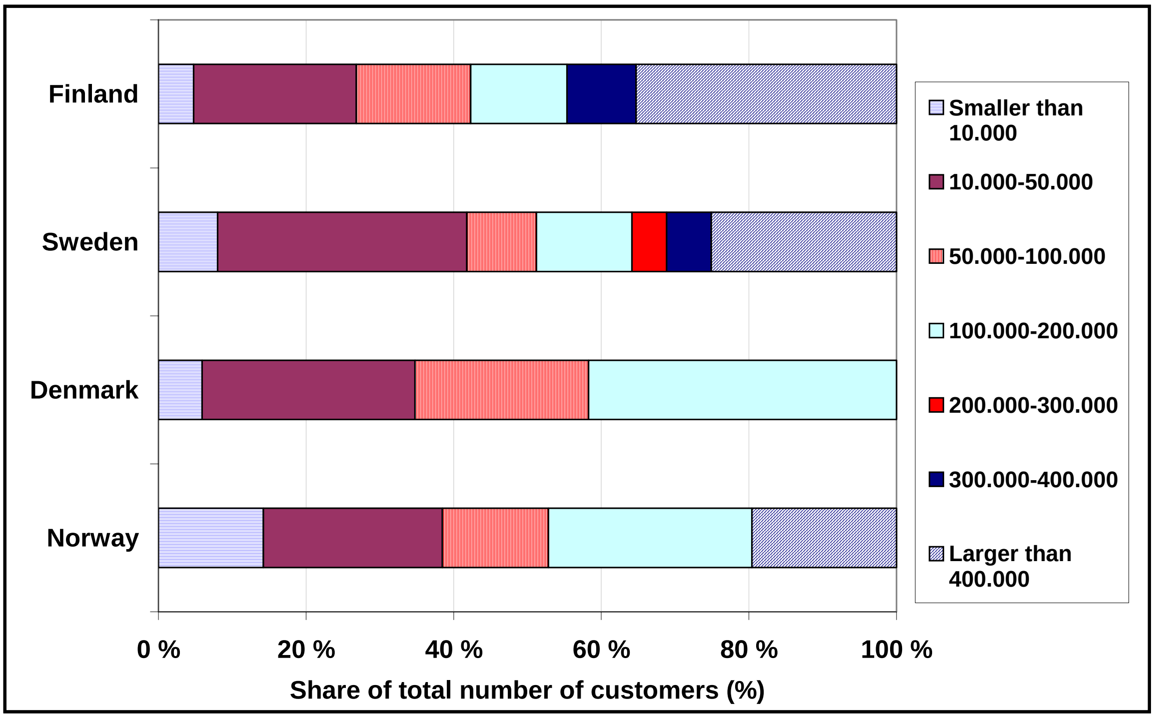

Figure 4-1 The distribution of the company size in the Nordic countries (2002).

As can be seen from Figure 4-1, the highest share of the total customers served by companies with less than 10.000 customers is found in Norway. Sweden has a relatively large share of customers served by companies having between 10.000 and 50.000 customers. Finland, on the other hand, has a large portion of the total customers served by larger companies, and the customers in Denmark are served by mid-size companies in the range 100.000-200.000 customers. These differences of company structure might have some impacts on the choice of returns to scale specification.

4.2 Business context

The business context under which the distribution companies operate differs on several aspects between the four Nordic countries. The definition of distribution, tasks to be attended to by distribution companies, unbundling requirements and how to determine the capital measure are among the aspects that differ.

Definition of distribution

What is to be defined as distribution varies in the four Nordic countries.

- In Denmark, voltage levels equal to and below 20 kV are included into distribution.
- In Finland distribution also includes some 110 kV lines. Most 110 kV lines are, however, considered regional grid. Some 45 kV lines are also included into distribution. The same goes for transformer stations transforming from 110 kV to lower voltage levels.
- In Norway, voltage levels equal to and below 22 (24) kV are included into distribution. Transformer stations transforming from higher voltage levels down to voltage levels included into distribution are reckoned as regional grid.
- In Sweden, voltage levels equal to and below 24 kV are included into distribution. Transformer stations transforming from higher voltage levels down to 24 kV and lower are included as distribution assets for those distribution companies owning such equipment.[21]

The varying definition of distribution is particularly problematic with regards to comparability of costs. The costs of the Finnish companies are necessarily higher due to the fact that higher voltage levels are included as distribution. Several solutions could solve this problem:

- Regional grids in Norway, Sweden and Denmark could be included.
- The costs of voltage levels higher than 24 kV could be excluded from the Finnish cost data, and the costs of transformer stations transforming from higher voltage levels down to distribution could be excluded from the Swedish cost data.
- The costs of higher voltage lines/cables in Finland could be excluded from the cost base while the costs of transformer stations transforming from higher voltage down to distribution levels could be included in Norway.
- Higher voltage output variables could be included into the model.

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[21] There are some exceptions to this definition in Sweden due to historical reasons. Some higher voltage installations around Stockholm are included as distribution.

- Include the costs of higher voltage grid represented by the tariffs paid by a distribution company to grids of higher voltage levels.

The preferable solution would depend on what would be easiest to implement. If it is less costs / efforts related to quantifying the costs of lines and cables in Finland in combination with quantifying the costs of transformer stations transforming from higher voltage levels to distribution in Norway, this should be the preferred solution. Comparability is the important issue in this respect, not if distribution is defined such or such. In the calculations of this project, the costs of the 110 kV lines have been excluded. This was possible in this context due to the fact that the Finnish regulator run its efficiency model based on costs excluding 110 kV lines.

Regulated tasks of the Nordic distribution companies

The tasks that distribution companies are required to attend to in the different countries vary to some extent, and might furthermore be more or less extensive. Table 4-2, which has been prepared through an investigation of governmental regulations and feed back from the regulators and the Nordenergi working group, gives an overview of the different tasks that the Nordic distribution companies are required to attend to. Particularities with regard to costs have also been included.

Table 4-2. Regulated tasks for distribution network operators.

	Denmark	Finland	Norway	Sweden
Electricity grid operations	Yes	Yes	Yes	Yes
Electricity grid maintenance	Yes	Yes	Yes	Yes
Electricity grid investments	Yes	Yes	Yes	Yes
Tariff setting	Yes	Yes	Yes	Yes
Metering, settlement and invoicing	Yes	Yes	Yes	Yes
Supervision and security of electric installations	Yes	Yes	Yes	Yes
Operations coordination	Yes	Yes	Yes	?
Required alert measures	Yes	Yes	Yes	?
Required power system planning	Yes	Yes	Yes	No
Energy forecasts for the service area	Yes	Yes	Yes	No
Energy efficiency measures / advice	No[22]	No	No	No
Securing customer influence	No[22]	Yes	No	No
Transaction costs, related to e.g., structural changes	No[22]	Yes	Yes	No
Control and supervision of payments to public service	No[22]	No	No	No
Insurance	No[22]	Yes	Yes	Yes
Dismantling of lines	No[22]	Yes	Yes	Yes
Costs related to big storms	Yes	Yes, not in DEA	Yes	Yes
Costs related to required compensation for lack of delivery	?	Yes	Yes	Yes

The distribution companies in Denmark have the responsibility of attending to several tasks where the costs are put directly through to the customers. The costs related to these tasks are to be reported separately, and are easy to exclude or include. Particularly worth mentioning are the insurance costs and the costs related to the dismantling of lines, costs that are included in the other Nordic countries.

