Business models for DSOs under alternative regulatory regimes

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Project objectives

The objectives of the DG-GRID project are:

- To review the current EU MS economic regulatory framework for electricity networks and markets, and identify short-term options that remove barriers for RES and CHP deployment.
- To analyse the interaction between the economic regulatory framework, increasing volume share of RES and CHP and innovative network concepts in the long-term.
- To assess the effects of a large penetration of CHP and RES by analysing changes in revenue and expenditure flows for different market actors in a liberalised electricity market by developing a costs/benefit analysis of different regulatory designs and developing several business models for economic viable grid system operations by DSOs.
- To develop guidelines for network planning, regulation and the enhancement of integration of DG in the short term, but including the opportunity for new innovative changes in networks in the long-term.

Project partners

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- Öko-Institut e.V., Institute for Applied Ecology, Germany
- Institute for future energy systems (IZES), Germany
- RISØ National Laboratory, Denmark
- Imperial College London, United Kingdom
- Instituto de Investigación Tecnológica (ITT), University Pontificia Comillas, Spain
- Inter-University Research Centre (IFZ), Austria
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Abstract

We expect sustainability and energy efficiency targets as set at the European and world level to be a continuing driving force behind an increasing penetration of distributed generation (DG) in distribution networks. But the costs and benefits associated with such a transition might be asymmetrically distributed across energy market actors. In this report we show how the owner of the distribution network, the distribution system operator (DSO) is affected by an increase in the level of DG penetrating the distribution network. We show, with the use of a financial (spreadsheet) model and taking into account a number of network and DG unit characteristics, that DSOs are likely to be negatively affected when DG penetration reaches high levels. At low DG penetration levels we expect DSOs to gain somewhat from DG presence in the network. In addition, we propose and analyse some regulatory measures through which any potentially negative impact of DG penetration on the DSO business can be mitigated or even neutralised.

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Summary

The larger presence of distributed generation (DG) in distribution networks can radically change the system of electricity supply. Whereas the current system is designed to transfer centrally generated electricity via high voltage electricity networks to local consumers connected to low voltage distribution networks, DG feeds-in electricity at the distribution level. The increasing penetration of DG in distribution networks brings costs and benefits to different electricity system actors.

In this report we investigate the *economic impact of DG* penetration in distribution networks *on the DSO business* taking into account a large number of factors such as network characteristics and DG characteristics. The opportunities for DSOs on the provision of ancillary services in the near future are not covered in this report but in another DG -GRID report (Jansen et al., 2007). In assessing this economic impact we take current DSO regulation as a starting point and analyse the economic impact under two differing network management philosophies: passive and active network management.

Using two modelling tools, the GSP model and the DSO model, we analysed:

1. The impact of DG on DSOs operating under a passive network management philosophy.
2. The impact of DG on DSOs operating under an active network management philosophy.
3. The impact of the potential value of deferred investments of DSOs due to DG on the outcomes under (1) and (2).
4. The incentive for the DSO to adopt an active network management approach instead of a passive network management approach.
5. The effectiveness of alternative regulatory arrangements in (a) neutralizing the possible negative impact of DG penetration, or (b) providing incentives for the DSO to adopt an active network management approach to enable the DSO to participate in the provision of ancillary services.

We find that DSOs operating under a passive network management regime generally do not profit from the presence of DG in their distribution network. Generally, this is also the case under an active network management philosophy. Important factors influencing the degree to which the DSO is subjected to any negative impact of DG penetration are the amount of DG within the distribution network, the rural or urban character of the distribution network and the concentration of DG in the distribution network.

Overall we conclude that improvements in regulatory arrangements aimed at compensating the DSO for the impact of DG might be warranted. Our model analysis on possible improvements in regulatory arrangements suggests that a combination of a special allowance and a direct revenue driver is most successful in compensating DSOs for the negative impact experienced from further DG penetration.

1. Introduction

1.1 Problem description

The larger presence of distributed generation (DG) in distribution networks can radically change the system of electricity supply. Whereas the current system is designed to transfer centrally generated electricity via high voltage electricity networks to local consumers connected to low voltage distribution networks, DG feeds-in electricity at the distribution level. The increasing penetration of DG in distribution networks brings costs and benefits to different energy system actors.

In this report we focus on the position of the operator of the distribution system (DSO) and the impact of an increase in DG in the distribution network.[1] The DSO is affected in different ways. On the one hand, the DSO might benefit from DG presence in the distribution network through a deferral of investments and a reduction in the level of distribution losses. Since decentralised generation effectively takes over centralised generation, less investment is needed in upward connections with the higher voltage networks operated by the transmission system operator (TSO).[2] On the other hand, the DSO might be negatively affected by an *increase* in network reinforcement costs and an *increase* in the level of distribution losses due to a higher rate of capacity usage for high DG penetration levels. In addition, the presence of electricity generation units in the distribution network creates opportunities for the DSO to enter the market for ancillary services.

In this report we investigate the *economic impact of DG penetration* in distribution networks *on the DSO business* taking into account a large number of factors such as network characteristics and DG characteristics. In other words, we aim to identify the drivers that cause DSOs to benefit or lose from increasing DG penetration in the distribution network. The opportunities for DSOs on the provision of ancillary services in the near future are not covered in this report but in Jansen et al. (2007).

In assessing this economic impact we take current DSO regulation as a starting point and analyse the economic impact under two differing network management philosophies: passive and active network management.

Hence, our research question is the following:

> *What is the economic impact of DG penetration in distribution networks, taking into account different DG and distribution network characteristics and two possible network management philosophies?*

The acknowledgment of the differential impact of DG penetration on the DSO is important for the design of distribution network regulation. Under a traditional cost-plus regime of distribution network regulation, the potential investment cost increase is automatically passed-through to end-consumers, but under current widely applied incentive-based regulatory regime this is

[1] The distribution network is defined to be a low voltage network below the national transmission network that (i) distributes electricity from the substation of the national transmission network to end-users connected to that network, and (ii) distributes electricity generated within the distribution network (DG) to end-users connected to that network. This includes all assets needed to perform this distribution task.

[2] It has to be noted that possible reductions in investments on the transmission network itself due to a higher DG presence on distribution level are entirely left outside consideration in this report.

not the case.[3] If it turns out that the DSO business is negatively affected by (increasing) DG penetration in the distribution network it raises the question whether the negative impact should be compensated for through the regulatory regime. Since the distribution of electricity is a regulated monopoly business, this would call for improvements in current regulation. This brings us to a second research question:

> *What are the possible regulatory improvements if the negative impact of DG penetration in distribution networks were to be compensated for?*

1.2 Methodology

In tackling the research question we use a modelling perspective. We have effectively combined two distinctive models that together provide insight into the posed research questions. On the one hand we have used the GSP[4] model, as described in Cao et al. (2007). The GSP model is a technical load flow model representing a distribution system. On the other hand we have used a financial spreadsheet model representing the DSO business: the DSO model. This is a financial regulatory model depicting the position of the DSO.

1.3 Report structure

The remainder of this report is as follows. In chapter 2 we elaborate on the DSO business and the impact of DG penetration and the regulatory regime on the DSO business. Here we introduce and describe concepts such as passive and active network management. Chapter 3 discusses the methodology and we present the two modelling tools used. Chapter 4 analyses the impact of an increasing penetration of DG in the distribution network on the DSO under regulatory arrangements as currently implemented. Chapter 5 analyses how the impact of DG penetration might be different under alternative regulatory arrangements. The latter alternative arrangements aim to neutralize the possible negative impact of DG penetration observed under current regulatory arrangements (the chapter 4 analysis). Chapter 6 concludes and presents some policy recommendations.

[3] However, some countries adopting an incentive-based regulatory regime allow for 'special' passing-through of investment costs to end-consumers through inclusion in the so-called regulatory asset base (RAB).

[4] GSP stands for 'Grid Supply Point', which is a technical term for a connection between a distribution network and the transmission network.

2. The DSO business model

2.1 Introduction

In this chapter we review the business environment of the DSO: the DSO business model. A business model in general refers to the business strategy on how to recover expenditures, including a proper rate of return on investment, with revenues. Here we discuss the current business model of a DSO. We specifically answer the following questions: what are the current DSO expenditures, and what are the current DSO revenues?

An important aspect of the current DSO business model is the regulation of revenues. In Jansen et al. (2007) it is explained that the primary task of the DSO, the distribution of electricity, is considered to be a natural monopoly. This has led to European legislation (the Electricity Directive of 2003, EC (2003)) on the access to distribution networks to third parties and regulation of either prices or revenues.

Figure 2.1 shows a graphical representation of the current DSO business model. It includes the sources and destinations of expenditures and revenues.

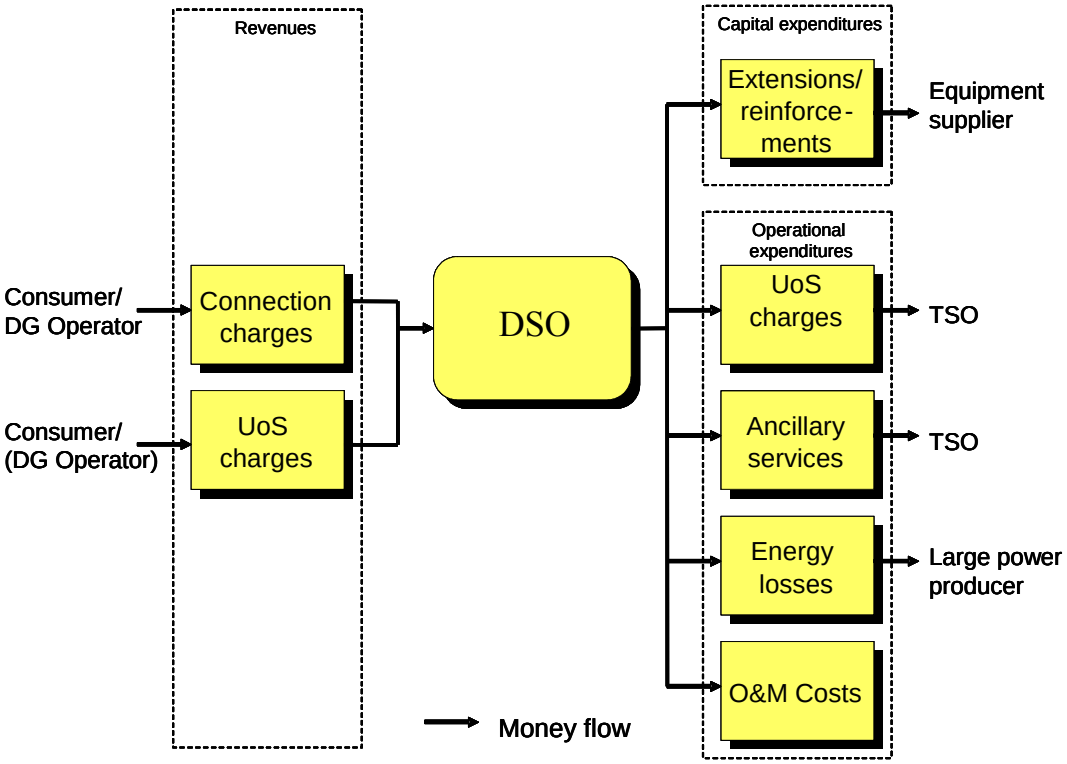


Figure 2.1 *Current DSO business model*

DSO expenditures are divided into two categories: (a) capital expenditures, and (b) operational expenditures. Capital expenditures include investments in distribution network assets such as transformers, switchboards, and cables, and the consequential depreciation costs and remuneration of debt. Operational expenditures encompass costs due to use of the transmission network, distribution losses, costs of ancillary services, and operational and maintenance costs of assets. Commercial costs related to energy measurement and billing to final consumers are also considered to be operational expenditures. Obviously, also these costs are impacted by DG penetration since DG operators are 'network customers' as well. However, an analysis on the impact of DG

penetration on these commercial costs is out of the scope of this report.

The *first* operational expenditure category relate to the passing-through of costs of electricity transmission to end-consumers connected on the distribution level. Small end-users at the lower voltage levels are partly responsible for the need to transmit electricity on the national high-voltage grid. These costs are allocated to end-users on the distribution level by means of a cascading principle. The DSO does not control this cost and is merely an 'administrative agent' for these use of transmission system charges (UoS). In other words, a rise in UoS charges of the TSO is met by an equal rise in UoS for the consumers and small producers on the DSO network. The *second* category of operational expenditures is the DSO payment to the TSO for the delivery of ancillary services. Ancillary services include reactive power support, voltage control, and frequency control. Currently, all services are solely provided by the TSO but in the near future it may be possible that DG is asked to provide some of these services. Jansen et al. (2007) will discuss both current arrangements for providing ancillary services and alternative regulatory arrangements. The *third* category involves the level of energy losses within the distribution network for which the DSO bears responsibility. Although, the specific regulatory arrangements on DSO energy losses can differ between EU member states, the general approach is to let the DSO compensate the losses with the purchasing of electricity on the wholesale market. Hence, distribution losses are valued at market-based rates.[5] The *fourth* and last category is basic operation and maintenance costs, which are closely related to the size and age structure of network assets.

Irrespective of the type of regulation to which the DSO is subjected (revenue cap, price cap) different charging systems are applied. Broadly we distinguish between (i) variable charges based on energy (electricity produced or consumed), (ii) fixed charges based on capacity (peak load or peak production), and (iii) initial connection charges (charges based on initial connection of consumer or generator to the distribution network).

In our analysis we assume connection charges to be shallow, i.e. the consumer of DG operator connected to the network does not bear the full cost burden of connection. This assumption largely corresponds with the connection charging regime applied across EU member states (Skytte and Ropenus 2006). It is observed that the majority of the EU member states under study apply shallow or 'shallowish' connection charging.

This is important to note since the impact of DG penetration in the distribution network for a significant part goes via capital expenditures (i.e. investments in network upgrades). Therefore, dependent on the connection charge regime DSOs receive an incentive in dealing with investments that are necessary for connecting DG to their network. In the case of deep connection charges, both the connection costs and the costs of extending the network for the DSO can be passed through to the DG operator; consequently the DSO in that case has no incentive to minimize investments. However, in the case of shallow or shallowish connection charges additional connection costs cannot be passed through, which gives the DSO an incentive to reduce investments in network upgrades as much as possible because avoidable investments are revenues for the DSO.

2.2 Network management philosophy

The overall *network management philosophy* regarding the operation of the distribution network is a crucial element in the assessment of the impact of increasing DG penetration. We distinguish between (i) passive network management and (ii) active network management.

[5] Other possible arrangements on distribution losses within the EU are (i) a regulated valuing of losses in which DSOs buy electricity at regulated values (for example in Austria), or (ii) a targeted approach in which the regulator sets a DSO specific distribution losses' target and rewards (punishes) DSO overachieving (underachieving). This is for example the approach adopted in the UK and Spain.

The current network management approach is based on an equal treatment of both consumers and distributed generators that want to be connected to the distribution network. New DG connections influence electricity flows in the distribution network. The network needs to be dimensioned on peak generating capacity of the DG unit resulting, in some cases, in incremental reinforcement in the network by the DSO. This is also called the *passive network management* approach, or 'fit and forget' approach: when DG enters the distribution network, upgrade investments based on peak DG output are undertaken and for the remainder any electricity production from the unit is taken as given.

An alternative approach is provided with an *active network management* philosophy. This approach is based on the concept of *intelligent networks* where technological innovations on power equipment and ICT are combined to allow for a more efficient use of distribution network capacity. In addition, it is characterised by active involvement of both consumers and distributed generators: load and generation characteristics are taken into account in network operations and planning. When confronted with new connections the *active* DSO explicitly recognizes the network contribution of electricity consuming and producing entities in its network planning and includes this in investment decision-making.

In the following paragraph the impact of increasing DG penetration in the distribution network on the DSO business is discussed with explicit distinction between passive and active management philosophy.

2.3 The impact of DG on the DSO business

2.3.1 Under passive network management

The increasing penetration of DG in the distribution network is a development external to the DSO. In other words, the DSO is not able to control the level and impact of DG in its distribution network. A DSO is obliged to connect both consumers and producers to its distribution network.

DG penetration affects the DSO in the following ways:
1. DG penetration affects the need for reinforcement and replacement in the distribution network.
2. DG penetration affects the level of distribution losses in the distribution network.
3. DG penetration affects the level of operation and maintenance costs related to investment needs described under 1).

An important distinction that needs to be made on the impact of DG on overall investment in the distribution network are investments in the distribution network itself on the one hand and investments in the connection between the Grid Supply Point (GSP) and the higher voltage transmission network, which is also owned by the DSO, on the other.[6] When a (larger) share of load on the distribution network is met by local generation, the need for upgrade investments with regard to the substation and transformers can be reduced, even when faced with growth in total load. The DSO saves on capacity expansion. However, when very large shares of DG are penetrating the network, with total DG generating capacity surpassing total load in the network, substantial *additional investment to reinforce the network may be required* to cover peak output of DG units.

[6] This distinction is also important since the impact of DG on the deferral of investment in the GSP - high voltage network is not directly included in the GSP model, but calculated separately. Therefore, this distinction is also made in our analysis in chapter 4. Furthermore, it has to be noted that possible reductions in investments on the transmission network itself due to a higher DG presence on distribution level are entirely left outside consideration in this report.

On the one hand, depending on the specific location of DG units in the distribution network and, more specifically the locations *vis-à-vis* load, *energy losses may be reduced*. Local electricity demand may now be met by nearby DG instead of centrally generated electricity that is being transported from the national network through the regional network. On the other hand, if the level of penetration and/or concentration of DG in the network were high, *energy losses may increase* due to higher energy flows in the opposite direction, i.e. from the DG to the distribution network substations.

2.3.2 Under active network management

An active network management approach by the DSO does not enable it to control the *number* of DG connections and the *level* of DG penetration but, instead of the passive network management approach, it is able to capture the potential benefits of specific DG characteristics in the provision of network services, for instance through the improved ramping up and down of DG units compared to conventional generation units. Another difference is that under an active network management approach solutions for network problems are exercised during real time operation, e.g. by changing generation dispatch or managing demand. In a passive network problems cannot be solved real time, but should be dealt with during the design of the network.

Adopting an active network management approach involves initial investment costs. These *implementation costs* relate to the design of the necessary information infrastructure (sensors, signalling devices, smart metering). The costs are to be recovered from the enhanced efficiency of network operations, and the potential deferral of investments in network capacity upgrades.

Under active network management, an increasing penetration of DG impacts the DSO business as follows:

1. DG penetration affects the need for reinforcement and replacement in the distribution network.
2. DG penetration affects the level of distribution losses in the distribution network.
3. DG penetration affects the level of operation and maintenance costs related to investment needs described under 1).
4. DG penetration can give rise to curtailment costs.[7]

With regard to energy losses it is important to mention that these losses can be reduced by a more optimal way of handling the network, whereas at the same time active network management in general can lead to more intensive use of lines and wires and therefore more energy losses.

Concerning the curtailment of electricity, electricity is said to be curtailed if the DSO requires DG operators to shed part of their electricity production for overall system efficiency goals. Such a situation can occur when local DG production exceeds local electricity demand and the costs of relieving the bottleneck(s) in the distribution network that follows are higher than shedding part of electricity produced. Curtailed DG operators must be offered monetary compensation for not being able to deliver their produced electricity to the market. Curtailment of electricity only applies to distribution networks where DSOs operate under active network management.

[7] It may be profitable for DSOs to curtail the supply of electricity of DG in case of network constraints and offering DG monetary compensation, instead of (partially) reinforcing the network. Curtailment is more extensively dealt with in Paragraph 3.2.2.

2.4 Conclusions

The discussion on the DSO business model and the two network management approaches highlights the following point trade-off.

A DSO has at its disposal two ways to deal with an increasing penetration of DG in its distribution network. Either the DSO reinforces the network in the 'traditional' passive way where the network is dimensioned on the (peak) output of the DG unit, or the DSO chooses to adopt an active approach by considering the possibility to influence (i.e. curtail) electricity output of the DG unit once connected to the network. Ideally, the DSO opts for the approach resulting in the least total costs, considering both operational costs (costs of distribution losses and costs of curtailment) and capital costs (network reinforcement). Up to a certain degree of DG penetration (as measured by either electricity produced by DG and fed into the distribution network or total DG peak capacity connected to the distribution network) the bottleneck in the distribution network that emerges when connecting another DG unit might be removed at least costs by network expansion. Above a certain degree of DG penetration, the same bottleneck might be removed at least costs by a combination of a minor network expansion and a (partial) curtailment of electricity produced by the DG unit connected part of the time.

3. Methodology

3.1 Introduction

We combine two different types of models to evaluate impact of DG penetration on the distribution network and the financial accounts of the DSO. The first model concerns a network specific load flow model of a distribution network referred to as the GSP model[8] (Strbac et al. 2006, Cao et al. 2007).

The second model concerns a (spreadsheet) model representing the financial revenues and expenditures of a DSO, i.e. the DSO business model. This model is specifically developed for this project. In the remainder of this report we will refer to the two models as 'GSP model' and 'DSO model' respectively.

Figure 3.1 shows the basic input-output relation between the GSP and DSO models. The upper half of this figure contains the *technological domain*. This contains the GSP model and all technical parameters relevant for analysis of distribution network issues. The lower half of the figure contains the *economic domain*. This contains the DSO model and all economic, regulatory and financial parameters relevant for our network analysis.

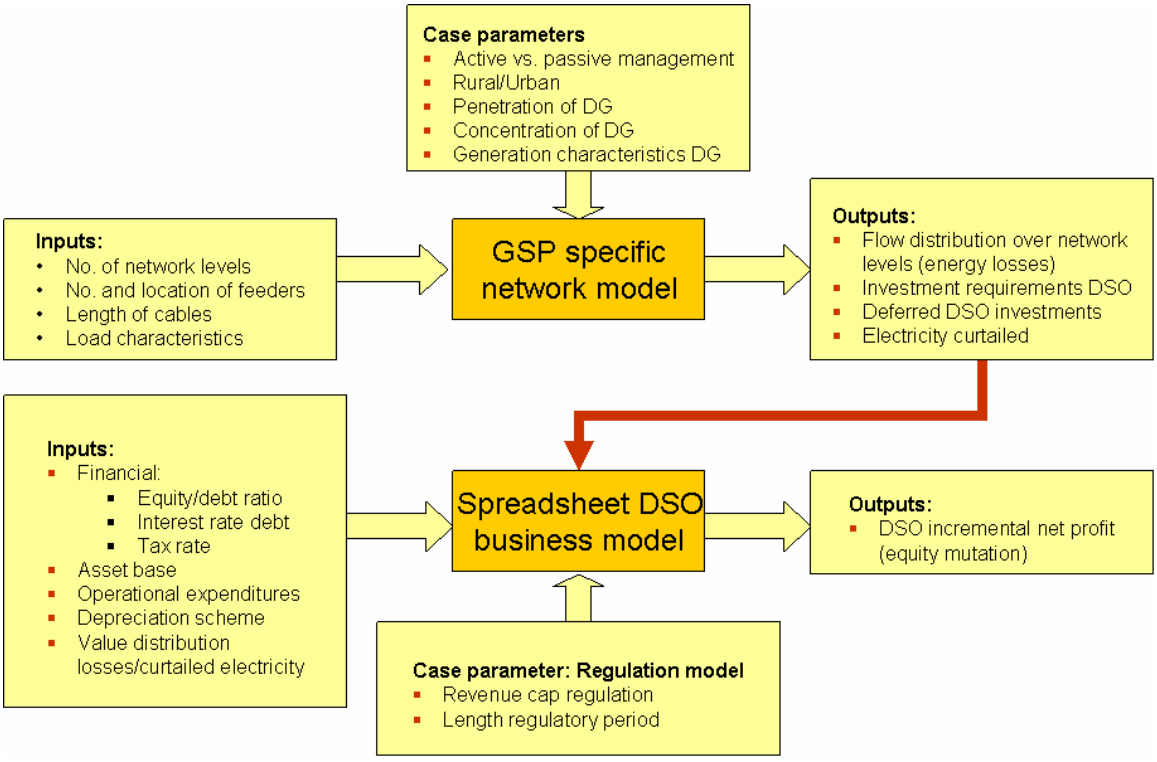


Figure 3.1 *Schematic view of linkage between the GSP and DSO model*

In the following three paragraphs we briefly present the GSP model (3.2), the DSO model (3.3), and discuss the interlinkage between both models (3.4).

[8] GSP stands for 'Grid Supply Point', which is a technical term for a connection between a distribution network and the transmission network.

3.2 The GSP model[9]

3.2.1 Description

The GSP model is based on the topology and design of an 'average' UK distribution network[10]. The primary unit of analysis is one grid supply point. This represents one virtual distribution system operator consisting of different low voltage level networks with substations and transformers between each of these networks. All companies also have a multitude of overhead lines and underground cables to convey power between system levels and eventually down to end users. Substations, cables and lines may vary in capacity and length and the detailed design may affect resistance and reactance values but, to a large extent, all of the distribution networks are similar. They are similar enough in topology and design philosophy to allow the adoption of a common modelling approach, on a GSP basis.

In all DSOs' GSPs in the UK, power is transferred through a number of well-defined system levels, which operate various 'standard' voltages. For the purposes of the analysis in this report, it is assumed that all GSPs are run in parallel and a simplified four-voltage-level network is used for all distribution areas: 132kV/33kV/11kV/0.4kV.

The operating voltage of 6.6 kV is sometimes used instead of 11 kV because of the way the system was developed. It seems, however, to be universally accepted that the preferred level is 11kV and replacement strategies endeavour to achieve the phasing out of 6.6 kV (Aquila, 2002) and (EME, 2002). Consequently, any other voltage levels used by some DSOs, such as 6.6kV and 66 kV, could be reclassified to align them with one of the standard voltages specified above.

While most distribution networks are operated in radial, some DSOs operate part of their networks in meshed configuration. Modelling meshed networks would however require the implementation of advanced load flow calculation, which is not the purpose of this model. It is therefore assumed here that each distribution network in the UK is operated in radial, from the GSP point to the end users. Furthermore, it is assumed that the model is composed of well-balanced three-phase circuits and transformers. A graphical representation of a generic distribution network, with various loads and distributed generators connected, is shown in Figure 3.2. For our analysis, the distribution network in the GSP model is dimensioned at a total load of 1155 GWh per year (being equal to the load of one grid supply point).

[9] This paragraph is taken from Pudjianto et al. (2006). For a more elaborate description of the model we refer to this reference and references therein.

[10] The GSP-model was used to analyse the impact of DG penetration in two specific EU countries: Finland and the UK (Cao et al. 2006). A comparison of results of the case studies provides insight into the robustness of results. Since the UK network better resembles other European countries' distribution network topology and design, the UK results have been used in our analysis. However, a similar analysis as performed in this report can be undertaken for other countries as well.

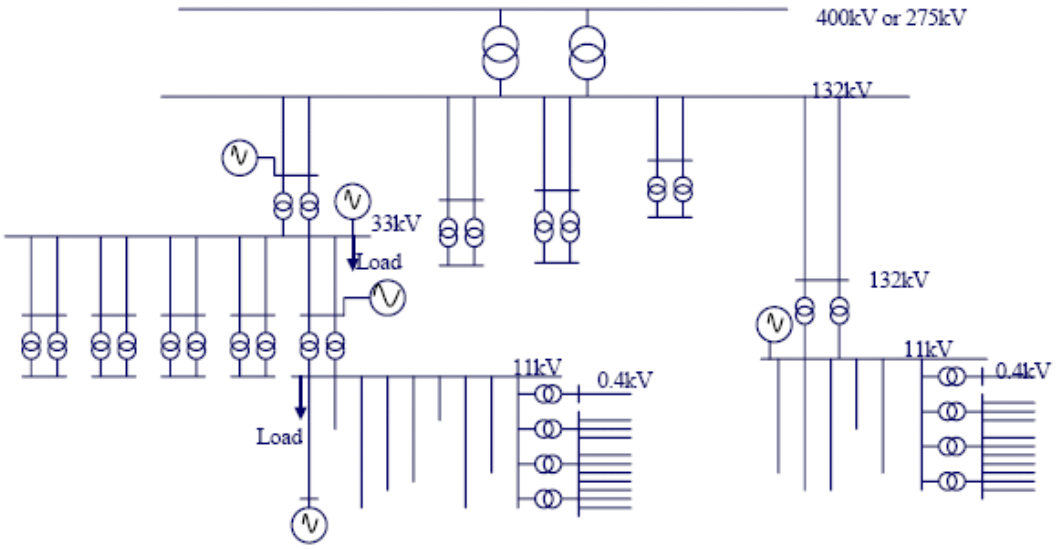


Figure 3.2 *Representation of the module-based distribution network design*
Source: Pudjianto et al. 2006.

3.2.2 Relevant GSP model output variables

Here we elaborate on the GSP model output that is used as an input for our DSO model. Figure 3.1 already illustrated the different output parameters. Table 3.1 lists output parameters in more detail.

Table 3.1 *GSP model output*[11]

Output	*Description*	*Unit*
Investments in distribution network	Total amount of investment required to connect DG to the distribution network.	[m€]
Operational and maintenance (O&M) costs	Operational and maintenance costs related to the investments in distribution network assets due to DG connections.	[m€]
Distribution losses	Amount of energy losses in the distribution network over one year.	[MWh/yr]
Implementation costs of active network management	Total investment costs required for enabling active network management (e.g. 'smart meters', ICT infrastructure etc.).	[m€]
Electricity demand	Total load on one grid supply point (GSP).	[GWh/yr]
Electricity curtailment	Amount of electricity curtailed, only applicable in cases of active network management.	[MWh/yr]
Potential deferred investment	Investments by DSO that are deferred as a result of DG penetration in the distribution network. Deferred investments relate to substation investments.	[m€]

The last output parameter, the potential deferred investment, needs additional explanation. Potential deferred investments refer to the decreasing need for DSOs to expand electricity flow capacity in and around the substation connecting the lower voltage levels of the distribution network with the higher voltage levels of the transmission network, in the presence of DG. If DG is

[11] Note, when mentioning amounts of € we refer to current value (i.e. nominal prices). GSP model output is in GBP and has been converted into € using an exchange rate of 1 GBP: € 1.45.

present in the distribution network, growth of electricity demand within the distribution network needs to be met by an increase in flow capacity from the transmission network to the distribution network. If DG enters the network, the growth of electricity demand can be met by DG produced electricity. This results in lower investment requirements for the DSO. We refer to this type of deferred investment as 'potential' since this benefit for the DSO only applies in case of certain growth of electricity demand on the distribution network.

The amount of potential deferred investment is referred to in Cao et al. (2006) as the network capacity replacement value of DG. This is not a direct model output but derived from Mendez et al. (2006) and combined with GSP model output. Therefore, we deal with the DG impact on potentially deferred investments in the GSP-high voltage network connection separately from the model analysis.

The increasing penetration of DG in distribution networks also reduces the need for potential future network reinforcement in the high voltage transmission network (in general, and the assets at the connection with the distribution networks (substations) in particular). The costs of using the transmission network (and hence the costs of transmission network investments) are generally passed on to the end-consumer via the DSO. Hence the DSO is not hold accountable for these costs and these costs do not influence the DSO model. Therefore, these costs are not included in the following analysis.[12]

3.2.3 GSP model case parameters

In order to explore the impact of DG penetration on the DSO business we identify different case parameters that simulate different conditions under which DSOs are faced with increasing DG penetration. We distinguish between different levels of DG in the network, different concentration ratios for DG units, different DG generation profiles, different network topologies and different types of network management. Table 3.2 lists these case parameters and the chosen values in the analysis.