In Finland costs caused by big storms have been allowed excluded from the regulatory cost base in the DEA. This has not been the case in the other countries, although some the Swedish Energy Agency (2005) actually defined what could be considered *force majeure* in evaluating delivery performance after acts of God.

The Norwegian distribution companies are required to attend to a set of tasks that are not included into distribution in the other countries. These tasks are particularly the preparation of energy forecasts for the service area, required power system planning and required alert measures. The costs of these activities are not detailed, and it is therefore difficult to evaluate the extent of them.

The Swedish grid companies are allowed to keep generation resources as a back up in case of security of supply situations. The book values are to be reported both inclusive and exclusive

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[22] Obligation to perform, but costs billed directly to final customer.

these generation assets. It should, therefore, be possible to exclude most of the costs related to these assets.

The question whether or not it is necessary with a harmonization of the tasks of the Nordic grid companies is dependent on how large the costs related to particular tasks are. If the costs related to the country specific tasks are small, or of a comparable size, it might not be necessary to go to the effort of harmonization.

A more thorough analysis with regards to which tasks are attended to by the distribution companies of the different countries, as well as a quantification of the extent of these tasks, is necessary in order to evaluate the need for harmonization or cost specifications. One example is rules related to required compensation for lack of supply: In Finland interruptions lasting longer than 12 hours qualify for direct compensation for the customer, in Norway compensation is currently spread onto all customers through the KILE-regulation but a direct compensation scheme is probably being introduced from 2007. In Sweden the current voluntary compensation schemes is proposed to be made mandatory, cf. Swedish Energy Agency (2005). The costs related to the compensation rules will, necessarily, have to be different between the countries.

When analyzing the tasks that the distribution companies of the Nordic countries are required to attend to, Activity Based Costing (ABC) might be worth considering. A comparison of similar tasks would be facilitated if ABC was to be introduced Nordic wide. With a harmonized ABC system, tasks that are attended to in one country and not in the other could easily be excluded. However, the fact that some countries have more extensive requirements within an activity than others would not be taken into consideration.

In a Norwegian study, Bjørndal et. al (2004) discuss the use of ABC related to introducing a standard cost type of revenue regulation for regulating distribution companies. The authors conclude, that the relevance of ABC based systems for regulating the revenues of electric grid companies primarily is related to activities driven by the number of customers. The reason for this is that requirements regarding separability of accounts, homogeneity regarding cost drivers and the possibilities to develop a reasonable standard cost across companies can be satisfied for these activities. For activities related to grid related costs, such as capital costs, operational costs and maintenance costs, ABC is considered less suitable. The reasons for this are that the business is characterized by large initial investments and the fact that it is difficult to find activity groups that are homogenous relative to the factors that in the long term contributes to the dimensioning of the investments. The authors therefore consider ABC suitable for regulating approximately 20-30 % of the costs.

Unbundling requirements

The requirements regarding unbundling between regulated grid activities and competitive activities vary to some extent in the Nordic countries. In Denmark management unbundling of the distribution companies is required, while legal unbundling is required in Sweden. Both Finland and Norway apply unbundling of accounts. However, approximately 40 Finnish companies are required to have legal unbundling. Norwegian companies have also reorganized in a way that several of them practice legal unbundling.

Different unbundling requirements might have two consequences with regards to comparability of costs across countries. Firstly, unbundling of accounts might offer more possibilities to shift costs between business areas than legal unbundling. Secondly, legal unbundling might imply higher costs due to the fact that functions might have to be duplicated.

Differences in organizational and accounting practices are, however, probably an equally large challenge within a country as it is across the countries. This is in any case an issue that the regulators have to attend to.

The cost allocation between distribution and regional grid is also an issue to be taken into consideration, particularly if only distribution is subject to international efficiency comparisons in a common Nordic regulatory model.

Capital measure

The capital costs are calculated in different ways in the Nordic countries, both with respect to the regulatory asset base, depreciation rates and regulatory rate of return.

Three ways to calculate the capital measure can be defined:

1) Book value is determined based on historic costs and depreciations over the lifetime of the different assets.
2) Replacement value is the value of the assets with the prices of today.
3) Technical value is calculated based on the replacement value, adjusted for the average age of the company's assets relatively to the technical lifetime.

The replacement values of the Danish grid companies were calculated pr. 1.1.2000. These values were depreciated based on the age profile of the grid assets. Each year following 2000, new assets were added to the 2000-values and adjustments for depreciations were made. The Danish depreciations are linear. Transformer stations are depreciated over 40-50 years, lines and cables over 30-50 years and buildings over 40-100 years.

The Finnish regulator is about to establish the technical value of the Finnish distribution companies based on a detailed specification of the grid assets. That means that the replacement values are calculated, after which they are adjusted according to the age of the assets of each component group relatively to the average life expectancy of the same assets. Any construction contribution is deducted from the technical value.

Although the efficiency model is run both with book value and replacement value, the Norwegian regulatory model is mainly based on book values. The book values are calculated based on gross historic costs adjusted for the accumulated depreciations, devaluations and construction contributions. During the first years after the market liberalization, the book values had to be determined for several grid companies. This was mainly done by calculating the replacement value, which was then adjusted for inflation to the year of investment, and then depreciated according to the financial depreciation rates. Each year following the initial determination of the book value, new assets were added to the initial values and adjustments for depreciations were made. The Norwegian depreciations are linear. Transformers and grid stations are depreciated over 25 years, lines and cables over 30 years, metering equipment over 15 years and buildings over 50 years.

The Swedish grid companies report the book value with and without generation assets. In addition, the regulator calculates the replacement values of the model networks determined through the Network Performance Assessment Model (Nätnyttomodellen). However, due to the fact that the modeled networks contain fewer assets than the real ones, the replacement values of the model networks underestimate the replacement values of the real grid. The Swedish depreciations are calculated as a real annuity. Transformers, stations, lines and cables are depreciated over 40 years and metering equipment over 18 years. Other assets are depreciated according to accounting practice.

To illustrate the problems of lack of comparability related to the capital measure, a comparison of the average book value relative to the replacement value can be useful: Norway had the lowest ratio of book value relative to the replacement value at 26 % in 2002, and Denmark the highest at 42 %. The relation between book value and replacement value in Finland and Sweden is respectively 39 % and 35 %. Although there are large differences within the different countries as well, there can be several explanations of the general trend which are related to data comparability:

- The calculation of the replacement value might differ with regards to the level of standard costs used pr category of asset.
- Different depreciation rates. Shorter life time contributes to a lower ratio between the book value and the replacement value.
- Real versus modeled grid assets. The replacement values in Sweden have been calculated relative to the "optimal grid" of the NPAM model, which should indicate that the ratio between the book value and the replacement value should be even higher.
- The degree of activation might differ.
- The age structure of the grid assets in the different countries might differ.

The regulatory rate of return applied on the capital measure differs between the four countries as well:

- Denmark operates with a ROR ceiling based on the long term construction bond interest rate plus 1 %.
- The Finnish ROR is based on the 5-year governmental bonds and a risk premium of 1,98 % or 2,14 % depending on the taxation.
- The Norwegian ROR is based on the moving average over 3 years of the governmental bonds plus 2 % risk premium.
- The Swedish ROR is set at 4,8 % real with an annual inflation adjustment.

The problem of using book values in the efficiency model is particularly related to the different depreciation rates. Companies operating in countries where the depreciations are based on a shorter lifetime have lower book values than companies operating in countries where the depreciations are based on a longer lifetime. In an efficiency model based on book values, companies having lower book values will score better in the model, everything else kept equal. This problem can be somewhat avoided through a calculation of book values based on assets, asset prices, average age and unified depreciation rates.