Table 3.2 *List of case parameters and values*

Case parameter	Values	Unit
1. Level of DG	[50, 100, 200]	[MW_p]
2. Concentration of DG	[low, high]	[discrete]
3. Share of intermittent generation	[0, 100]	[%]
4. Type of network	[rural, urban]	[discrete]
5. Type of network management	[passive, active]	[discrete]

Below, we briefly comment on each case parameter:

1. The *level of DG* penetration in the network

This parameter indicates the amount of peak DG capacity in the network. In the GSP output used for analysis, this amount ranges from 50 to 100 to 200 MW. Given the total level of demand of 1155 GWh in the distribution network, and assumed load factors for intermittent (30%) and non-intermittent (60%) distributed electricity generation. This results in a relative penetration rate of 10 to 90% of total load. Note that the DG penetration ratios mentioned are different from the ratios reported in Cao et al. (2007). In Cao et al. the penetration ratios concern the penetration of DG in all UK distribution networks combined, with the assumption that total DG is connected to only a part of the total of 200 grid supply points. In other words, DG penetration for separate distribution networks might be higher than the penetration ratios mentioned for the whole UK.

[12] When taking the perspective of *society* rather than the *DSO* the potential value of deferred investment should be included in a quantification of the costs and benefits of an increasing DG penetration.

2. The concentration of DG capacity
The spatial concentration of DG within the distribution network is either high or low, where concentration refers to the physical location of the DG unit.[13]

3. The share of intermittent generation in total DG capacity
Distributed electricity producing units vary in electricity generation profile. Whereas some DG units can produce at relatively constant rate, others are volatile in electricity generation. The former category of units is referred to as being non-intermittent DG; the latter is referred to as intermittent DG. A related distinction is that between controllable and non-controllable DG units in the sense that DG units producing electricity intermittently can in principle be controllable. For example, small-scale CHP units at industrial sites are in principal controllable (and hence can respond to changes in electricity prices) but since their electricity production follows industrial heat demand, the resulting electricity production profile is referred to as being intermittent. Within the GSP model, all DG integrated in the distribution network is either fully non-intermittent or fully intermittent and there is no distinction between controllable and non-controllable, which is a simplification of reality where an indefinite portfolio of DG units with different electricity generating profiles exist. This implies that there are no possible portfolios of DG capacity with part producing non-intermittent and part producing intermittent. Hence, in our analysis we explore the two extremes of 0% intermittency of total DG capacity and 100% intermittency of total DG capacity.

4. The type of network
The GSP model distinguishes between two types of distribution networks: rural networks and urban networks. Rural networks generally show low levels of spatial concentration of load whereas urban networks show high spatial concentration of load. This implies relatively 'long' electricity line connections in rural networks and 'short' connections in urban networks. Concerning the impact of DG on both types of networks two aspects need to be mentioned. First, the 'concentration' and 'distance' characteristics lead to a different impact of DG penetration on for example distribution losses in the network. Second, DG penetrations can give rise to different technical problems in rural and urban networks. This implies different requirements for DSO investments in both networks.[14]

5. The type of network management
The different types of network management have been extensively discussed earlier in this report. There is a distinction between passive network management and active management. The former network management type can be described as a 'fit and forget' network management approach where network requirements caused by new DG connections are met by 'simple' capacity expansion. The latter type of network management approach uses 'intelligence' in the network to cope with new DG connections.

3.3 The DSO (spreadsheet) model

3.3.1 Description

The DSO model is a spreadsheet model representing the financial statements of a DSO. It lists expenditures and costs and calculates net profit throughout a longer period of time. The model has the following specific characteristics:
1. The model is *incremental* regarding DG related costs.
2. The model is *dynamic*.
3. The model is based on a *revenue cap* regulatory regime.

[13] The two levels of concentration relate to the 'density' levels distinguished in Cao et al. (2007, DG Grid report D8). They distinguish four levels varying from 'low' to 'medium-low', 'medium-high' and 'high'.
[14] For specific technical description of the problems DG penetration can pose for network operators and the consequences for investment requirements we refer to Cao et al. (2007, DG Grid report D8).

The model is incremental

The focus of our analysis in this report is on the impact of increasing DG penetration in the distribution network on the DSO. In analysing the financial impact we therefore focus on the changes in cost and revenue items caused by increased DG penetration. Costs and revenue items related to 'business as usual', i.e. operations related to servicing of customers, are not included. The model analysis is therefore *incremental* to the normal DSO business. This enables a strict assessment of the impact of DG on the DSO.

The model is dynamic

The DSO model covers a number of regulatory periods, each covering several years. This approach is aligned with current practice where the DSO, being a regulated actor, is confronted with a network performance assessment once in every regulatory period.

The model is based on a revenue cap regulatory regime

EU member states have implemented different types of regulatory regimes, ranging from traditional cost-plus regime to incentive based regimes, and different variants of these methods. For a discussion on the types of regulatory regimes we refer to Jansen et al. (2007). There is no dominant regulatory regime across the EU but the overall trend suggests a move to incentive based regulation. We have chosen one specific type of incentive based regulation as a starting point of our DSO model: revenue cap regulation. This basically states that the DSO is only allowed maximum total allowed revenue (TAR) for its services in one year, with the TAR in one year being equal to the TAR in the previous period corrected for (i) a requirement on improved efficiency performance, (ii) change in overall price level (inflation), and (iii) optional compensation schemes for adverse developments in demand[15]. Since the DSO model uses and presents nominal prices the revenue cap scheme included in the DSO model does not contain a correction for inflation. The foregoing results in the following formula:

$$TAR_t = TAR_{t-1}(1 - X) \pm AF$$

where:

TAR_t = Total allowed revenue in year t

X = Required yearly improvement in efficiency performance

AF = Adjustment factor

The total allowed revenue in the starting year is dependent on the total regulated asset base (RAB), the weighted average cost of capital (WACC) and the operational expenditures. The RAB represents the value of the DSOs asset base.

$$TAR_0 = f(RAB, WACC, OPEX)$$

In traditional incentive-based regulation DSOs are not allowed to include all new investments into the regulated asset base: i.e. no automatic pass-through of investment costs to end-consumers is allowed for. However, some EU member states do allow for 'exceptional' investments to be included in the RAB.[16] The only country to have such a rule regarding specifically DG related investment is the UK. In the remaining analysis we assume that DSOs are not allowed to pass-through the costs of DG related incremental network reinforcement costs.

[15] In the DSO business model, it is assumed that no adjustment factor, for example related to demand growth, is currently used. Further on in this report we analyse the use of an adjustment factor to compensate DSOs for the possible negative impact of DG penetration in the distribution network.

[16] This is also referred to as incentive-based regulation based on the 'so-called' building blocks' approach. For a more elaborate discussion on this specific approach we refer to Jansen et al. (2007).

The DSO model describes the financial accounts of one DSO over a larger period of time. It basically consists of a number of cost and revenue items that together determine the financial result of the DSO for a given number of consecutive years. Table 3.3 presents the cost and revenue items in the DSO model.

Table 3.3 *Financial account items of a DSO in the DSO model*

Item	Description
Depreciation costs	Depreciation costs of network assets
Cost of debt (debt remuneration)	Costs of financing investments in network assets
Operational and maintenance costs	Operational and maintenance costs related to the investments in distribution network, contains a.o. wages
Energy losses	Energy losses in the distribution network for which the DSO bears responsibility. Specific arrangements on DSO compensations for these losses may differ over countries
Curtailment costs	Under active network management, electricity generation by DG units might be partially shed due to low load within the network at some point in time. The lost value of this electricity needs to be compensated. Although the contractual arrangements under which this can occur are uncertain, the DSO is assumed to be partly responsible for compensation (Jansen et al. (2007) elaborate on the different compensation measures).
Revenue (revenue cap)	The DSO model is based on revenue cap regulation. The total allowed revenue for the DSO in a period is dependent on the total allowed revenue in the previous period, and optional compensation drivers (adjustment factors), e.g. for changes in demand, number of DG connection etc.
Corporate tax	Net DSO profits are subjected to corporate taxation

Focus on curtailment cost

All but one of the displayed items is observed on current balance sheets of 'real-world' DSOs. The balance sheet item *cost of curtailment* needs to be elaborated. In the previous chapter we explained the phenomenon of curtailed electricity in distribution networks. A DSO applying active network management and using intelligence within the distribution network to optimise system efficiency may under conditions require the DG operator to shed part of his electricity production. This beholds a particular cost for the DG operator. The DG operator foregoes the opportunity to sell his electricity on the market. In addition, the DG operator might forego additional benefits such as feed-in tariffs put in place for 'green electricity' or CHP generated electricity. The DG operator will demand a form of compensation for his foregone revenues, which is something the DSO can provide. After all, the DSO receives benefits from the shedding of distributed electricity production. Therefore, the DSO and the DG operator enter a commercial arrangement that deals with the sharing of these curtailment costs of the DG operator (or inversely the sharing of system benefits for the DSO). DSOs, based on the specific arrangements entered with DSO operators, should decide whether it is more economic to curtail electricity of DG units (for a particular time period) or reinforce the network.

3.3.2 DSO model input parameters

The DSO model contains a large number of parameters, covering technical, regulatory, economic and financial aspects. Figure 3.3 contains the model parameters. Appendix A contains all parameter values and justification of their assumed values in our analyses.

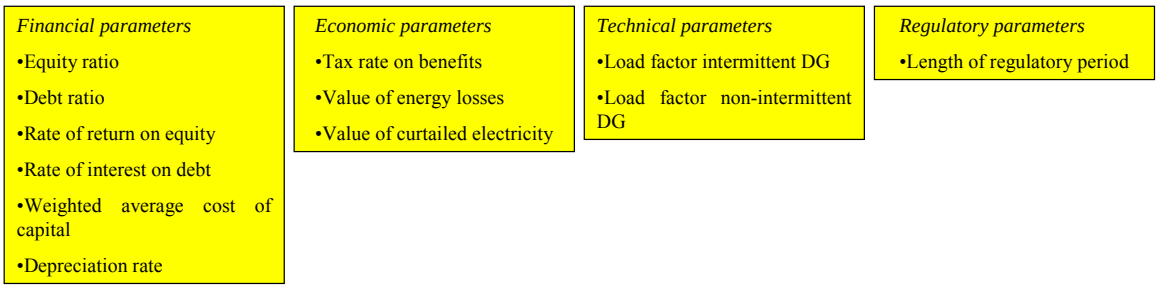


Figure 3.3 *DSO model input parameters*

3.4 Reconciling GSP model output and DSO model input

Reconciliation of GSP model output and DSO model input involves a number of modifications regarding the dimension of time. Note that the GSP model produces 'static' results whereas the DSO model covers a period of several years over which it analyses gradual integration and impact of DG throughout the years. Hence, the following two issues need to be dealt with:

1. The rate of DG penetration over time.
2. The allocation of DG related investments, costs and benefits.

Rate of DG penetration

In order to analyse the impact of a gradual penetration of DG in the distribution network assumptions need to be made on the realisation of DG connections over the 12-year period analysed in the DSO model. We assume that total DG capacity, as given by the case parameter (being 50, 100 or 200 MW), is connected to the distribution network over a period of 10 years. This implies that in every year 1/10th of the total DG capacity to be connected over the whole period is connected to the distribution network (being 5, 10 or 20 MW). In other words, total DG capacity increases linearly over time. This *implementation trajectory* is displayed in Figure 3.4.

Allocation of investments, costs and benefits

Upfront investments may be required to allow for the gradual DG penetration in the network. Investments undertaken can result in operational and maintenance costs over time. Once DG is connected to the network costs (benefits) may be incurred (reaped) by the DSO.

The GSP model provides one fixed amount of required investment costs which, in a dynamic model such as the DSO model, need to be spread out over time aligned with the realisation of DG connections. This is shown in Figure 3.4. The additional assumption is that investments need to be undertaken one year ahead of DG connections. This explains the parallel lines in Figure 3.4. When 50% of total DG capacity is to be installed in Year 10, then 50% of total investments need to be undertaken in Year 9.

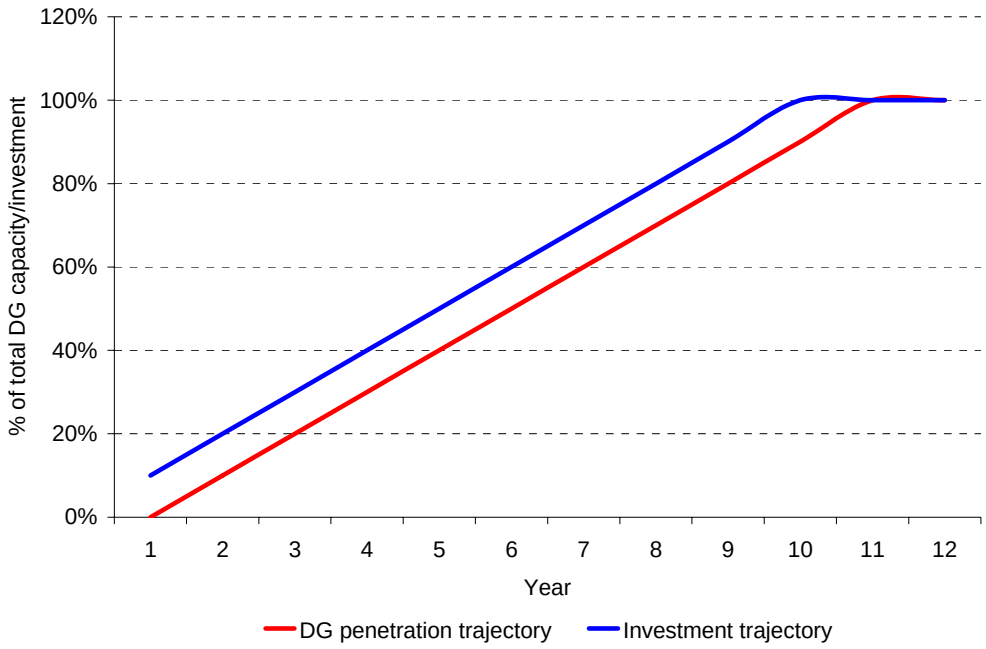


Figure 3.4 *DG penetration trajectory and investment trajectory*

As for the 'allocation' of investment costs over time, costs and benefits in operational aspects need to be dealt with as well. For example, a reduction in distribution losses in the distribution network brought about by an increasing penetration of an amount X of DG will not directly materialise if only 1/10th of amount X is installed. Given that total capacity in year 2 is only 1/10th of the total amount of capacity at the end of the 12-year period, the positive impact of DG on the level of distribution losses in the network will also have materialised for only 1/10th. In practice, distribution losses tend to increase quadratic. However, the linearity assumption is necessary since the data output provided by the GSP model is static: it does not produce a transition to a certain DG penetration level but instead produces the final outcome. We tested our model results on sensitivity to other assumed trajectories and find that the assumption does not change the results to the extent that it changes the overall conclusions in this report.

Summarising our main assumptions in reconciling GSP output with DSO input requirements:

1. The total amount of DG capacity is assumed to penetrate the distribution network in a *period of 10 years* in a *linearly* fashion.
2. Investments needed to facilitate DG penetration are assumed to precede DG connection *one year ahead*.
3. Operational costs and benefits of DG penetration for the DSO are assumed to be incurred/realized at same pace as DG capacity is connected.

In Appendix B.2 a sensitivity analysis is carried out, which shows the sensitivity of financial results for the different assumptions that have been made above.

3.5 Illustrative example

For illustrative purposes, we discuss one specific case. In this example, a DSO is confronted with an amount of 100 MW of non-intermittent DG capacity. Given total distribution network load of 1155 GWh per year this is equivalent to a penetration rate of about 45%. The penetration rate is measured in percentage of total load served by DG.[17] This DG capacity entering the distribution network is assumed to be relatively concentrated within this network. The distribution

[17] Non-intermittent DG is assumed to operate at a load factor of 60%.

network has the characteristics of a rural network. The DSO is assumed to operate under a passive network management philosophy. Table 3.4 summarises the assumed case variables and Figure 3.5 shows the costs of this level of DG penetration in three consecutive regulatory periods of four years each.

Table 3.4 *Case parameter values of example*

Case parameter	Values
DG penetration	[100 MW]
Concentration of DG	[High]
DG intermittency	[No]
Network type	[Rural]
Network management	[Passive]

Figure 3.5 displays the impact of a 45% DG penetration in the distribution network on the DSO when the distribution network has the characteristics presented in Table 3.4. We show the impact on (1) capital expenditures (charts with red bars), (2) operational expenditures (charts with blue bars), (3) tax expenditures (grey), and (4) the total incremental net profit that results when all separate items are added up (black) throughout the period of 12 consecutive years.

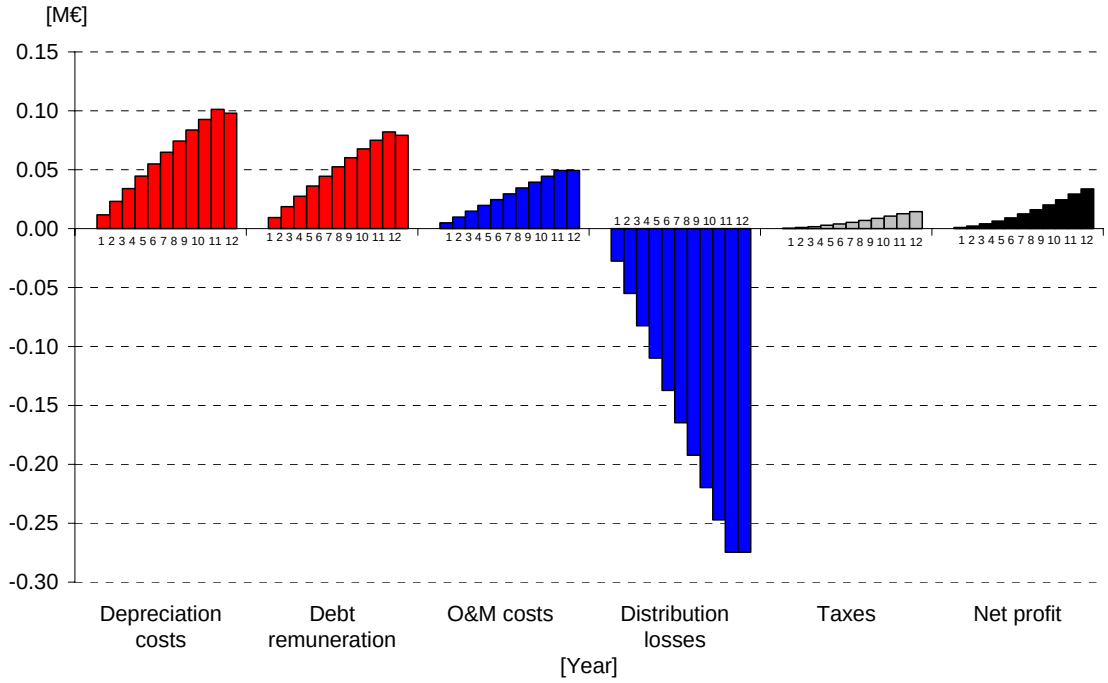


Figure 3.5 *The impact of DG penetration on capital expenditures, operational expenditures, taxes and total incremental net profit*

Figure 3.5 shows that capital expenditures increase when DG penetrates the network in this particular case. This is caused by required investments in capacity upgrades. These capacity investments cause an increase in yearly operational and maintenance costs (an operational expenditure). However, DG penetration enables the DSO to substantially reduce total energy losses in the network, which causes a negative incremental cost on distribution losses. This positive impact more than compensate the negative impact of DG on capital expenditures and operational and maintenance costs. This can be witnessed in the last figure about total incremental profit. As a result, the DSO has to pay more taxes and thus tax expenditures increase.

However, the relative impact of DG entering the distribution network on the position of a DSO cannot be fully understood from the figures presented above. In order to get insight into the

meaning of these figures for a DSOs real-life financial performance, total incremental profits for the DSO need to be related to the overall business of a DSO. In other words: how much does the DSO *relatively* gain when DG enters the network in specifically this example?

In order to answer this question we relate incremental profit to the 'general profit' that a DSO can earn under 'business as usual' operations. Since the DSO is a regulated entity, implies a regulated profit margin for every Euro invested in the distribution network. Therefore we introduce the term 'regulated profit', defined as:

$$\bar{\pi} = RAB \times WACC$$

where:

$\bar{\pi}$ = Regulated profit
RAB = Regulated Asset Base[18]
$WACC$ = Weighted average cost of capital

Relating incremental net profit to regulated profit

When total incremental net profit as displayed in Figure 3.5 is added over time, the total improvement in the financial DSO position is €160,000[19] over a period of 12 year. Over the same period, the 'normal' profit level of the DSO can be calculated from the DSO business model: this is the profit that the DSO would obtain under business as usual (i.e. no penetration of DG in the distribution network).[20] Note that the DSO assumed in the model is based on a GSP representing about 11 GWh per year of lead. Combination of both figures in this illustrative example gives the following result: DG penetration increases DSO net profit with of 0.13% (of 'regular' regulated profit).

[18] Note that this RAB excludes all investments due to DG penetration. These are included in the incremental analysis. This amount of RAB only consists of historical investments in network assets besides DG related asset investments. The value for total RAB for one GSP distribution network with total load of 1155 GWh per year has been estimated through econometric analysis of UK distribution network operators at about 75 m€.

[19] This can also be dubbed the mutation in equity of the DSO.

[20] This total profit totals € 51,300,000.

4. Problem analysis

4.1 Introduction

In this chapter a total of 16 different distribution networks is analysed using the DSO model, with input from the GSP model. All 16 distribution networks are analysed on their impact on the DSO under both passive and active network management; hence a total of 32 cases are analysed. Table 4.1 and 4.2 present the 32 cases. Note that the cases vary with the case parameters as presented in Table 3.2.

Table 4.1 *Description of cases 1 to 16*

	Case															
Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Level DG [MW]	100	100	100	100	50	50	50	50	200	200	200	200	100	100	100	100
2. Concentration DG	H	H	H	H	L	L	L	L	H	H	H	H	L	L	L	L
3. Share of intermittent generation [%]	100	100	0	0	100	100	0	0	100	100	0	0	100	100	0	0
4. Type network	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
5. Management type	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A

Note: Explanation to the values mentioned in this table: concentration of DG varies from high (H) to Low (L), the network typology is either rural (R) or urban (U), and network management philosophy is either passive (P) or active (A).

Table 4.2 *Description of cases 17 to 32*

	Case															
Parameter	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1. Level DG [MW]	100	100	100	100	50	50	50	50	200	200	200	200	100	100	100	100
2. Concentration DG	H	H	H	H	L	L	L	L	H	H	H	H	L	L	L	L
3. Share of intermittent generation [%]	100	100	0	0	100	100	0	0	100	100	0	0	100	100	0	0
4. Type network	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
5. Management type	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A

The analysis on the impact of DG penetration in the specific cases set out in above tables is undertaken in four steps, which are presented in Table 4.3. Reasons for this approach are twofold. First, we like to explicitly analyse the differences in impact under a passive and an active network management approach. Second, the potential value of deferred investment caused by an increase of DG penetration is treated separately since it is only realised in the long-term and is very dependent on factors such as age of existing network assets and the rate of growth of electricity demand.

The four analyses are followed by some concluding remarks.

Table 4.3 *Overview of analyses in Chapter 4*

Analysis	Network management philosophy	Potential value deferred investment of DG	Section
1	Passive	Excluded	4.2
2	Passive	Included	4.3
3	Active	Excluded	4.4
4	Active	Included	4.5

4.2 Analysis 1: DG impact under passive network management

Currently, new DG connections in the distribution network are facilitated through a passive network management philosophy from the DSO. This traditional 'fit and forget' approach involves 'simple' capacity upgrading to meet peak capacity requirements of distributed electricity generation.

Figure 4.1 shows the impact of various levels of DG penetration on the financial performance of the DSO. The impact is measured by relating total incremental net profit due to DG penetration to 'regular' regulated profit (DSO profits under 'business as usual') and expressed in a percentage change of the latter.

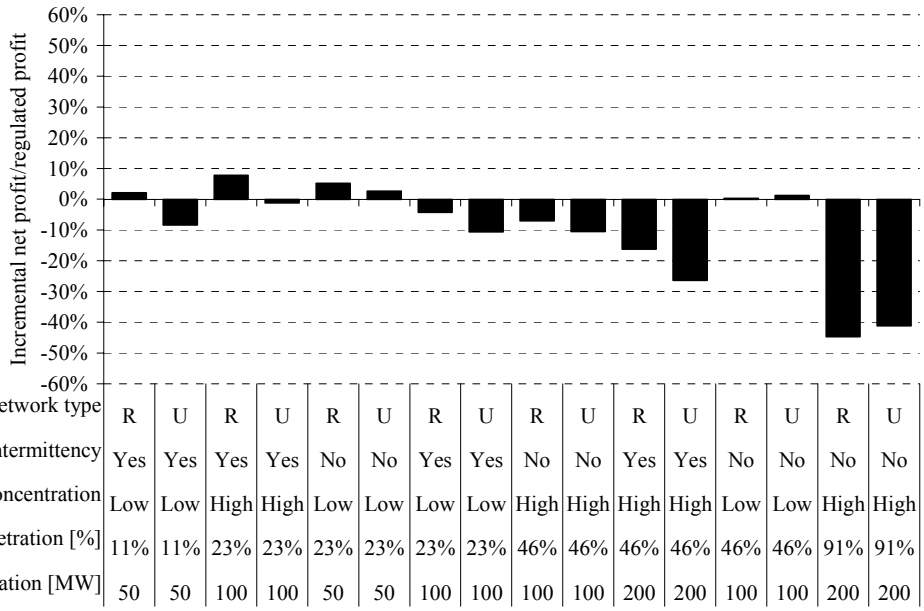


Figure 4.1 *The impact of DG under passive network management*

As Figure 4.1 shows, the impact of DG penetration on the DSO is ambiguous. Whereas DSOs profit from DG penetration at some of the lower penetration levels (11 and 23% DG penetration as measured against total distribution network load), higher penetration levels generally 'hurt' the DSO. In addition, the concentration of DG within the distribution network seems to matter to a large extent. When DG is relatively spread out over the distribution network, DSOs have a higher chance of benefiting from DG penetration. The overall level of the DG impact on the incremental profits of the DSO is somewhere between +8% and -44%.

Figure 4.2 splits up the net result shown in Figure 4.1 into the separate expenditures. Capital expenditures such as depreciation costs and remuneration of debt are shown in red, whereas the operational expenditures such as distribution losses and operational and maintenance costs are shown in blue. Here we see which expenditure items 'drive' the net result.

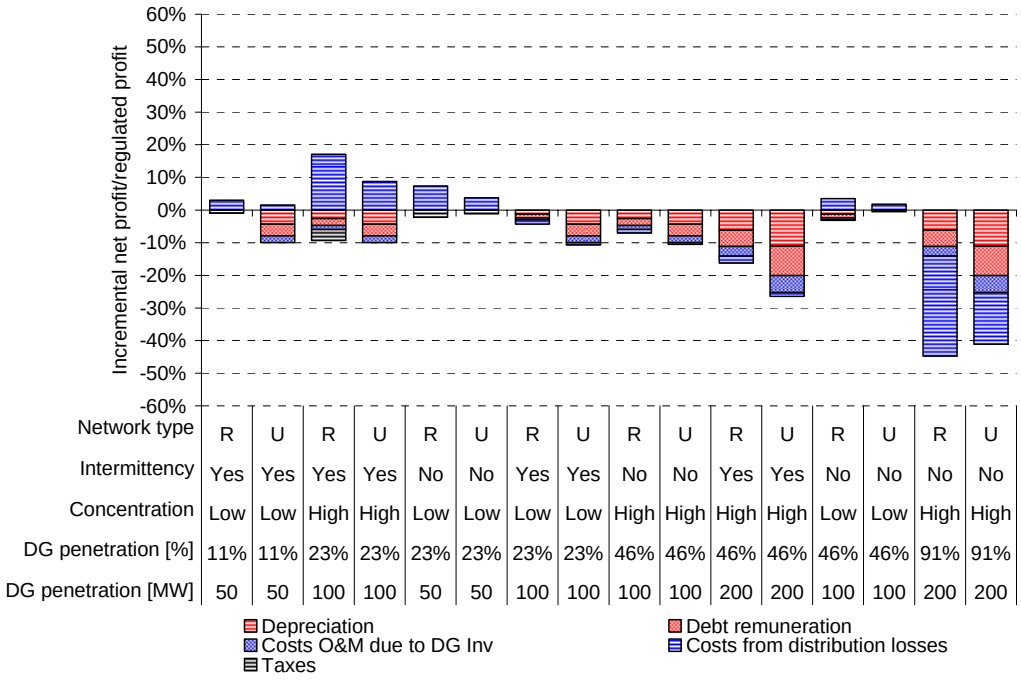


Figure 4.2 *The impact of DG under passive network management, split up into capital and operational expenditures*

In general we observe a large influence of the change in distribution losses due to DG penetration on the net result. At low penetration levels, DG penetration leads to a decrease in the overall network loss. At higher DG penetration levels however, distribution losses may increase due to higher usage of existing distribution network capacity.

We summarise the main observations regarding the analysis on the DG impact on DSOs operating under a passive network management:

1. Network reinforcement costs increase with DG penetration.
2. The increase in reinforcements costs is larger for in urban than in rural networks.
3. The increase in reinforcements costs is larger when DG is more concentrated in the distribution network.
4. Distribution losses first decrease with the DG penetration level until minimum is reached, and then increase with the DG penetration level.

As indicated in the presentation of the methodology in chapter 3, the applied models do not include the impact of DG penetration on the need for reinforcement of the connection between the distribution network owned and operated by the DSO on the one hand, and the transmission network owned and operated by the TSO on the other. Hereafter we explore how results would change when this impact is also considered.

4.3 Analysis 2: DG impact under passive network management including the potential value of deferred investment

Because DG is located near to consumers, the net demand to be supplied from transmission and distribution networks can decrease, postponing the need to reinforce the system in case of load growth or to reduce the investment required in case of equipment replacement (Cao et al. 2006) This is what we refer to as being the 'deferred investment value' of DG penetration.

As explained in the elaboration of the methodology on p. 18/19, the value of deferred investment can not be implicitly integrated in the model analysis. The reasons are threefold.

Firstly, the GSP-model used in our analysis and described in Cao et al. (2006) does not incorporate the value of deferred investment due to DG penetration in the distribution network. Instead, the report separately discusses the potential value of investment deferral by using figures from Mendez et al. (2006).[21] Secondly, a crucial parameter in the estimation of the value of deferred investment in the distribution-transmission connection is *load growth*. Since both the GSP and DSO business model do not deal with demand dynamics (assumption of static demand), it is not possible to integrate the analysis on deferred investment value into the analysis presented in the previous paragraph. Thirdly, the values of deferred investment reported in Mendez et al. (2006) do not deal with certain parameters in our analysis: rural vs. urban networks, passive vs. active network management, or the share of intermittent generation of total DG capacity. It is therefore difficult to fully reconcile results.

Table 4.4 shows the main figures of the value of deferred investment for one GSP distribution network in a very limited number of cases: only the amount of DG capacity and degree of DG concentration are differentiated.

Table 4.4 *Value of deferred investment*

DG penetration level	Concentration of DG	Value of deferred investment	'Required' load growth needed for full realisation of benefit	Value of deferred investment per year (within the 12 year time period)
[MW]	[Low, High]	[m€]	[%]	[m€]
50	Low	5.51	0.9	0.46
100	Low	11.25	1.9	0.94
100	High	11.19	3.8	0.93
200	High	8.83	7.6	0.74

Source: Imperial College London, ECN calculations.