There are also challenges to be resolved if replacement values are to be used. Unless the business context (influencing on e.g. the material costs for similar assets) and environmental conditions (climate, ground conditions etc.) are considerably different, unified standard costs to be used in determining the replacement values have to be agreed upon. If operational conditions of the countries are considerably different, causing the investment costs to differ, this should ideally be taken into consideration through a differentiation of the standard costs used. However, using standardized costs without adjusting for different operational conditions might offer a simplification in a common Nordic efficiency model related to the environmental variables. If the replacement values are differentiated with regards to operational conditions, one or more environmental variables have to be included as an output variable in order to reflect these cost differences in the model. Companies with high replacement values due to difficult operational conditions would otherwise score low in the efficiency model, only due to the fact that they operate under a difficult environment. Using fully standardized replacement values that are not differentiated with regards to different operational conditions do, however, not reflect differences in operational expenses that are related to different operational conditions.

Determining the replacement values of an “optimal grid”, like done in Sweden, offers additional challenges to using the replacement values of the real grid. The “optimal grid” has to be modeled in a way that takes all operational differences into consideration. Although using the replacement values of a modeled grid offers some advantages related to taking inefficiency of bad investments into consideration, it also punishes investments done due to happenings out of the control of the grid companies.

A unified rate of return to be used might have to be agreed on as well. This seems, however, as the least problem of determining the capital costs for the efficiency model.

4.3 Data availability and definitions

In this section, the data availability and structure used in the Nordic countries are compared. The data has been grouped into technical, quality and financial data. The output specifications along the three dimensions customer service, transportation work and capacity provision draws on both technical, quality and financial data.

Technical data

The technical data available in the four Nordic countries varies to some extent, so do the data structure. This can be seen from Table 4-3.

Table 4-3. Technical data for distribution. Availability, structure and definitions[23].

	Denmark	Finland	Norway	Sweden
Definition of low voltage	0,4 kV	0,4 kV	≤ 1 kV	≤ 1 kV
Energy delivered (MWh)	From 2004	Diff wrt voltage levels	Diff wrt customer group	Diff wrt voltage levels
Number of customers	Available in sector (meters)	Diff wrt voltage levels	Diff wrt customer group (connection points / subscribers)	Diff wrt voltage levels (connection points)
Number of connection points	No	Yes. 400kV, 220kV, 110kV	Equal to no. of customers	Available from NPAM data
Network length	Lines and cables (land and sea). 0,4kV, 10-12-20kV,	Lines 0,4kV, 6-70kV, 110kV. Cables 6-70kV, 110kV.	Lines and cables (land and sea). 0,2-0,4kV, 0,5-1kV, 3,3-7,2kV, 11-24kV	Lines and cables. (≤ 1kV, 1-24kV)
Number of transformers	2002 and 2003		Yes	Yes
Transformer capacity	Yes		Yes	Installed capacity
Peak power (MW)	No	Highest hourly mean	Peak power injection and extraction. Tariff base	Total subscribed demand
Network losses (MWh)	No	Possible to estimate	Yes	Yes. NB own generation
Number of network stations	Yes	Diff into ≥100kV and <110kV	Yes	Yes

The Danish regulator collects fewer technical data than the other Nordic regulators. However, additional technical data is available in the sector, primarily through the Association of Danish Energy Companies.

The differentiation of the data reported differs. While the measures “energy delivered” and “number of customer” are differentiated with regards to voltage level in Sweden, they are differentiated with regards to customer group in Norway. One implication of this is that a harmonization would be required if a differentiation of these measures is necessary in order to secure comparability of distribution grid companies with different customer structures. Additionally, the definitions of how to calculate energy delivered and what is a customer (subscriber or connection point) might differ, even within a country.

Grid length is a measure which is reported in all countries. However, the voltage levels differ, so do the degree to which grid length is differentiated into lines and cables, land and sea. The grouping of grid length is dependent on the actual grid structure and investment strategies of the distribution companies of the different countries, and is difficult to fully harmonize due to the fact that the structure is different. However, a harmonization could be necessary if

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[23] Abbreviations: wrt = with regards to, NPAM = Network Performance Assessment Model.

there are large cost differences related to the grid assets and this measure is to be included in the efficiency model. Creating a grid index could, however, be an alternative.

Transformers are to a varying degree reported. If this measure is to be included in the efficiency model, this measure would have to be requested for Finland.

Peak power, which would represent the capacity dimension, is not reported in Denmark. The three other countries all have different definitions of peak power: Sweden has defined peak power as the total subscribed demand; Norway has defined peak power to be the peak power used for tariffs, while Finland has defined peak power as the highest hourly mean. If this measure is to be used related to a Nordic regulation, a unified definition has to be agreed upon.

Physical network losses are not reported in all four countries. This measure could be relevant in a joint Nordic efficiency model related to determining the cost base. Network losses can be purchased in a joint Nordic power market, and unified unit costs could be used here. However, there is probably a need for clarification of what is to be counted as physical network losses. Examples of this are whether or not own consumption and street lighting is counted as network losses.

Quality measures

In all Nordic countries some kind of quality data is collected. However, the definition of these data varies to a large extent. Table 4-4 provides an overview of the quality data available in the Nordic countries.

Table 4-4. Quality data for distribution. Availability, structure and definitions.

	Denmark	Finland	Norway	Sweden
Energy not supplied (MWh)	No	From 2005	Outages > 3 min, grid > 1kV. Notified / not-notified. Diff. customer groups.	Yes. In NPAM
No. interruptions	Available in sector. Outages > 1 min, grid > 0,4 kV. At Connection points	Outages grid > 0,4kV, All interruptions, can be split into long (> 2 min) and short. Connection points	Outages > 3 min, grid > 1kV. Notified / not-notified. Diff. customer groups. Connection points (grid station)	Outages > 3 min. Notified / not-notified. Diff by own grid, neighboring grid and gen. assets. Point of customer
Duration of interruptions	No	Avg. duration pr interruption, pr customer. Can be split into long & short	Outages > 3 min, grid > 1kV. Notified / not-notified. Diff. customer groups.	Avg. duration pr inter-ruption, pr customer. Notified / not-notified. Outages > 3

	Denmark	Finland	Norway	Sweden
			Connection points (grid station)	min. Diff.
Frequency of interruptions (no. interruptions/no. subscribers)	Available in sector. Outages > 1 min, grid > 0,4 kV. At Connection points	Calculated	No	Outages > 3 min. Notified / not-notified. Diff by own grid, neighboring grid and gen. assets. Point of customer
Voltage dips	No	Connection points	From 2005	?

The most important difference related to quality data in the Nordic countries is related to the definitions. The definitions vary with regards to the length of the interruption, which voltage levels are included as well as the point of registration.

The Finns collects interruption measures for all outages, the Danes outages lasting longer than 1 minute, the Swedes and the Norwegians outages lasting longer than 3 minutes. The Finns differentiate between short- and long-lasting interruptions, where long-lasting interruptions are defined as outages lasting longer than 2 minutes. The Norwegians will in the future also collect quality measures related to short-lasting interruptions, which would mean outages lasting shorter than 3 minutes.

All countries except Sweden collects interruption measures at the connection point between high and low voltage distribution. Sweden collects interruption measures at the point of customer, which naturally results in higher numbers as when the connection point between high and low voltage is used. Interruptions on the low voltage distribution are, in other words, included in Sweden. The Danes will collect quality measures at the point of the customers from 2006.