The difficulty in reconciling these figures with the figures presented in the previous paragraph is the time period in which the benefits are realised. Generally, the reported figures in Table 4.4 are based on the network reinforcements needed based on the maximum gap between distribution network load and decentralised electricity generation throughout a day (peak vs. off-peak demand). The full value of deferred investment due to DG penetration can only be added to the presented results in Figure 4.1 when either (i) the assets and equipment needed for the connection with the transmission network need to be replaced, or (ii) sufficiently high growth rates in total load are realised, *within the 12 years time span of the DSO business model*. To give an illustration, in order to fully realise the benefit of deferred investment of a penetration of 50 MW of DG capacity in a distribution network with a load of 1155 GWh per year where concentration of DG is low, the yearly rate of growth in load would have to exceed 0.9%. The respective required rate of growth for a 200 MW penetration is 7.6%. The required growth rates for these and remaining cases is shown in Table 4.4. According to the World Energy Outlook (IEA 2006), growth in final electricity consumption in OECD Europe is expected to be about 1.7% in the period 2004-2015. This implies that the assumption of the full value of deferred investment being realised within 12 years is very strong for the high penetration/high concentration cases. Full realisation of the benefits of deferred investment in the case of low DG penetration can reasonably expected.

This being said on the figures on the value of deferred investment, Figure 4.3 shows the results when these figures are combined with the figures in the previous chapter (see Figure 4.1).

[21] Cao et al. (2006) refer to value of deferred investment as 'the replacement value of DG'.

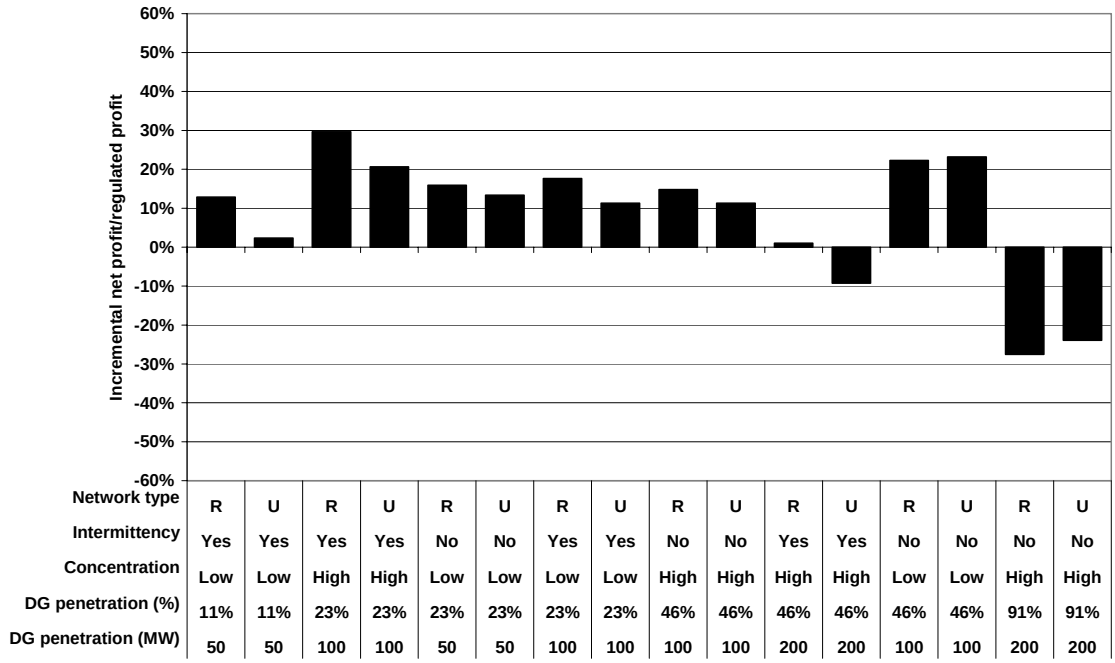


Figure 4.3 *DG impact under passive network management including the potential value of deferred investment*

Figure 4.3 shows the results for the analysis where the potential value of DG in deferring investments is included. Now, DG penetration in the distribution network only seems to have adverse impacts when very high penetration levels are reached and where DG is highly concentrated within the network. Note that intermittency of DG units was not sufficiently dealt with in the analysis on the value of deferred investment, and hence, is not properly reflected in the above figure. Intermittency unmistakably is an important feature when evaluating the exact value of deferred investment due to DG penetration since reinforcement investments can only be deferred if decentralised electricity generation takes place during hours of peak-demand. This remains a point for future research that is outside the scope of this report.

4.4 Analysis 3: DG impact under active network management

When DSOs adopt a more active approach towards network management and DG penetration, the net impact of an increasing DG penetration on the performance of a DSO might be different than under a passive network management. In chapter 2 it was described why and how the impact can be different.

Figure 4.4 shows the impact of DG within various distribution networks on the DSO performance. Reported figures are the net incremental profit due to DG penetration as percentage from total regular profit, over a period of 12 years.

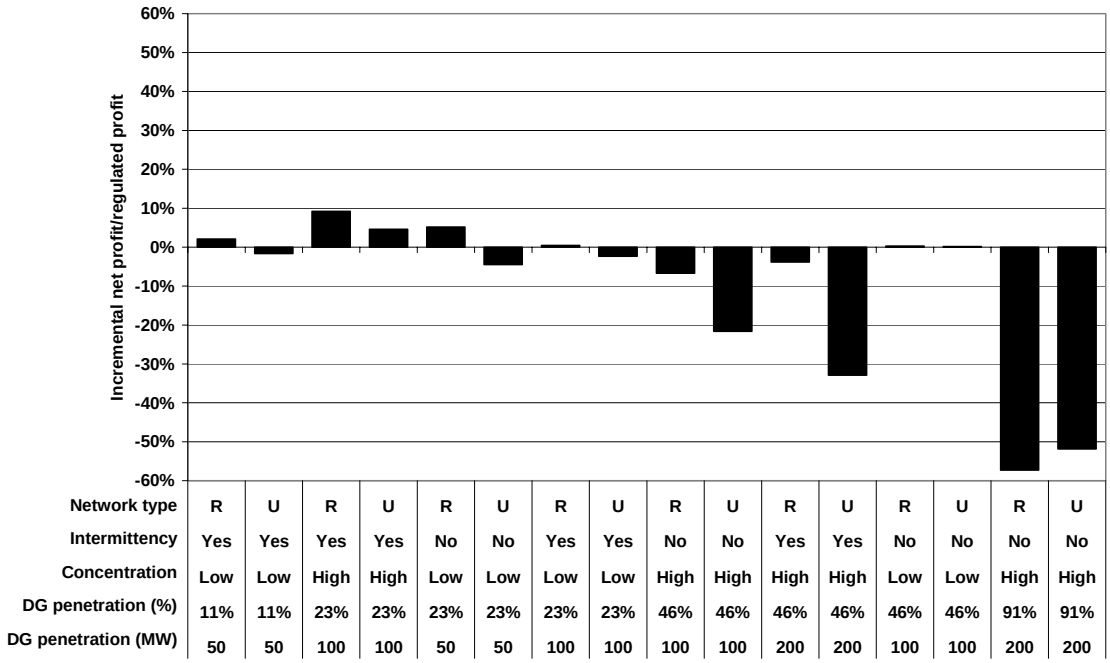


Figure 4.4 *The impact of DG under active network management*[22]

We observe that DSOs tend to benefit from the presence of DG in their distribution network at penetration levels at and lower than 23% of total load. When DG penetration levels exceed 40%, the DSOs tend to suffer from the presence of DG. Again, the spatial distribution of DG over the distribution network matters for the analysed net impact. The net impact varies from +9% to -57%. Figure 4.5 shows the driving forces behind these net results in more detail by separately showing all cost items.

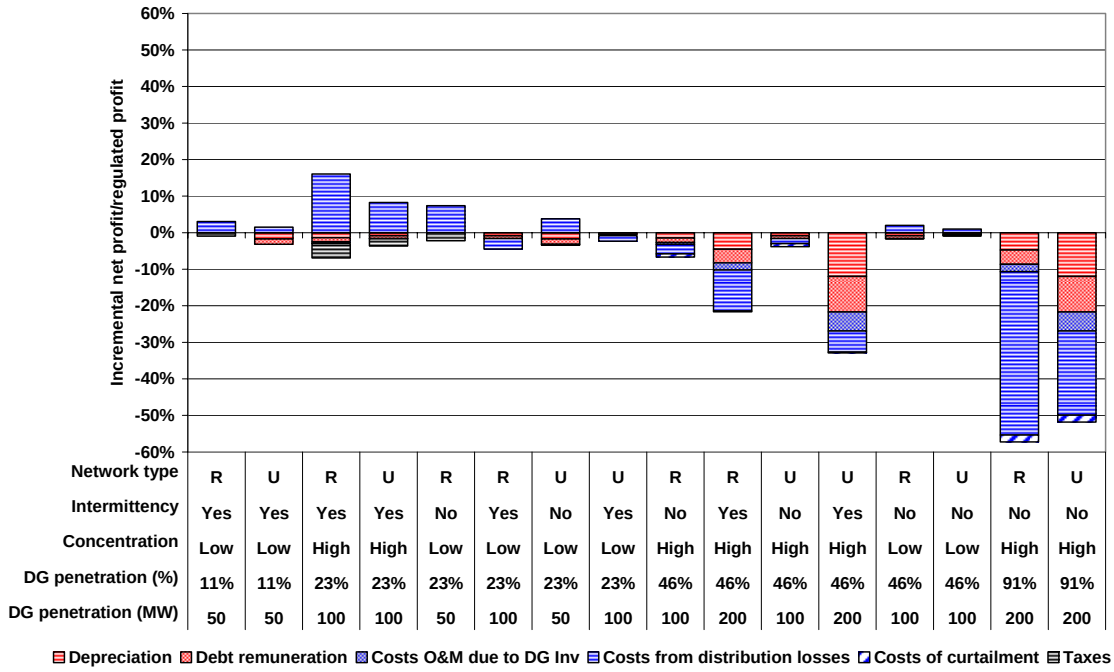


Figure 4.5 *The impact of DG under active network management, split up into capital and operational expenditures*

[22] Note that for two out of the 16 cases, the net impact is coincidentally zero.

From Figure 4.5 we infer that again distribution losses are a large explanatory factor behind main results. In other words, the net change in distribution losses due to DG penetration is a good predictor for the overall impact of DG presence in the distribution network on the financial position of the DSO. Another important observation is the large amount of capital expenditures at higher DG penetration levels in distribution networks where DG concentration is high.

The main observations on the impact of DG when a DSO adopts an active network management approach are the following:

1. Overall, the presence of DG in the network has a neutral or negative impact on the financial position of the DSO.
2. Only when DG presence enables a considerable reduction in distribution loss, which is the case for low DG penetration rates in distribution networks where DG is spread out over the network, does the DSO benefit from DG.

4.5 Analysis 4: DG impact under active network management including the potential value of deferred investment

As was discussed in Paragraph 4.3, DG penetration can beneficially impact the DSO through the deferral of investment in assets and equipment enabling the electricity flow from the transmission network to the distribution network. The discussion in Paragraph 4.3 also holds for the analysis in this paragraph. The values for deferred investment derived by Cao et al. (2006) do not distinguish between passive and active network management. Hence, the figures from Table 4.4 are again used to compute the overall impact of DG penetration on the DSO business under active network management. The results are shown in Figure 4.6.

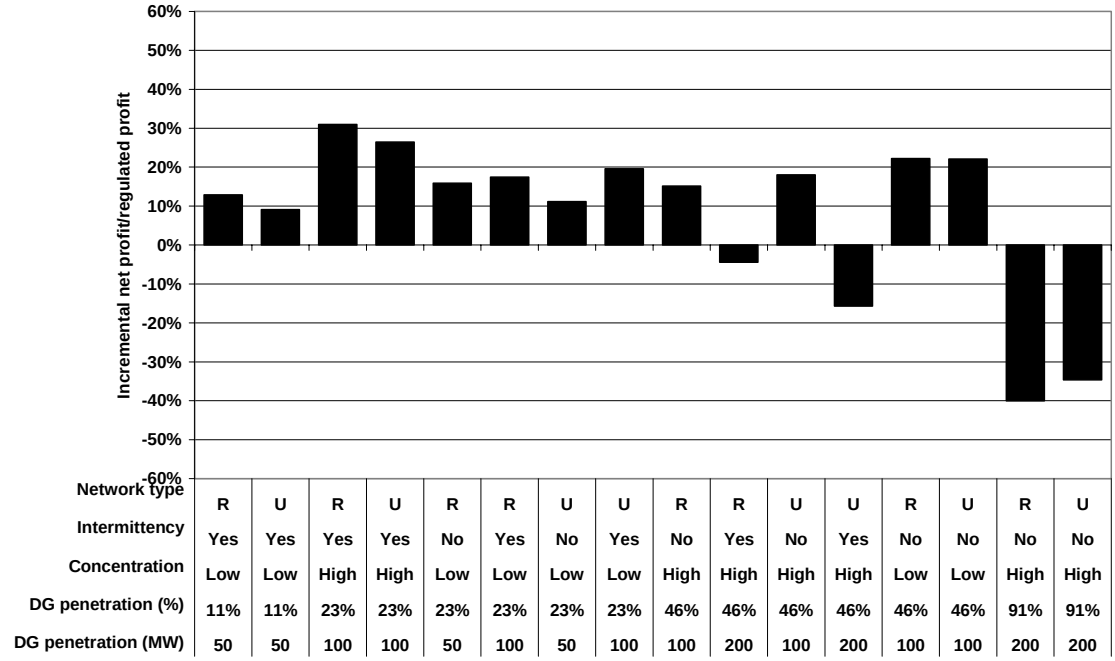


Figure 4.6 *DG impact under active network management including the potential value of deferred investment*

As was the conclusion under Analysis 2, including the impact of DG on possible deferred investments, the overall impact of DG on DSOs is positive except for four cases. These are the cases where DG penetration is high and very concentrated within the distribution network.

4.6 Analysis 5: Comparing the impact of passive and active network management

Having analysed the impact of increasing DG penetration in distribution networks on the DSO when assuming a passive network management approach and an active network management approach respectively, allows us to compare the outcomes under both approaches and derive a possible implicit incentive for the DSO to switch from a passive to an active network management approach.

For a comparison of DG impact under active and passive network management, the results of Figure 4.1 and Figure 4.4 are combined and presented in Figure 4.7 below. In this figure, the results for passive and active network management for a given distribution network are shown consecutively (i.e. 'pair wise').