The Danes and Finns collects interruption measures in high voltage distribution defined as higher than 0,4 kV. The Norwegians define high voltage as higher than 1 kV. This would also have implications with regards to the magnitude resulting from the registration.

The magnitude of the interruption measures of the 4 countries varies consequently rather extensively, as can be seen from Table 4-5.

Table 4-5. Key factors related to quality (2002).

	Denmark	Finland	Norway	Sweden
Number of interruptions pr customer	0,59	3,47	0,13	1,22
Duration of interruptions pr customer	44,09	108,45	10,30	151,75

The need for harmonization of the quality measures is large.

Financial data

Financial data is reported in all Nordic countries, although with different degree of details. This can be seen from Table 4-6.

Table 4-6. Financial data for distribution. Availability, structure and definitions[24].

	Denmark	Finland	Norway	Sweden
Number of employees	Full time equivalent	Yes	Number of employees and full time equivalent	No
OPEX	Yes	Yes. Calculated up to 70kV for DEA (110kV lines excluded)	Yes	Yes
Disaggregated OPEX values	Salaries, grid losses, other opex	Grid losses, other opex	Salaries, grid losses, part of internal common costs, other opex	Salaries, grid losses, part of internal common costs, other opex
CAPEX (see also 4.16 – 4.25)	Depreciations specified, RV and BV are available	Depreciations specified, RV and BV are available	Depreciations specified, RV and BV are available	Depreciations specified, RV and BV are available
Non-controllable costs	Transmission grid charges	Transmission grid charges	Property taxes, transmission grid charges	Property taxes, transmission grid charges

4.4 Necessary Harmonization

In order to secure comparability in a joint Nordic efficiency model where the data from all Nordic companies is to be included, several actions have to be taken with regards to harmonization. A joint Nordic efficiency model including all companies with as comparable data as possible, will therefore have to be seen as a long term target. Short term, the same Nordic model framework can be implemented in the Nordic countries. However, data should be considerably more comparable before introducing a joint Nordic efficiency model including all companies.

Cost accounting

There is particularly a need for harmonization of the cost accounting. There should be a thorough evaluation of the tasks that the distribution companies of the different countries have to attend to, as well as whether or not similar tasks are of a comparable size. Should the initial evaluation show large differences between the countries, the work of harmonizing the cost accounting and reporting structure should be started. This could involve introducing

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[24] Abbreviations: BV = book value, RV = replacement value.

some kind of ABC or a joint classification of costs related to comparable tasks. Tasks that are particular for one country should be reported separately.

Capital valuation

The calculation of the replacement values is another relatively extensive harmonization activity necessary in order to develop a fully joint Nordic efficiency model. The costs related to different types of assets would have to be agreed upon on a Nordic basis. If book values are to be used in a Nordic efficiency model, the most reasonable way would probably be to calculate the book values based on unified replacement values, the average age of the assets and unified life expectancy of these assets. The current book values would not be comparable due to the fact that the depreciation rates differ. Harmonizing the depreciation rates would probably be a very slow process, as this could imply changing the whole financial reporting of the country. Of course, this would also be related to the choice of regulatory design.

Technical definitions

The definitions of the relevant technical variables should be harmonized when introducing a joint Nordic efficiency model. This would particularly include the following variables:

1) Transportation work represented by energy consumed, energy transported or other relevant measures.
2) Customer service represented by the number of customers, either measured by the number of meters, connection points or subscribers.
3) Capacity provision represented by peak power measured in a unified way.
4) Reliability of supply. The required harmonization in this area does, however, have larger implications for the grid companies than the above harmonization. The reason for this is that the level of details varies quite extensively. A harmonization with regards to the length of the interruption measure and the level at which it is measured might have rather large consequences for the costs of the distribution companies, at least during an implementation phase.

Disclaimer

The extent of harmonization is, of course, dependent of the use of the results from a common efficiency model in the regulation. Harder integration of the results implies a higher degree of harmonization.

5. Analysis

This chapter presents result and analysis of efficiency of electricity distribution firms in the Nordic countries. The chapter consists of 3 sub sections (A,B,C). Each sub section presents a model and an analysis of efficiency measurement. The first two sections deal with short and long run cost efficiency models. The third model focus on efficiency measurement when also quality aspects are taken into account. Quality refers to 'bad' non desirable characteristics of electricity distribution such as interruptions.

The overall purpose of the estimation is show the applicability and features of methods and not to present final 'true' results in terms of efficiency scores.

All the models used in the measurement of efficiency can be found described in Färe and Grosskopf (2004).

5.1 Short run input oriented model without quality aspects

In the short run model some of the input variables are assumed to be non controllable by the operating unit, i.e., they are included in the construction of reference technology but not scaled on in the estimation of efficiency. A short run model should be seen as a part of a long run model, and it's purpose is to supports the correct incentives in the short run.

Variables

The variables being used in the short run input oriented model includes:

1) Controllable input: Total operating costs (OPEX) measured in EUR.
2) Non- controllable inputs: Grid length low voltage (LV), Grid length high voltage (HV), replacement value of capital (RV) measured in EURO. (Grid length may under-estimate capital input. Therefore a second capital variable, replacement value of capital, is included. Together the two variables give us a better measure of real capital input).
3) Outputs: Energy delivered (MWh) and Number of customers.

Data consists of observations from 432 units in all 4 Nordic countries.

Results

The results from the first model are presented in Table 5-1 under different assumptions of returns to scale. Efficiency is measured on a scale 0 to 1 where companies achieving 1 are efficient. Average efficiency is the geometric mean of individual efficiency scores.

Table 5-1. Efficiency scores input oriented model under different assumptions of returns to scale. 432 units from all 4 countries.

	CRS	NIRS	VRS
Average efficiency	0,63	0,65	0,66
No of efficient units	41	54	58

CRS= Constant returns to scale, NIRS= Non increasing returns to scale, VRS= Variable returns to scale.

The results show that the common Nordic reference technology is constructed by units from all 4 countries, and that many less efficient units have a reference technology based on combinations of units from two or more countries. Table 5-2 shows the number of efficient units from each country, used in the construction of the reference technology (so called self evaluated units, i.e., units that are reference to themselves and not reference to other units, are not included in the number of efficient units). A common Nordic production technology as a reference for performance measurement was also used in the study by Edvardsen and Førsund (2002) on international benchmarking of electricity distribution utilities.

Table 5-2 Number of efficient units in each of the 3 different returns to scale models. 432 units from all 4 countries.

	CRS	NIRS	VRS
Norway	2	2	3
Finland	18	24	24
Sweden	15	22	23
Denmark	6	6	8

These results support the idea of having a common Nordic electricity distribution technology as a reference for performance measurement. The results also indicate some scale effects, in terms of decreasing returns to scale.

Looking at the distribution of the efficiency scores, the results show lower scores for the second quartile when the units are sorted by size of operating expenditures (OPEX), see Table 5-3.

Table 5-3 Distribution of efficiency scores under different assumptions of returns to scale.

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
CRS	0,68	0,55	0,64	0,65

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
NIRS	0,69	0,56	0,65	0,70
VRS	0,73	0,57	0,65	0,70

The efficiency scores in the above short run model can be decomposed into (1) a scale efficiency measure and (2) a 'pure' technical efficiency measure. On average, scale efficiency was 0,95, i.e., efficiency could partly be explained by the 'size' of operation. Scale efficiency was highest for middle size units and lower for small and large units.

Simulation of changes may prove very useful in understanding the consequences from changes in inputs and outputs on efficiency. As an example, simulations of inputs and outputs around the average data point are presented in Table 5-4.