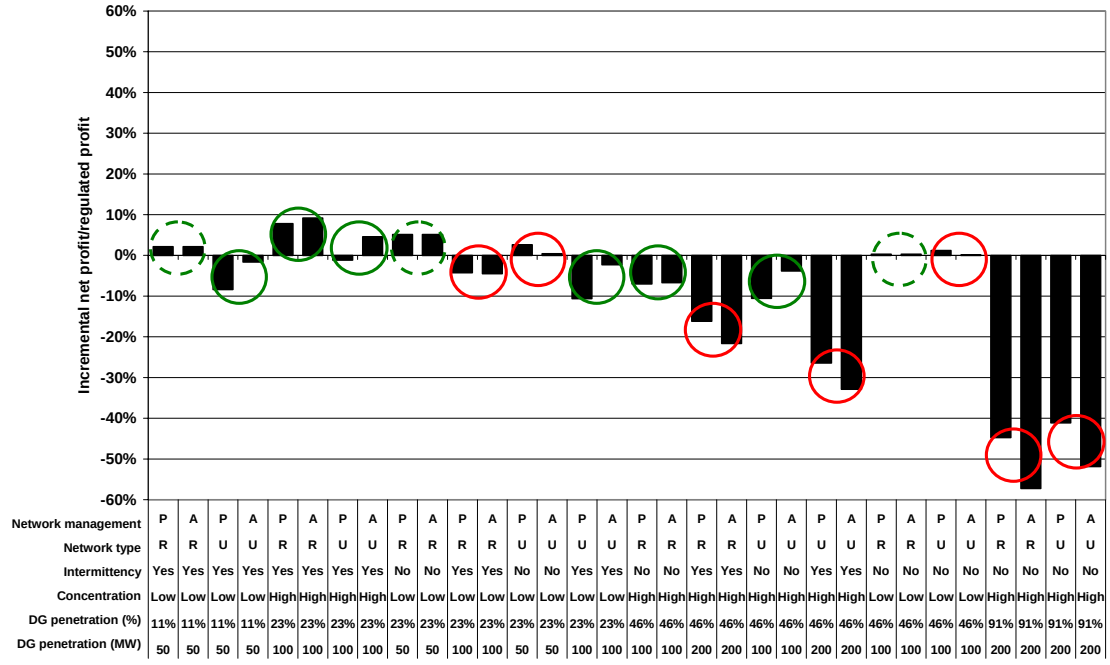


Figure 4.7 *The difference in DG impact under passive and active network management*

In Figure 4.7 we observe that the impact of implementing an active network management approach in the face of increasing DG penetration is ambiguous. For six out of sixteen cases (e.g. distribution networks), active network management either reduces the cost or increases the benefits of DG penetration for the DSO (green circles in Figure 4.7). In another seven cases, active network management either increases costs or reduces benefits (red circles in Figure 4.7). In the remaining three cases, the impact of increasing DG penetration is equal under either a passive or active network management approach (dashed green circles in Figure 4.7).

From the above observations we might conclude that there is an incentive for DSOs to adopt an active network management philosophy in cases where DG penetration is low. Stated differently, network reinforcements triggered by low levels of DG penetration can be partly reduced if an active network management approach is adopted. The same can not be said for the cases with high DG penetration. This results to some extent from the limitations of the GSP model since it does not account for the possibility of combining both network approaches. This means that with new DG units entering the distribution network (high DG penetration), only *active* network management is applied whereas the network is not expanded according to *passive* network management principles. Consequently, we cannot draw firm conclusions with regard to

the implicit incentive for DSOs to adopt an active instead of a passive management approach in cases of high DG penetration.

In Figure 4.8 the net incremental result is split into the separate expenditure items.

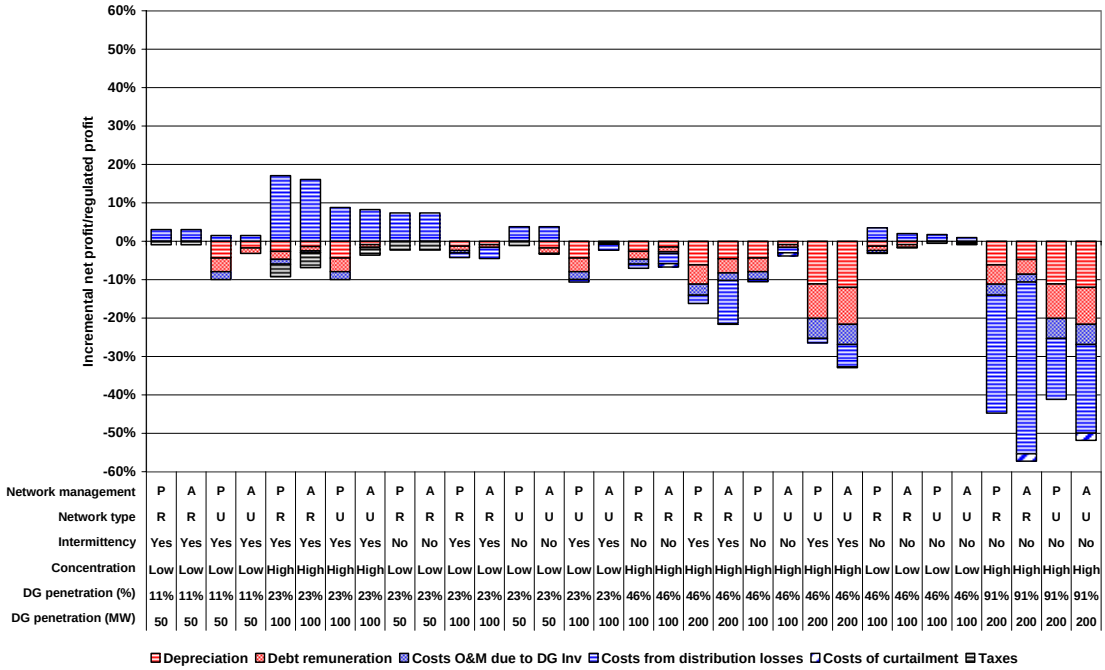


Figure 4.8 *The difference in DG impact under passive and active network management, split up into capital and operational expenditures*

From Figure 4.8 we get insight into the cost items that drive results. When DSOs are confronted with low DG penetration levels (about 23% and lower), adopting an active network management approach can lower total capital expenditures (and the related operational and maintenance costs). At higher penetration levels however, the differing net impact under passive and active network management is dominated by the difference in distribution losses. Since active network management enables higher usage of capacity, distribution losses tend to be higher under active network management.

4.7 Putting results in perspective

The previous paragraphs showed the impact of an increase in DG penetration. The results were expressed in the incremental net impact on DSO profits relative to the profit obtained by the DSO under business as usual (i.e. no increase in DG penetration). The results for both passive and active network management approaches showed quite a large variance: varying from -44 to +8% for cases where passive network management applied, and from -57 to +9% for cases where active network management applied.

We can put the results in perspective by either taking the viewpoint of the DG operator connected to the distribution network or the consumer that receives electricity from the same distribution network. In Table 4.5 present the range of figures of the following indicators, representing both viewpoints:

1. the incremental net impact of DG penetration (in m€) related to the amount of DG capacity (in kW) connected to the network;
2. the incremental net impact of DG penetration (in m€) related to the amount of electricity produced by DG units (in MWh);

3. the incremental net impact of DG penetration (in m€) related to the amount of electricity distributed to end-consumers (e.g., electricity consumption) within the distribution network (in MWh).

Table 4.5 *Indicators relating incremental net impact of DG penetration with DG characteristics and electricity consumption*

Indicator	Unit	Range
Incremental net impact/DG capacity	[€/kW]	- 147 to + 53
Incremental net impact/DG production	[€/MWh]	- 5.04 to + 2.74
Incremental net impact/electricity consumption	[€/MWh]	- 2.26 to +0.36

The range of -147 to +53 € per kW of installed and connected DG capacity can be put in perspective by pointing to the costs of investing in DG capacity, for example in small-scale CHP units. The investment costs for a CHP unit consisting of a 25 MW gas turbine are estimated at € 979 per kW (Harmsen 2005), while the investment costs of a single on-shore wind turbine of 2MW are estimated at €1050 per kW (Tilburg et al. 2006). These investment cost estimations are for the case of the Netherlands should not be taken as an indication: real investment costs for DG units might vary largely across EU countries. Given these rough indications we find that the incremental net impact of DG penetration in the network can reach up to around 14% of the initial DG investment costs.

The other two indicators can be compared to the average electricity wholesale prices across EU spot markets. DG Energy and Transport (2006) shows electricity wholesale prices for different EU spot markets to vary in a range of about 40 to 50 € per MWh. Using this rough indication we find that the incremental net impact of DG penetration when related to total electricity produced by DG units is in the range of -13 to +5% of electricity wholesale prices. When the incremental net impact is related to overall electricity consumption within the distribution network we find the impact to be in the range of -6 to +1% of electricity wholesale prices.

4.8 Conclusions

Based on the analysis in this chapter we can draw conclusions on:
1. The impact of DG on DSOs operating under a passive network management philosophy.
2. The impact of DG on DSOs operating under an active network management philosophy.
3. The impact of the potential value of deferred investments of DSOs due to DG on the outcomes under (1) and (2).
4. The incentive for the DSO to adopt an active network management approach instead of a passive network management approach.

We find that DSOs operating under a passive network management regime generally do not profit from the presence of DG in their distribution network, except for some low penetration level cases where concentration of DG units in the network is high. Higher penetration levels result in a negative overall impact. The concentration of DG within the network is a particular influential factor: the more concentrated the presence of DG in the distribution network, the more negative the impact. The driver for the generally positive results for low penetration levels and the generally negative results for high penetration levels are distribution losses.

DSOs operating under an active network management philosophy are generally confronted with comparable results as the passive network management case. Penetration of DG in the network is favourable for the DSO for low penetration levels, but seems to become less favourable the higher the penetration rate and the more concentrated the DG in the network. However, it should be noted that the negative results are relatively small for the majority of the cases ana-

lysed: the net impact of DG penetration is within the range of 8% of the 'business as usual' profit DSOs make.

The added value of DG with respect to the putting of or deferral of investments 'above the distribution network' (the connection with the higher voltage level network) can be substantial. However, the realization of this positive value for the DSOs is dependent on a larger number of factors beyond the scope of this investigation. These relate to the load growth dynamics and the status of interconnection equipment (economic lifetime and depreciation so far). However, considering the maximum replacement values of DG, it can be expected that the overall impact of DG penetration on the DSO business can be neutral or positive in the majority of cases.

Observing the differential impact on the DSO under passive and active network management we conclude that there is an implicit incentive for the DSO to adopt an active network management approach in a number of cases, in particular the case where DG penetration is low or mediocre. For high DG penetration levels no firm conclusions can be drawn. In general, active network management increases the options for DSOs to deal with network constraints. Therefore, DSOs should be able to obtain more efficient operational and investment outcomes. However, the expected obtained benefits should exceed the costs of 'making the network active' before implementation takes place.

Regarding the implications of the analysis for the next chapter on alternative regulatory arrangements we note that there are several cases where the DSO is negatively impacted by DG penetration, regardless of the network management philosophy. This implies that an alternative regulatory arrangement compensating the DSO for the negative impact might be warranted.

In addition, improved regulatory arrangements can contain additional incentives for DSOs to facilitate DG penetration. It can, for example, increase the potential for DSOs to benefit from entering the market for ancillary services in the near future. This is more extensively discussed in Jansen et al. (2007). Hence, the regulatory measures presented and analysed in the next chapter can serve two purposes that need to be distinguished: (1) neutralizing the impact of DG for the DSO, and (2) giving incentives to adopt an active network management philosophy.

5. Analysis of regulatory measures

In this chapter we present a number of measures that can compensate the possible negative impact of DG on DSOs, and analyse their feasibility and effectiveness. In the latter analysis, we again use the DSO model.

First we present the possible regulatory measures (5.1). In addition, we analyse these measures with the DSO model (5.2).

5.1 Potential regulatory measures

Both Bauknecht et al. (2007) and Jansen et al. (2007) propose some different alternative regulatory measures. These generally involve adaptations to the regulatory regimes currently implemented within the EU. For a description of current regulatory regimes we refer to Jansen et al.(2007). Four alternative regulatory measures proposed by the latter are:

1. *Special allowance in the regulated asset base* (RAB) for the DSO for DG related investments.[23]
2. Including an *additional quality indicator* through which DSOs are compensated for higher DG presence in their distribution network.
3. Including a *DG factor in the productivity benchmark analysis*.
4. Allowing a *DG based direct revenue driver* in the revenue cap formula.

Below we briefly present these alternative regulatory measures.

5.1.1 Special allowance in RAB

In presenting this measure to compensate DSOs for any negative DG impacts on the distribution network it is important to make a distinction between the so-called 'building blocks' and 'totex' approach (Jansen et al. 2007). In the totex approach, both operational and capital expenditures of DSOs are benchmarked and used in determining the X factor. In the building blocks approach only the operational expenditures are benchmarked while capital expenditures, e.g. network investments, need approval from the regulatory authority before they can be included in the RAB. The measure proposed only has added value in regulatory systems where a totex approach is adopted. After all, in a building blocks regime, the regulator already has the option to allow for specific DG related network investments to be included in the RAB.

The degree to which these investments are included in the RAB (e.g. the pass-through rate) can be 100% or less. There are some reasons for setting the pass-through at a percentage lower than 100%, which will be discussed in 5.2.1.

5.1.2 Additional quality indicator

This approach in fact introduces a third factor (besides the X and Q) on the performance of DSOs regarding the facilitation of DG penetration in the DSO network. The nature of the performance indicator is substantially different from the Q factor elements (minutes of disruption, number of disruptions etc) to warrant inclusion of DG performance in this factor.

The K factor could include indicators on the delivery of benefits from DSO's to DG operators as the use and distribution of system information, the storage of electricity and the provision of lo-

[23] Note that this is partly the case in the UK regulatory regime.

cal balancing services thereby rewarding (penalizing) DSOs that are performing well (bad) on these indicators.

5.1.3 Productivity benchmark factor

DG penetration can be considered as one of the inputs to the productivity benchmark analysis, which determines more or less the efficiency discount (X-factor)[24] and via the allowed expenditures (capital and operational costs) ultimately the allowed revenues (via use-of-system and connection charges) of the DSOs.

In the case a benchmark approach is followed by the national regulator, firms are compared to each other on their costs and with that on their productivity. The cost reduction that a firm should be able to achieve is based on an efficiency discount (X-factor), which is determined by the productivity change during that period[25]. So the productivity change is the variable that is compared between firms. The productivity change is usually defined as the mutation in the standardized economic costs divided by a standardized and composite output variable.

The composite output variable contains cost drivers like number of customers, units of electricity distributed, and network length.[26] The parts of the output variable differ somewhat between countries. Probably, it is possible to add the capacity of DG on the network or the units of DG electricity distributed explicit into the composite output variable.

5.1.4 Direct revenue driver

In this approach, the regulatory formula is extended with an additional component. Per connected kW of DG capacity and/or kWh of DG electricity fed into the grid the DSO is allowed to increase its revenue cap with a fixed amount. It depends on the relation between the costs of DG and the allowed costs by the regulator, whether or not this fixed amount gives an additional reward to the DSO for connecting DG units and transporting their energy. The tighter the regulatory regime, the lower the chance those DSOs are given an additional revenue driver.

5.2 Model analysis of regulatory measures

In this paragraph, we model and analyse the measures presented previously, except for the compensation through DG inclusion into the productivity benchmark. The reason for this is the limited level of detail of the DSO model on the one hand, and the difficulty of modelling productivity benchmarking on the other.

In this analysis we have added a fifth possible regulatory arrangement that combines two already identified alternative arrangements; a special RAB allowance and a direct revenue driver.[27]

In this approach, part of the additional investment costs is recovered through direct pass-through, while a direct revenue driver can cover another part. This means that the investment

[24] Dependent of the chosen regulatory method the connection between productivity and X-factor is direct or more indirectly as the regulator takes the company specific situation into account.

[25] In practice mostly partly the productivity change of the former regulatory period or some expected productivity change measure is used.

[26] For UK, see Pollitt (2005) for some other countries Jamasb and Pollitt (2001).

[27] A cost-based compensation mechanism (RAB allowance) and an incentive based mechanism (revenue driver) are combined here (Bauknecht et al. 2006). The rationale for this 'hybrid' approach is the fact that a full incentive based approach is difficult to implement (e.g. in benchmarking procedures) due to the large number of factors that influence DSO performance in this respect. Apart from non-DG related factors such as network characteristics (rural vs. urban) and type of soil and number of waterway crossings for example, the previous chapter also identified important DG related factors such as DG penetration level, and DG concentration.

risk is shared between end-consumer and DSO. End-consumers bear the risk of the investment costs that are directly passed-through, while the DSO bears the (upward and downward) investment risk on the remaining part. Given the fixed revenue driver (in €/kW/year), a DSO could under- or over perform expectations on which this figure is based. In other words: they are incentivised to take the most efficient and effective investment decisions. In the UK this combination has put into effect since 2005. There is a sort of open-end risk for consumers in the scheme laid out above if investment costs can move unlimited upwards because of the absence of restrictions to the number and size of investment projects. In order to limit the risk for consumers Ofgem has capped the investment costs that can be passed through at 0.5% of price control turnover in each year (Ofgem 2004).