Table 5-4 Simulation of inputs and outputs and effects on efficiency score around the average data point. Constant returns to scale (CRS).

Efficiency	OPEX	LV	HV	RV	MWh	Customers
0,55	average	average	average	average	average	average
0,68	minus 20%	no change	no change	no change	no change	no change
0,73	minus 20%	minus 10%	no change	no change	no change	no change
0,75	minus 20%	minus 10%	no change	minus 10%	no change	no change
0,79	minus 20%	minus 10%	no change	minus 10%	plus 10%	plus 10%

In the simulation example the efficiency score increased from 55 % to 79 % due to 10 or 20 per cent changes in one or more inputs and outputs. The simulation tool illustrates the possibility to identify expected results on efficiency from changes in inputs and/or outputs. Simulation may also prove useful in discussion of what will be possible to reach in terms of efficiency improvements given limitations by how much an input, or output, or both, can be changed.

Another issue is about inclusion or exclusion of variables in the efficiency model, and the effect on the efficiency score. A test for the sensitivity of inclusion/exclusion of variables has been carried out. The test starts with all 4 input variables and continues with the exclusion of one by one variable, so that the last model is collapsed to only include operating costs (OPEX) as the input. On the output side, all models include the two outputs: (1) delivered energy and (2) number of customers. The results are presented in Table 5-5.

Table 5-5 Efficiency scores and number of efficient units for different types of models when input variables are successively reduced. Constant returns to scale (CRS).

	OPEX, RV, LV, HV	OPEX, LV,	OPEX, LV	OPEX
Efficiency score	0,63	0,59	0,53	0,50

	OPEX, RV, LV, HV	OPEX, LV,	OPEX, LV	OPEX
No efficient units	41	24	7	5
No of self evaluated units	11	4	0	0

The results in Table 5-5 indicate that the efficiency scores are sensitive to inclusion of all the 4 variables, i.e., all variables play a significant role in the estimation of efficiency, given the definition and measurement of the variables. Definition and measurement of variables could, of course, in it self be an explanation to the results. The number of efficient units constructing the reference technology is 41 in the largest model and only 5 in the simplest model. The increasing number of efficient units could be an indication that the model with 4 input variables is not ‘big’ enough in order to capture the features of the electricity distribution technology. One may consider increasing the model in terms of inputs and/or outputs.

Aggregation of inputs or outputs in efficiency models is a similar issue to the inclusion of variables. For example, if output variables are aggregated into one variable, the efficiency score will not change if the 2 variables are in a fixed proportion to each other, and this proportion is the same for all units. If not the same proportion, the efficiency scores will change, to a larger or lesser extent. As an example of this type of aggregation problem, the output variable delivered energy is tested for aggregation and disaggregation into high voltage customers and low voltage customers. Due to data problems, i.e., disaggregated data is not available for all countries, the illustration is limited to a selected sub-sample. Table 5-6 shows the results for the two cases.

Table 5-6 Efficency scores for two different models – with or without aggregation of delivered energy to low and big voltage customers. Swedish data. Short run input based model with constant returns to scale (CRS).

	One aggregated output	Two variables of output
Efficiency score	0,73	0,78

The illustration indicates that the two variables of output can not be converted into each other by a fix coefficient and one has to consider measuring delivered energy as two variables instead of one aggregated variable. If we have had no or very small differences in results when going from one to two variables, indicating a fix relationship, one could consider to use only one overall variable.

5.2 Long run input oriented model without quality aspects

In the long run model operating costs as well as capital costs are assumed to be controllable variables. Also the lines and cables, in terms of grid length, are assumed to be controllable variables. The model specification is similar to the short run model with the exception that non-controllable costs are included in the estimation of efficiency.

Variables

The variables being used in the long-run input oriented model includes:

1) Inputs: Total operating costs (OPEX) measured in EUR, replacement value of capital measured in EUR, grid length low voltage (LV), grid length high voltage (HV).
2) Outputs: Energy delivered (MWh) and Number of customers.

Data consists of observations from 432 units in all 4 Nordic countries.

Results

The results from the second model are presented in Table 5-7 under different assumptions of returns to scale. Efficiency is measured on a scale 0 to 1.

Table 5-7. Efficiency scores of an input oriented model under different assumptions of returns to scale. 432 units from all 4 countries.

	CRS	NIRS	VRS
Average efficiency	0,61	0,62	0,64
No of efficient units	24	30	38

CRS= Constant returns to scale, NIRS= Non increasing returns to scale, VRS= Variable returns to scale.

As expected the results show that the average long run efficiency is lower compared to the result from the short run model. The result also indicates scale effects, similar to the short run model.

The reference units, constructing the common Nordic technology, are almost the same in the long and the short run model. However, a few units are not efficient in both the short and long run model.

5.3 Long run model with quality aspects

The above models do not include quality aspects of the electricity distribution technology. An input based model always focus on potential reduction in inputs. Such a traditional input model may not take into account quality aspects of output in a way that support the overall incentive to reduce the risk for bad (undesirable) outputs in terms of interruptions and energy not delivered. As an alternative to a traditional model an output based model that can handle good as well as bad outcome of electricity distribution is suggested. The suggested output based model (based on a directional distance function approach) is able to simultaneously increase desirable outputs and decrease undesirable outputs.

Variables

A long run efficiency model, with quality aspects included as bad outcomes, includes the following variables:

1) Total operating costs (OPEX) measured in EUR, Grid length low voltage (LV), Grid length high voltage (HV), replacement value of capital measured in EUR.
2) Good outputs: Energy delivered (MWh) and Number of customers (CUS).
3) Bad outputs: Number of interruptions (INT), average duration of interruptions (DUR).

The models assume constant returns to scale (CRS), strong disposability of good outputs and weak disposability of bad outputs.

Due to lack of harmonization of definition and measurement of interruptions and duration among the 4 Nordic countries the estimations and analysis are limited to Finland, Norway and Sweden respectively. The results below are all based on country specific reference technologies, and not a common Nordic reference technology.

In this type of models for efficiency measurement efficiency is reported as the maximum, in absolute terms, by which a good output can be increased and a bad output can be reduced. The maximum amount will be lower for a small unit and higher for a large unit, given a potential for efficiency improvement. Zero in possible improvement for good and bad outputs characterizes efficient units.

Results

Table 5-8 presents the, on average, results for Finland, Norway and Sweden. The efficiency score is a measure by how much an output can be increased/decreased. On average the results shows that outputs can be increased/ decreased with 11152 in Finland, 12976 in Sweden and 2089 in Norway. Table 5-8 also presents the potential increase/ decrease in outputs in per cent. For example, for Finland the potential increase in energy delivered (MWh) is 3 % and interruptions could be decreased by 9 %. Potential for improvement is present in all 3 countries. Looking at a possible improvement by variable the results differ among the countries. The potential for quality improvements seems to be higher in Norway than in Sweden and Finland. In all countries the results indicates small potential increases in delivered energy.

Table 5-8 Results, on average, for Finland, Norway and Sweden (separate country models). Efficiency score and 'efficiency' by output variable in per cent. With quality aspects included.

	Efficiency score	No of efficent units	MWh %	CUS %	INT %	DUR %
Finland (81 units)	11152	20	3	32	9	1
Sweden (168 units)	12976	42	2	46	36	3
Norway (129 units)	2089	28	1	11	79	60

The above results with quality aspects included in the model have been compared with an output based model without quality aspects. This comparison will indicate the sensitivity on results for inclusion of quality aspects. Table 5-9 presents the average results for the output based model with no quality aspects included.