5.2.1 Special allowance in RAB

As described and explained in Paragraph 3.3, the DSO model allows for a revenue cap for the DSO. Introducing a special allowance for any investments in DG to be included in the RAB is recognition of the fact DG increases capital expenditures of the DSO. This type of compensation measure can be described as follows:

$$TAR_t = TAR_{t-1}(1 - X) + y\%\ I_t^{DG}$$

where:

TAR_t = Total allowed revenue in year *t*

X = Required yearly improvement in efficiency performance

y = Share of eligible DG related investments in distribution network assets

I_t^{DG} = Total eligible DG related investments in distribution network assets in year *t*

The share of eligible DG related investments that may be directly remunerated may vary. A 100% pass-through fully compensates the negative impact of DG penetration on *capital expenditures*. However, as we have seen in previous analysis on the impact of DG penetration on the financial performance of DSOs, an important driver for overall net impact is the operational expenditure on distribution losses. We saw that operational expenditures were an increasingly important share of total net impact when DG penetration and concentration of DG within the network is high to very high.

Figure 5.1 shows the impact of DG penetration upon DSO performance when a special allowance of *70% of total DG related investment is* included (e.g. parameter y is set at 70). The figure presents both the figures on the impact with this compensatory rule (black bars) and without compensatory rule (red lines, which are based on Figure 4.7).

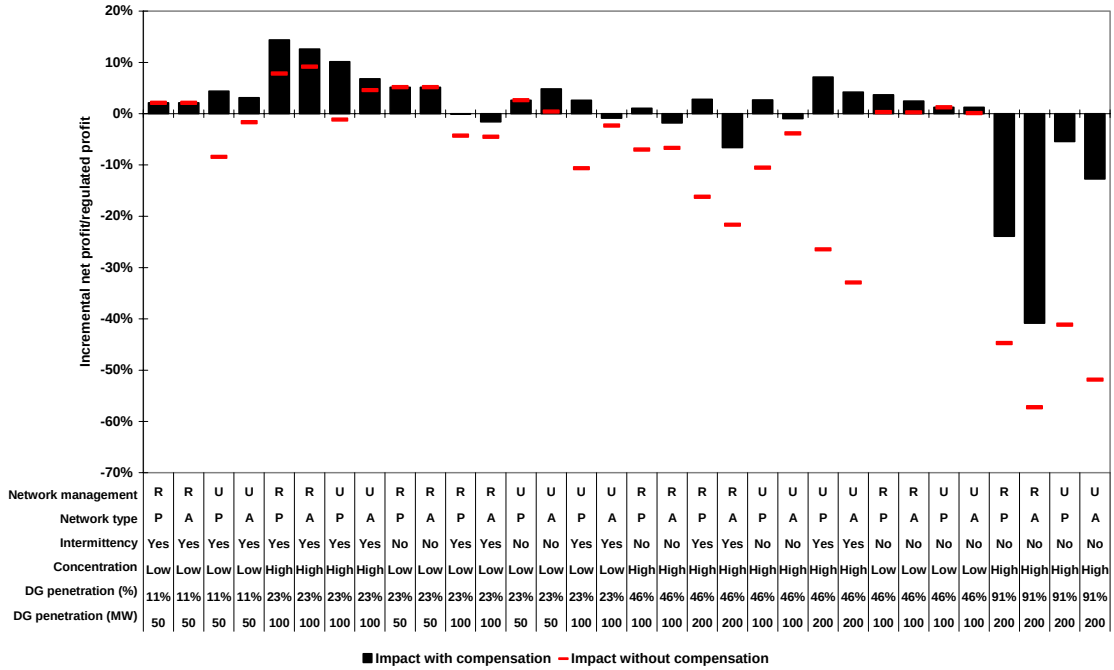


Figure 5.1 *Impact of DG with compensation measure on special RAB allowance*

In Figure 5.1 we observe that the special allowance succeeds in mitigating the negative impact of DG on DSO business in the majority of cases, for both passive and active network management. Only cases where DG penetration is very high show an overall negative impact on DSO performance. However, the compensation mechanism also implies an additional 'benefit' for cases where the impact of DG was already positive. This is especially the case for low penetration rates. In order to avoid such unnecessary allowances from occurring, a gradual compensation rule on special RAB allowances could be implemented. A distinction could be made with regard to the *level of DG penetration*. Therefore, we test the following compensation measure:

$$TAR_t = TAR_{t-1}(1 - X) + y\%\ I_t^{DG}$$

where:

$y = y^L$ for low penetration rates (≤23%)

$y = y^M$ for medium penetration rates (23%< and ≤46%)

$y = y^H$ for high penetration rates (>46%)

Figure 5.2 shows the results for an analysis where the assumed values for y^L, y^M, y^H are respectively 30, 70, and 90%.

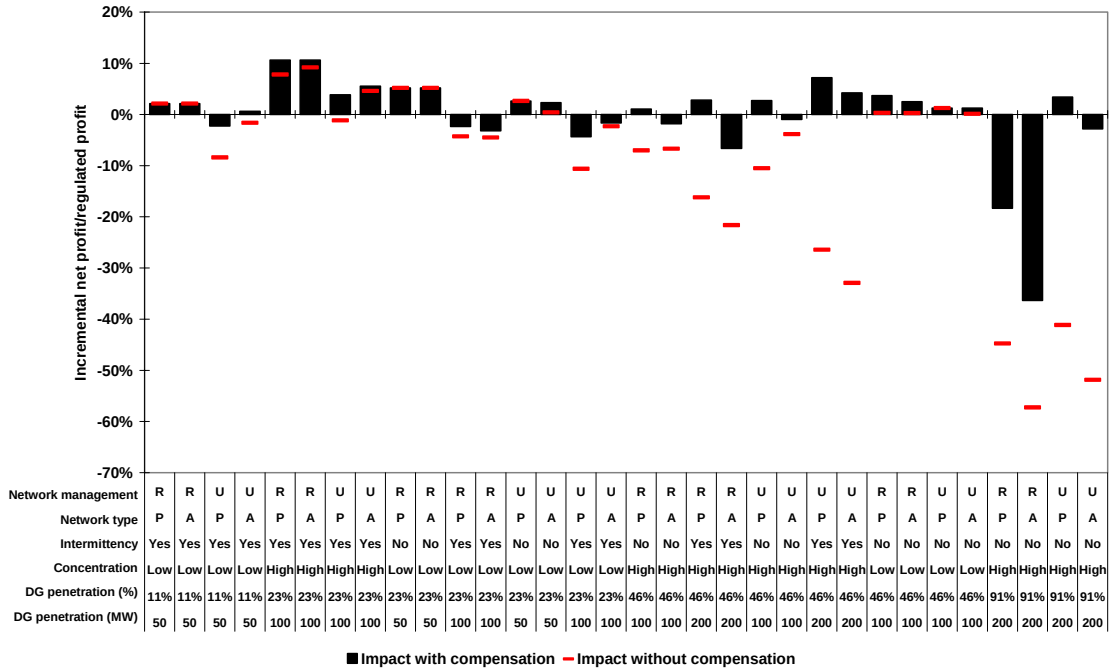


Figure 5.2 *The impact of DG with compensation measure on special RAB allowance (penetration rate dependent)*

We now witness that a more 'tailor-made' approach is more successful in both compensating DSOs for the costs related to DG, and in reducing 'wasteful' compensation to DSOs that do not need to compensate any negative DG impact. However, full compensation for DSOs that are confronted with very high DG penetrations is not possible within this compensation mechanism. The reason for this is the following. The negative impact of DG penetration in the cases with very high penetration rates is primarily caused by increasing distribution losses (e.g. operational expenditures), whereas compensation through a special RAB allowance is based on capital expenditures only.

5.2.2 Quality indicator

By adding a quality factor to the regulatory revenue cap formula, individual DSOs can be 'rewarded' with higher total allowed revenue when DG penetration in their network is high whereas DSOs with low DG penetration receive relatively lower 'rewards'. However, as a general condition, the performance of DSOs should be assessed on quality indicators that can be influenced by the DSO. Obviously the DSO does not have a direct influence on the number and size of DG units. DSOs are required to connect all consumers and producers to the distribution network. A DG related quality indicator that fulfils this condition is the level of distribution network losses *given* certain DG penetration levels, or the overall system efficiency of the DSO.

This idea is captured in the following formula:

$$TAR_t = TAR_{t-1}\left(1 - X + K_{Ind}\right)$$

where:

TAR_t = Total allowed revenue in year t

X = Required yearly improvement in efficiency performance

K_{Ind} = Quality indicator for individual DSOs, dependant on DG penetration levels

As an illustration we set up the following scheme. We identify separate values for quality indicator *K* according to Table 5.1.

Table 5.1 *Overview of penetration rates and accompanying values for the quality indicator*

DG penetration level [%]	Value for K_{Ind} [%]
11	0.75
23	1.50
46	5.00
91	10.00

The results of the model running with this specific formula are presented in Figure 5.3.

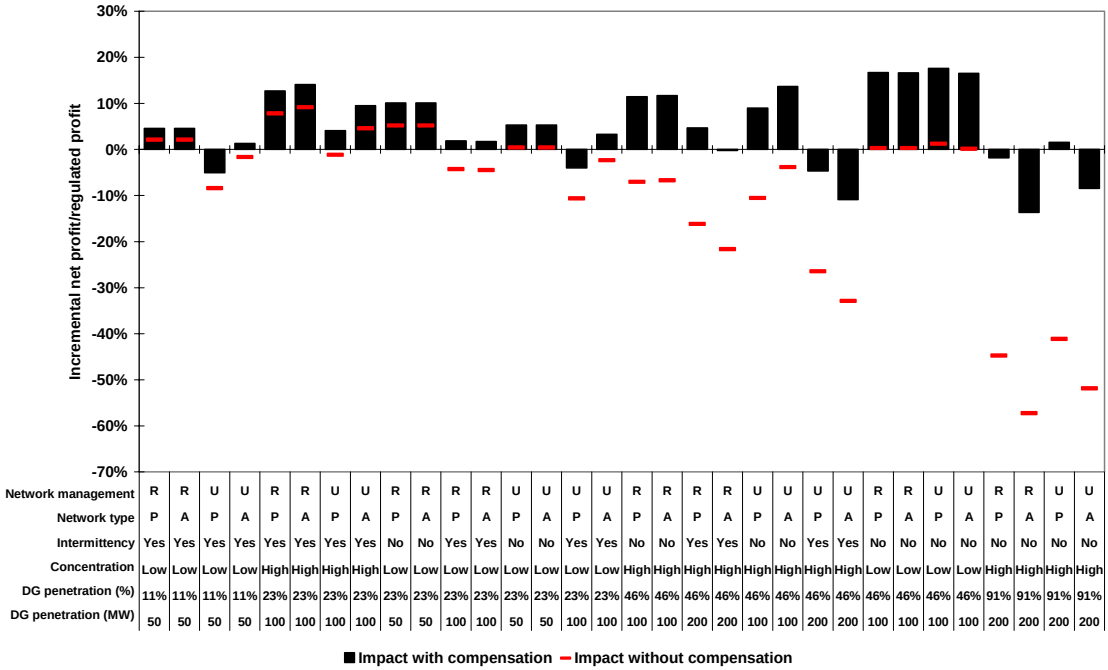


Figure 5.3 *The impact of DG with compensation through a quality indicator*

5.2.3 Direct revenue driver

This compensatory measure involves an extension of the revenue cap for the individual DSO with a fee for DG related revenue drivers. Here we model two different revenue drivers: a 'capacity-based' revenue driver (e.g. fee per DG kW capacity connected to the distribution network) and an 'energy-based' revenue driver (e.g. fee per MWh fed into the distribution network). This type of compensation measure can be described as follows:

For a capacity-based revenue driver:

$$TAR_t = TAR_{t-1}(1 - X) + F \cdot kW^{DG}$$

For an energy-based revenue driver:

$$TAR_t = TAR_{t-1}(1 - X) + F \cdot MWh^{DG}$$

where:

TAR_t = Total allowed revenue in year t

X = Required yearly improvement in efficiency performance

F = Compensation fee (revenue driver)

kW^{DG} = Total DG capacity connected to the distribution network

MWh^{DG} = Total amount of electricity fed into the grid from DG units

In Figure 5.4 and Figure 5.5, we present the impact of DG penetrating the network when compensation fees are installed of respectively € 3.50 for a kW of DG capacity and € 2.50 for a MWh of distributed generated electricity.

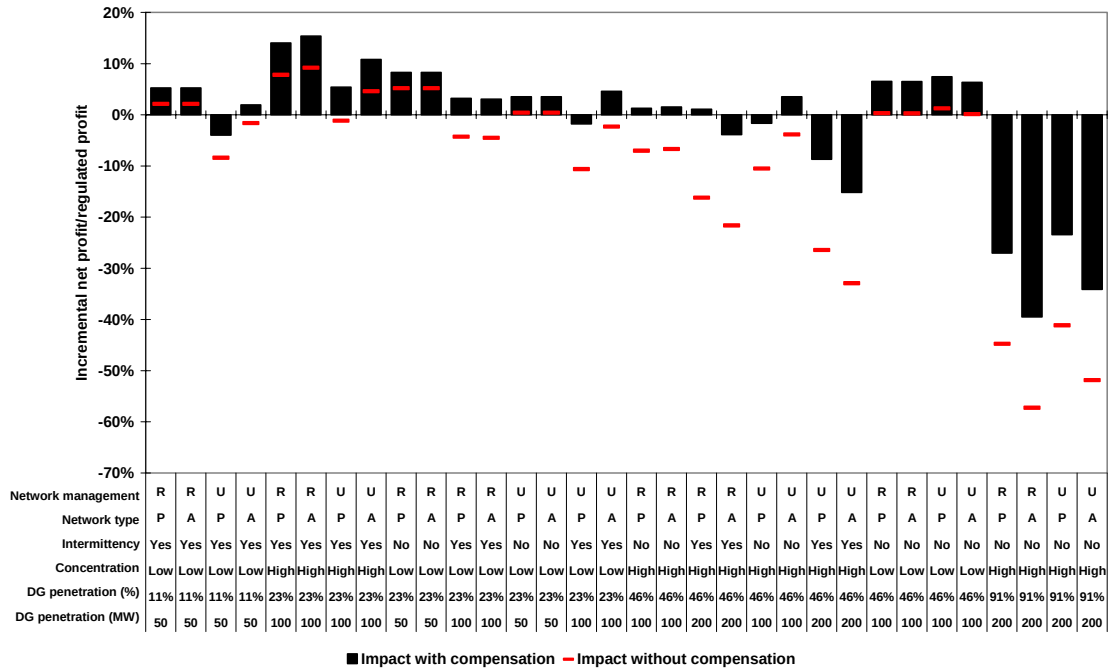


Figure 5.4 *The impact of DG with compensation through a capacity-based revenue driver*

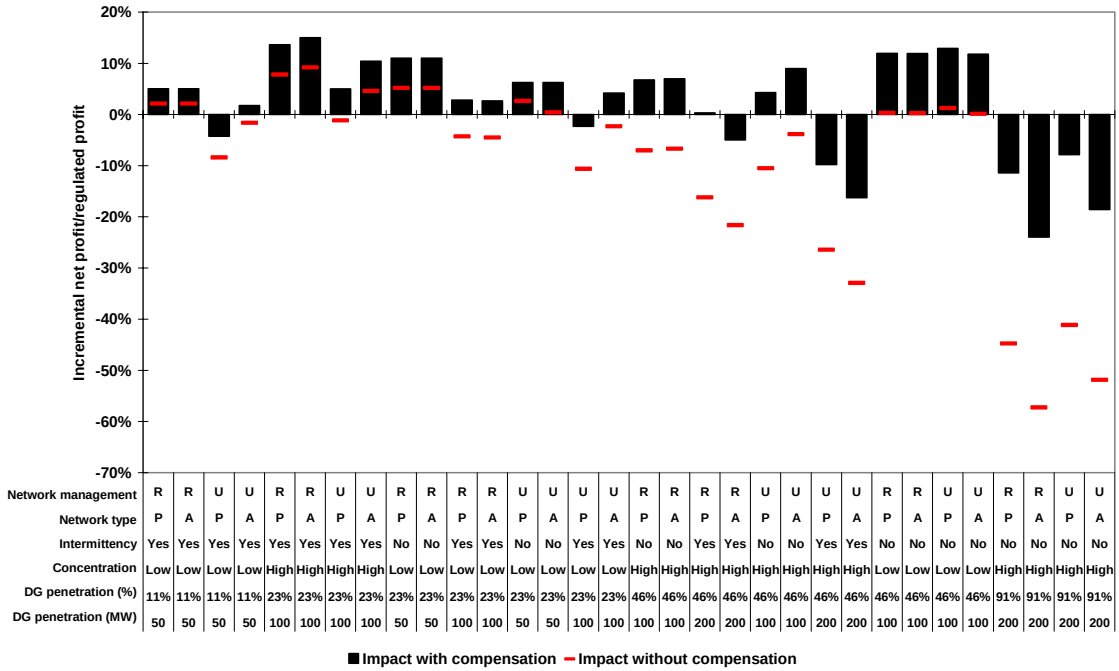


Figure 5.5 *The impact of DG with compensation through an energy-based revenue driver*

From the above two figures we learn that a capacity based fee is in general successful in 'relieving the pain' of DSOs, except for the very high DG penetration cases. In addition, it seems that the energy-based revenue driver is more successful in compensating the DSO than the capacity based revenue driver. As mentioned earlier on the regulatory measure involving a special RAB allowance, the reason is that a capacity based regulatory measure is generally not successful when the negative DG impact is primarily caused by 'energy' (e.g. distribution losses). This is confirmed in the figures on a compensatory rule involving an energy-based compensation fee. This mechanism is especially successful in countering the negative impact of DG penetration levels above 46%.