Table 5-9 Results, on average, for Finland, Norway and Sweden. Efficency score and "efficency" by output variable in per cent. No quality aspects included.

	Efficiency score	No of efficient units	MWh %	CUS %
Finland (81 units)	12762	11	3	37
Sweden (168 units)	15873	15	3	56
Norway (129 units)	8334	4	2	42

For all the 3 countries the average efficiency scores increased significantly when the model was run with no quality aspects included, i.e., the average efficiency is lower if we not take into account quality aspects. The potential improvement for increase in the good output is higher if quality is not considered in the model.

The above results should be seen as illustration of methods, and improvement in data quality may change the results.

6. Recommendations

The discussion and analysis of this project have shown that a joint Nordic efficiency model is possible and has several advantages:

- A common model would imply that more companies are included. This secures comparativeness due to the fact that the chance of finding a similar company increases with a more extensive range of companies.
- Companies estimated as efficient in one country might have an efficiency potential that appears only when compared to companies of other countries.
- Having a common Nordic efficiency model might improve on the regulatory efficiency.

Although the design of a common efficiency model ideally has to be seen in light of a common regulatory framework, which is being discussed in Subproject B, using a common efficiency model might have some value in itself with respect to revealing information. However, in that case the utilization of a common efficiency model will have to be adapted to the different national regulatory frameworks. The same rules apply with regards to comparability when the efficiency model is used as a supplemental tool to the national regulation as when it is implemented in a joint Nordic regulatory design.

Benchmarking is only one of several possible instruments for a regulator to assess the relative performance of the regulated firms. The use of a formalized performance assessment model, such as in this report, permits the economic interpretation and usage of the results in an objective and systematic fashion. However, the appropriateness of any method entirely depends on the intended usage.

In broad terms, the objectives of regulators or industry for employing benchmarking can be related to one or more of the categories learning, motivation and coordination.

Learning models. If the model is initiated to support learning and efficiency improvements by regulated firms, the approach is characterized more by information openness towards firms than towards the market. Industry benchmarking projects are usually characterized by a reciprocity principle for data sharing, stating that data and results are restricted to participants only. DEA provides in this context particular strengths, as the peers (in convex technologies) or the dominating firms (in nonconvex cases) provide valuable and concrete information for performance improvement targets. However, such information can merely select potential best practice firms, the actual operational changes will necessitate in-depth process benchmarking that may, or may not, be promoted by the participating firms. When learning, it is sufficient if the results are correlated with best practice, they do not necessarily need to be adjusted to the exact level. Further, unless there is some need for information verification and/or coordination, the regulated firms would normally develop, administer and run learning models by themselves rather than leaving it to the regulator(s).

Motivation models. Whenever a formal performance assessment model is used directly or indirectly to set revenues of the regulated firms, we talk about motivation or incentive provision. Several approaches are possible. The model may be used directly to determine the entire reimbursement, as in a yardstick regime, to calculate an individual efficiency-related element or addition to the reimbursement, or to estimate an industry-wide efficiency parameter, such as the X in the CPI-X regimes. The impact on benchmarking design is primarily linked to (i) the economic importance of the model outcome for the individual firm, (ii) the individual vs. collective implementation of its results, and (iii) the treatment of sunk costs. These elements are further discussed in Agrell and Bogetoft (2003c). Here, it suffices to conclude that a model supporting incentive provision due to requirements of robustness, information verifiability and relevance preferably is more aggregated (to allow for substitutions while avoiding accounting gaming) and output focused (to avoid micromanagement).

Coordination models. When the objectives of the benchmarking explicitly are to support decision making of operational changes in firms, we say that coordination is at hand. A network manager may use benchmarks of operations, not only to motivate local networks, but also to allocate resources and staff according to their profile. Decisions related to specific type of processes, equipment and organizational solutions may also be made based on comparative information. Coordination models require a careful analysis of the model and the reference set to assure useful results. As opposed to the earlier models, coordination models do not necessarily rely on the entire data material, nor purport to cover a large span of operations and conditions, but serve to inform in a more narrow technical and economic setting. In practice, managers may handpick potential comparators and then selectively collect data on some (sub)process executed by these firms, say cable undergrounding or metering in urban areas. Clearly, it would be inappropriate and costly for the regulator(s) to develop coordination models. However, a well constructed motivation model may provide a starting point for further information collection towards a coordination model.

Principally, four development strategies are possible in the context of benchmarking of electricity networks. The strategies differ in the level of harmonization of either model specification or data specification as in Table 6-1. Depending on the objective above (learning, motivation, coordination) the strategies may be more or less interesting.

Table 6-1. Model and data harmonization.

		Model specification	
		Joint	*Separate*
Data specification	*Joint*	Common Nordic model, operated on homogenous data	Separate models, drawing on a harmonized data base and definitions
	Separate	Common Nordic model, run separately on national data	Status quo, national models and databases

Nordic model and data. The most ambitious project would be a common Nordic performance assessment model, run on a homogenous data set. This level of coordination could enable a common regulatory policy and unbiased ranking of all Nordic firms. However, it assumes common initiative and investments in both model and data development.

Nordic model - National data. One may also imagine a common initiative to conclude on a performance assessment model, structure, variables and orientation, without committing to common operation and/or task descriptions. This approach would enable a streamlining of the performance expectations, but using only national rankings as to avoid the legal-political problems related to diverse task definitions.

National models - Nordic data. A bottoms-up approach would be to harmonize the data definitions and collection process, without agreeing on a common model. This might be a way to circumvent problems related to different performance evaluation principles and sunk investments into specific methods, while offering greater information value for each of the national models using Nordic data.

National models and data. The current situation is characterized by heterogeneous, albeit related, performance assessment models operated only national data. The drawbacks being evident, the only advantage of this approach may be its limited need for Nordic coordination.

There are, however, several challenges that have to be solved before implementing a joint Nordic efficiency model. These are challenges related to securing comparability between the companies of the four countries. This is quite an extensive work on the hand of the regulators, where the regulators have to compare status quo in-dept, as well as discuss and agree upon joint definitions with regards to

- cost accounting
- capital valuation
- technical definitions

After having agreed upon these definitions, the national reporting structures have to be harmonized in order to facilitate the collection of comparable data. The reporting structure does not have to be identical in the four countries, but has to make it possible to include / exclude costs related to relevant / irrelevant tasks and voltage levels.

Implementation

Implementing a common Nordic efficiency model based on a full scale Nordic dataset requires a harmonization process that will take some years. Both in-dept analyses of status quo, discussions in order to reach agreement with regards to definitions and reporting structures, changing and implementing systems and structures as well as validating data in a joint Nordic dataset are time consuming processes. A first step on the way to a full scale Nordic efficiency model could therefore be a common model framework which could be run on the national datasets of the four countries. When first defining the model framework, it is easier to find the tasks and definitions that are required to be harmonized in the next step.

It is therefore important to start the work of introducing a common Nordic efficiency model by discussing and agreeing upon a joint model framework based on a set of unified principles for the efficiency model which corresponds to the preferred common regulatory design. The model development includes the following steps: 1) Analysis of regulatory interface with benchmarking (preference structure and application), 2) Choice of model structure, orientation and evaluation horizon, 3) Choice of production technology (returns to scale and disposability), 4) Choice of variables and environmental proxies, 5) Choice of estimation approach (parametric or non-parametric)

Recommendations

Due to the fact that the choice and the design of efficiency model depends on the regulatory framework in which it is to be applied, a recommendation with regards to the full scale design of the efficiency model is not being made at this point. However, some principles for a joint Nordic efficiency model can be recommended:

The *input measures* of a joint Nordic efficiency model should be kept simple. Using the total costs as an input variable is therefore recommended. It is, however, important to account for possible different price levels, environmental conditions and varying age structures of the grid assets in a common Nordic efficiency model. This can be done on the input side as well as the output side, having different implications with respect to the model design.

The o*utput specification* should be more detailed than the input specification, with measures capturing at least customer service, transportation work, and capacity provision. Depending on whether or not the input measures are adjusted for differences in costs between and within the countries, additional output variables might have to be included into the model.

Quality aspects should be included into a common Nordic efficiency model in one way or the other. Different ways of including quality aspects into the efficiency model have been discussed and tested through pilot runs in this project. The discussion and pilot runs show:

1) Reliability of supply measures are the most important quality aspects to include in an efficiency model, and should be prioritized in the first place. Secondly, quality of service measured should be included.
2) The costs of the customers related to inferior quality should be included as an input in order to internalize the total societal cost related to the provision of quality. This will secure comparability across grid companies with good and bad quality.
3) A combination between the measures "the number of interruptions" and "duration of interruption" seems to provide a good representation of the costs of the customers related to inferior quality.

Due to the several gains that can be achieved from a common Nordic efficiency model, we recommend the regulators to start the discussions regarding the establishment of such a model as soon as possible. This would require

4) A principal discussion regarding the purpose of the efficiency model, primarily seen as part of a joint Nordic regulatory framework.
5) An in-dept analysis of the cost structures of the grid companies of the different Nordic countries, as well as the tasks that the grid companies are required to attend to.

6) A harmonization of the cost and reporting structures.
7) Discussions regarding model design, and particularly analyses of comparability and specifications / variables that improves on this.
8) Discussions regarding data specifications.

7. References

Agrell, P. and P. Bogetoft (2000) *Ekonomisk Nätbesiktning*. Final Report, Swedish Energy Agency, SUMICSID AB. (In Swedish)

Agrell, P. and P. Bogetoft (2002) *Ekonomisk Nätbesiktning 2000,* Report ER 7:2002, Swedish Energy Agency, SUMICSID AB. (In Swedish)

Agrell, P. and P. Bogetoft (2003a) *Dynamic Regulation,* Report AG2-V1, Norwegian Energy Directorate NVE, SUMICSID AB.

Agrell, P. and P. Bogetoft (2003b) *Norm Models,* Report AG2-V2, Norwegian Energy Directorate NVE, SUMICSID AB.

Agrell, P. and P. Bogetoft (2003c) *Benchmarking for Regulation*, Report FP4, Norwegian Energy Directorate NVE, SUMICSID AB.

Agrell, P. and P. Bogetoft (2003d) *ECOM+ Final Report*, SUMICSID AB

Agrell, P. and P. Bogetoft (2004) *Evolutionary Regulation: From CPI-X towards contestability*, ENCORE position paper, Amsterdam.

Agrell, P. and P. Bogetoft (2005a) *Cost Reporting Guide, ECOM+* , SUMICSID AB

Agrell, P. and P. Bogetoft (2005b) *NVE Network Cost Efficiency Model*, Final Report, SUMICSID AB.

Agrell, P. and J. Tind (2001) A Dual Approach to Nonconvex Frontier Models *Journal of Productivity Analysis*, vol. 16, pp. 129-147.

Aigner D, Lovell, K. and Schmidt, P. (1977) Formulation and Estimation of Stochastic Frontier Models, *Journal of Econometrics*, 6, 21-37.

Aigner, D. J. and S. F. Chu (1968) On Estimating The Industry Production Function, *American Economic Review*, 58(4) 826-839.

Baarsma, B., Berkhout, P. and J. Peter Hop (2004) Op prijs gesteld, maar ook op kwaliteit. De Prijs van stroomonderbrekingen – op zoek naar φ. SEO report no 726.

Battese, G.E. and T.J. Coelli (1992) Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India, in Gulledge, T.R. and C.A.K. Lovell (eds.) *International Applications of Productivity and Efficiency Analysis,* Kluwer Academic Publishers, Boston, 149-165.

Bjørndal, M., Bjørnenak, T. and Johnsen, T. (2004) *Aktivitetsbasert kalkulasjon for regulerte tjenester. Erfaringer, prinsipielle retningslinjer og mulig anvendelse for nettvirksomhet i kraftsektoren.* SNF working paper 2004.

Bogetoft, P. (1994b) Incentive Efficient Production Frontiers: An Agency Perspective on DEA, *Management Science*, 40, pp.959-968.

Bogetoft, P. (1996) *DEA on Relaxed Convexity Assumptions*, Management Science, 42, , pp. 457-465.

Bogetoft, P. (1997) DEA-Based Yardstick Competition: The Optimality of Best Practice Regulation, Annals of Operations Research, 73, pp. 277-298.

Bogetoft, P. (2000) DEA and Activity Planning under Asymmetric Information, *Journal of Productivity Analysis,* 13, pp. 7-48.

Bogetoft, P. and D. Wang (2005) *Estimating the Potential Gains from Merger, Journal of Productivity Analysis*, 23, pp. 145-171,.

Bogetoft, P. J. Tama, J. Tind (2000) *Convex Input and Output Projections of Nonconvex Production Possibility Sets*, Management Science, vol. 46(6) pp. 858-869.

Borger, B. and K. Kerstens, (1996) *Cost efficiency of Belgian local governments: A comparative analysis of FDH, DEA, and econometric approaches*, Regional Science and Urban Economics, 26, , pp. 145-170.

Coelli, T.J., D.S.P. Rao and G.E. Battese (1998) *An Introduction to Efficiency and Productivity Analysis* , Kluwer Academic Publishers, Boston .

Commission of the European Communities (2005) *Technical Annexes to the report from the Commission on the Implementation of the Gas and Electricity Internal Market*. Commission staff working document, Brussels 5.1.2005.

Cooper, W. W., Seiford, L. M. and Tone, K. (2000) *Data Envelopment Analysis*. Kluwer Academic Publishers.

Cox, D.R. and D.V. Hinkley (1974) *Theoretical Statistics*, Chapman and Hall, London.

Deprins, D., D. Simar, and H. Tulkens (1984) *Measuring Labor Efficiency in Post Offices*, pp. 243-267 in M. Marchand, P. Pestieau, and H. Tulkens, "The Performance of Public Enterprises: Concepts and Measurements", North Holland.

Edvardsen, D. F., and F. R. Førsund (2003) International Benchmarking of Distribution Utilities. *Resource and energy Economics,* 2003..

Estache, A. and D. Martimort (1999) *Politics, Transaction Costs, and the Design of Regulatory Institutions*. Policy Research Working Paper No. 2073, World Bank.

Frontier Economics (2003) *Developing monopoly price controls, Workstream B, Balancing incentives.* A final report prepared for OFGEM, Standard project document, London.

Färe, R. and Grosskopf, S. (2004) *New Directions: Efficiency and Productivity*. Kluwer Academic Publishers.

Giannakis, D., Jamasb, T. and Pollitt, M. (2005) Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks. Energy Policy 33 (2005) 2256-2271.

Greene, W. H. (1997). *Econometric analysis* (3rd Ed.). Prentice Hall.

Korhonen, P. J., Syrjänen, M. J. (2003) Evaluation of Cost Efficiency in Finnish Electricity Distribution. Annals of Operations Research 121, 105-122.

Land. K., Lovell, C. A. K. and S. Thore (1993) Chance-Constrained Data Envelopment Analysis, *Managerial and Decision Economics* 14(6) 541-54.

Lovell, C.A.K. (1993) Production Frontiers and Productive Efficiency. In Fried, H.O., C.A.K. Lovell and S.Schmidt (eds) *The Measurement of Productive Efficiency: techniques and applications,* Oxford, Oxford University Press

Mogstad, O. (2003) *Registrering og rapportering av feil og avbrudd I Norden. Krav, organisering og innhold.* SINTEF TR A5801.

Nordel (2004) Annual Statistics 2002. www.nordel.org

Olesen, O. B. and N. C. Petersen (1995) Chance Constrained Efficiency Evaluation, *Management Science*, (41)3, 421-452.

Petersen, N.C. (1990) *Data Envelopment Analysis on a Relaxed Set of Assumptions*, Management Science, 36, , pp. 305-214.

Robert, A. (2001) *Quality issues for system operators with special reference to European regulators.* Report, Belgian Transmission System Operator (ELIA) Brussels.

Samdal, K. and Kjølle, G. (2003) *Sluttbrukeres kostnader forbundet med avbrudd og spenningsforstyrrelser: Del 2: Spørreundersøkelse - Resultater*. SINTEF TR A5754.

Swedish Energy Agency (2005) *En leveranssäker överföring*. Report from the special commission on quality in electricity distribution STEM 2005-04-26

Tulkens, H (1993) On FDH Efficiency Analysis: Some Methodological Issues and Applications to Retail Banking, Courts, and Urban Transit, *Journal of Productivity* Analysis, 4, 183-210.

Weyman-Jones, T.G. (2001) *Stochastic non-parametric efficiency measurement in UK electricity distribution*, Economics Research Paper, Department of Economics, Loughborough University, 01/10.

Appendix A: Technical model definition

Economists typically think of firms as optimizing, i.e., they have a goal and they make production choices to do the best they can in achieving that goal given the technological constraints they face. The textbook example of a firm optimization problem is profit maximization. All of the efficiency measures presented below are essentially consistent with that goal.

For a given level of production, efficiency requires that firma use the fewest possible resources, i.e., they are saving or reducing inputs (costs) as much as possible. As a consequence we refer to these as input-saving or input-oriented measures of efficiency. These are in contrast to output-oriented efficiency measures where the idea is to produce as much output or revenue as possible from a given level of resources. Under certain conditions input- and output-oriented measures will give the same results, but in general that is not the cases.

Among the efficiency measures we distinguish between those that require data on prices and those that do not require price data. Since we do not have price data the measure and models refer to technical measures of efficiency.

Estimation of input oriented efficiency scores

In the estimation of short and long run input technical efficiency we measure technical efficiency as the greatest proportion that inputs could be radially reduced and still produce the same output. Alternatively, it is the ratio (the size of) minimal feasible input usage to (the size of) current input usage. This measure is usually referred to as the Farrell Input-saving Measure of Technical Efficiency and it is defined as

$$F_i(y,x) = \min\{\lambda : \lambda x \text{ can produce y}\}$$

The Farrell input measure of technical efficiency with both controllable and non-controllable input factors, is estimated as the solution to the following (DEA) linear programming problem

$$\begin{aligned}
&\min \lambda \\
&s.t. \\
&\sum_{k=1}^{K} z_k y_{km} \geq y_{jm}, m = 1,2,..M, \quad \text{outputs} \\
&\sum_{k=1}^{K} z_k x_{kn} \leq \lambda x_{jn}, n = 1,2,...N, \text{controllable inputs} \\
&\sum_{k=1}^{K} z_k x_{ks} = x_{js}, s = 1,2,...N, \ \text{non-controllable inputs} \\
&and \\
&z_k \geq 0 \text{ if CRS} \\
&\sum_{k=1}^{K} z_k \leq 1 \text{ if NIRS} \\
&\sum_{k=1}^{K} z_k = 1 \text{ if VRS}
\end{aligned}$$

for unit j. Different models with respect to returns to scale can be obtained by changing the restriction set on the sum of the intensity variable z.

Estimation of output oriented efficiency scores with quality

Farrell measures of efficiency are under fairly general conditions, useful tools for measuring technical and economic efficiency. However, they have some limitations that arise from their radiality and in cases when there is joint production of good (desirable) and bad (undesirable) aspects of output. In the latter case, the traditional Farrell DEA model would typically seek to expand the vector of both types of outputs, rather than crediting firms for reducing the undesirable output.

The so called directional distance function can be customized to simultaneously seek expansion of desirable outputs and reduction in undesirable outputs. In the case of efficiency measure based on values to directional distance functions we use the term efficiency indicator instead of efficiency index.

The directional distance function is associated with an explicit direction in which efficiency is gauged (the radial direction is only one of many possible directions). This requires that we specify a direction vector for the good output aspects (g_y) and for the bad output aspects (g_b). The indicator of output efficiency is defined as a value to the output directional distance function $\vec{D}_o(x, y, b; g_y, g_b)$ as

$$\vec{D}_o(x, y, b; 1, -1) = \max\{\beta : (y + \beta \times 1, b - \beta \times 1) \text{belong to the technology } \}$$

in the case of direction +1 for good aspects of output and direction –1 for bad aspects of output. The indicator will tell us how much good output can be increased and bad outputs simultaneously can be are reduced.

To estimate technical efficiency requires solving the following linear programming problem illustrated for unit j in the case of a long run model with constant returns to scale and no non- controllable factors.

$$\begin{aligned}
&\max \beta \\
&s.t. \\
&\sum_{k=1}^{K} z_k y_{km} \geq y_{jm} + \beta \times 1, m = 1,..M \text{ good aspects of output} \\
&\sum_{k=1}^{K} z_k b_{kr} \geq b_{jr} + \beta \times 1, b = 1,..R \quad \text{bad aspects of output} \\
&\sum_{k=1}^{K} z_k x_{kn} \leq x_{jn}, n = 1,..N, \qquad \text{inputs} \\
&\text{and} \\
&z_k \geq 0, k = 1,..K.
\end{aligned}$$

Different models with respect to returns to scale can be obtained from setting restrictions on the sum of the intensity variable.

nemesys

The Nordic Efficiency Model for Electricity distribution SYStems (NEMESYS) aims at developing a common regulation model for electricity distribution in the Nordic region (NordPool region). The project contains three major subprojects:

A) Regulatory System Analysis

Based on an established methodology for regulatory approaches, a careful analysis is performed of the interactions implied by the integrated energy market directives and the degrees of freedom in the institutional and industrial setting in the Nordic countries. This phase also includes a forward and outward looking review of regulatory systems, industry performance and the dynamics of industry development and regulation.

B) Regulatory Mechanism Design

Based on the structured methodology in A, the mechanism design subproject develops a regulation framework that addresses the current and future challenges and that has the potential to accommodate the country specific factors in a systematic and objective manner.

C) Efficiency Model Development

In parallel with A and B, the project performs analysis and development of a performance measurement platform that corresponds to the regulatory standards and information requirements. The process includes estimating the data and processing needs and to demonstrate its applicability in the entire region using representative industry data. The model explicitly addresses the horizon, investment and quality dimensions of the service, in addition to operating cost and task complexity.

The NEMESYS project is commissioned by Nordenergi and staffed by SUMICSID AB as project coordinator and EC Group AS, Gaia Group OY, SKM Energy Consulting AS and RR Institute of Applied Economics as project partners.

http://www.nemesys.sumicsid.com

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