Since the impact of DG penetration is very much dependant on the overall level of penetration, we propose to differentiate the compensation fees over DG penetration levels. Figure 5.6 shows the results for the following regulatory measure:

$$TAR_t = TAR_{t-1}(1 - X) + F_1 \cdot kW^{DG} + F_2 \cdot MWh^{DG}$$

Where the following values apply:

Table 5.2 *Overview of penetration rates and accompanying values for the compensation fees*

Penetration rate	Value for F_1	Value for F_2
Low (11 - 23%)	2.50	0.00
Medium (46%)	3.00	2.50
High (91%)	1.00	3.50

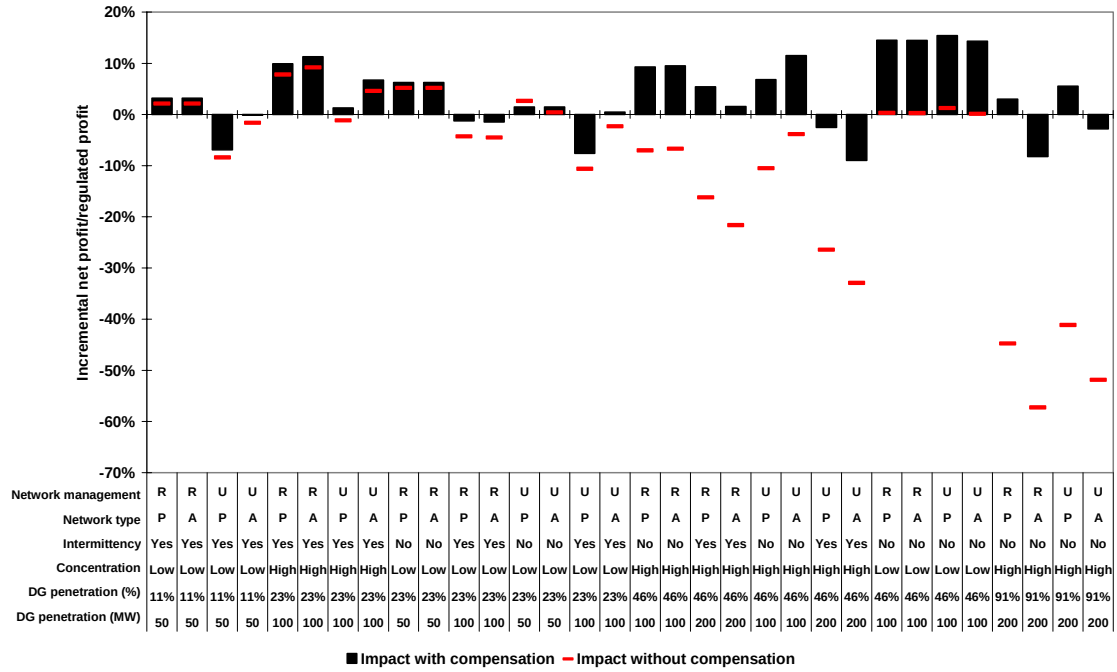


Figure 5.6 *The impact of DG with compensation through penetration rate dependent compensation fees*

Figure 5.6 shows that a compensation mechanisms that uses both capacity and energy based revenue drivers is reasonably successful in countering the negative impact of DG. The range of DG impact when compensation is included is now -9% to +15.5%.

5.2.4 Special allowance in RAB and direct revenue driver

Technically, the mechanism of this alternative regulatory rule is similar to the previous regulatory rule, because also here both a capacity and energy based compensatory element are distinguished. While the direct revenue driver in this scheme is still based on energy, the capacity based direct revenue driver is replaced by a special RAB allowance for DG related investments. While the special RAB allowance still bears a relationship with total DG capacity, it is a more subtle relation since a more tailor made compensation is provided. Whereas a capacity related direct revenue driver involves a DG capacity dependent compensation fee, the RAB allowance implicitly takes into account other important cost drivers besides total DG capacity (e.g. density of DG in the distribution network, network characteristics etc.).

Technically, this regulatory regime can be described as follows:

$$TAR_t = TAR_{t-1}(1 - X) + y\% \cdot I_t^{DG} + F \cdot MWh^{DG}$$

where:

TAR_t = Total allowed revenue in year t

X = Required yearly improvement in efficiency performance

y = Share of eligible DG related investments in distribution network assets

I_t^{DG} = Total eligible DG related investments in distribution network assets in year t

F = Compensation fee (revenue driver)

MWh^{DG} = Total amount of electricity fed into the grid from DG units

In Figure 5.7 the impact of DG penetration on DSOs is shown when the above-described regulatory formula is applied. Here it is assumed that 50% (parameter y) of DG related investments are labelled as special RAB allowance and the direct revenue driver (parameter F) has the value of € 2 per MWh.

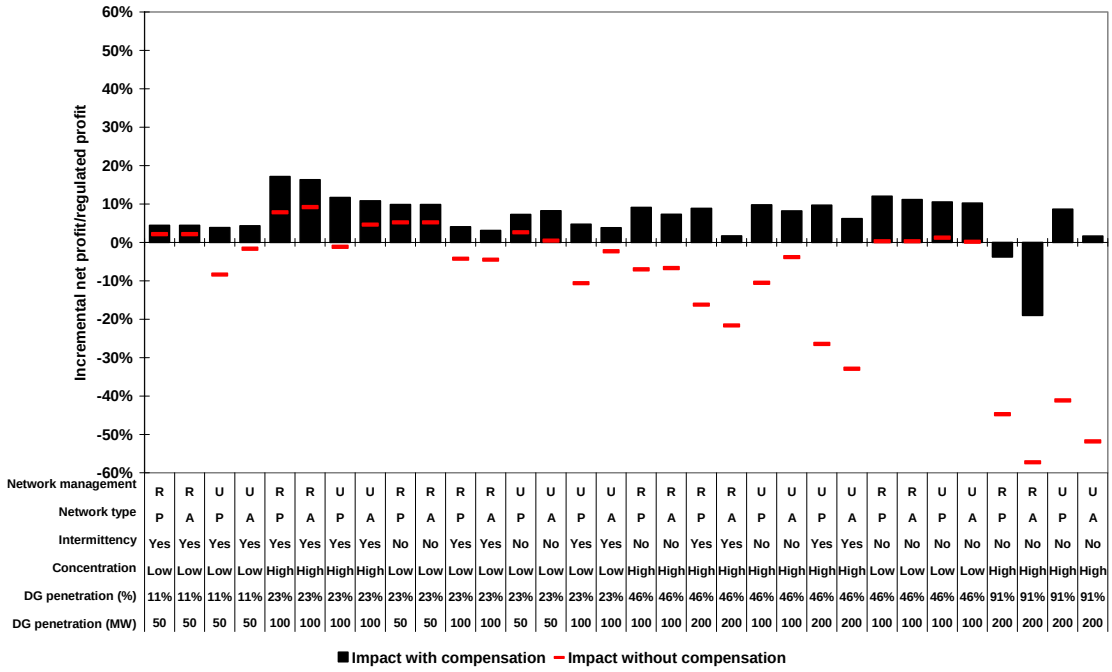


Figure 5.7 *The impact of DG with compensation through special RAB allowance and energy based direct revenue driver*

Figure 5.7 shows that it is difficult to set compensation consisting of a combination of a special RAB allowance and direct revenue driver in such a way that in all cases DSOs are compensated and at the same time large-scale overcompensation in some cases is prevented. For instance, with the parameter values chosen above, some cases characterized by a high penetration (91%) and high concentration of DG are not compensated enough. Changing the parameter values (e.g. the percentage of investments to be allowed in the RAB and the fee per MWh of DG fed into the grid) does not lead to compensation for the DSO in these cases *without* bringing considerable benefits to DSOs that do not need larger compensation.

6. Conclusions and policy recommendations

DG presence in the distribution network creates opportunities and benefits for the DSO. New market opportunities are discussed in Jansen et al. (2007). Possible benefits for DSO include: deferred investment and possible reduction in distribution losses.

The current DSO business model is characterized by regulated revenue from network services (based on either a price or revenue cap) and costs related to the purchasing of system services with the TSO, compensation of energy losses, and general operation and maintenance costs. The impact of DG on costs and benefits of the DSO is different depending on the business model: is it based on passive or active network management. Moreover, the impact of DG on specific cost and revenue items can be ambiguous. Whereas the *level of DG* penetration is an important parameter in this sense, other network or DG specific parameters can potentially have a substantial influence as well.

In this report we investigate the *economic impact of DG* penetration in distribution networks *on the DSO* taking into account a large number of factors such as network characteristics and DG characteristics. The opportunities for DSOs on the provision of ancillary services in the near future are not covered in this report but in Jansen et al. (2007). In assessing this economic impact we take current DSO regulation as a starting point and analyse the economic impact under two differing network management philosophies: passive and active network management.

Using two modelling tools, the GSP model and the DSO model, we analysed:
1. The impact of DG on DSOs operating under a passive network management philosophy.
2. The impact of DG on DSOs operating under an active network management philosophy.
3. The impact of the potential value of deferred investments of DSOs due to DG on the outcomes under (1) and (2).
4. The incentive for the DSO to adopt an active network management approach instead of a passive network management approach.
5. the effectiveness of alternative regulatory arrangements in (a) neutralizing the possible negative impact of DG penetration, or (b) providing incentives for the DSO to adopt an active network management approach to enable the DSO to participate in the provision of ancillary services.

Table 6.1 shows the main results of our analysis after which a short elaboration on general results follows.

Table 6.1 *Overview of results on impact of DG penetration on DSO business*

Network management philosophy	Potential value deferred investment	Impact on DSO net profit (range for 16 cases)
Passive	Excluded	+ 8% to -44%
Passive	Included	+30% to -28%
Active	Excluded	+ 9% to -57%
Active	Included	+31% to -40%

(1) We find that DSOs operating under a passive network management regime generally do not profit from the presence of DG in their distribution network, except for low DG penetration levels. Network reinforcement costs increase with the level of DG penetration. The increase in reinforcement costs is larger for urban networks than for rural, and larger when DG is more concentrated in the distribution network. Distribution losses first decrease with the DG penetration level until minimum is reached, and then increase with the DG penetration level

(2) DSOs operating under an active network management philosophy are generally confronted with comparable results as the passive network management case. Penetration of DG in the network is favourable for the DSO for low penetration levels, but becomes unfavourable the higher the penetration rate and the more concentrated the DG in the network. However, it should be noted that the negative results are relatively small for the majority of the cases analysed: the net impact of DG penetration is mostly within the range of 8% of the 'business as usual' profit DSOs make.

(3) The added value of DG with respect to the putting of or deferral of investments 'above the distribution network' (the connection with the higher voltage level network) can be substantial. However, the realization of this positive value for the DSOs is dependent on a larger number of factors beyond the scope of this investigation. These relate to the load growth dynamics and the status of interconnection equipment (economic lifetime and depreciation so far). However, considering the maximum replacement values of DG, it can be expected that the overall impact of DG penetration on the DSO business, can be neutral or positive in the majority of cases.

(4) Observing the differential impact on the DSO under passive and active network management we conclude that there is an implicit incentive for the DSO to adopt an active network management approach in a number of cases, in particular the case where DG penetration is low or mediocre. For cases with high DG penetration conclusions still cannot be drawn; first more research is needed about the costs for the DSO when combining passive and active network management.

(5) Regarding the implications of the analysis on alternative regulatory arrangements we note that there are several cases where the DSO is negatively impacted by DG penetration, regardless of the network management philosophy. This implies that an alternative regulatory arrangement compensating the DSO for the negative impact might be warranted. Moreover, we have seen that in such cases there the incentive for DSOs to move from a passive network management approach to an active network management approach is not always present.

From the model analysis we found that an alternative regulatory arrangement based on a combination of a special RAB allowance and a direct revenue driver seems most successful in compensating the negative DG impact on DSOs. When applying this alternative regulatory arrangement DSOs will be able to recover their costs and at the same time are stimulated to connect existent and new types of DG without largely 'overcompensating' some DSOs that experience little or even no negative impact. The most sophisticated revenue driver seems to be a driver that accounts for all connected kW of DG capacity as well as for all kWh of DG electricity fed into the grid. However, it is stressed that there is no 'one size fits all' solution for the neutralization/incentivisation problem. Since the negative impact of either operational expenditures (distribution losses) or capital expenditures (network upgrades) in some specific cases (for mostly cases with high penetration rates and concentrated DG units) is very dominant, a specific regulatory arrangement with compensatory elements based on either 'DG energy produced' or 'DG capacity connected' can not fully compensate the DSO without unnecessarily 'subsidize' other DSOs. However, it should be noted that a mediocre 'overcompensation' of DSOs for the negative impact they experience from DG penetration of the network might work effectively as an incentive to fully facilitate DG connection within their distribution network.

This leads us to propose the following policy actions:

1. Current regulation of DSOs should recognize the impact of DG on DSO performance. The impact of DG crucially depends on the level of DG penetration and specific network characteristics, such as the concentration of DG in the network alternative regulation. Alternative regulation should sufficiently take into account the drivers behind the DSO impact.

2. As a specification of recommendation 1, we suggest to implement a regulatory formula where the impact of DG on both operating expenditures (with the main driver being electricity generated by DG units, impacting distribution losses) and capital expenditures (with the main drivers the amount of DG units connected to the distribution network) are included.

3. In determining the specific values in the alternative regulatory formula we would recommend to aim for some 'overcompensation' of possible negative DG impact on DSOs in order to provide them an explicit incentive to facilitate and accommodate new DG connections in their distribution networks.

4. When considering the above recommendations on the neutralization and possible incentivisation of DSOs it should be kept in mind that the desirability of regulation aimed at these aspects is intertwined with the developments in the field of ancillary services provision by DSOs (as discussed in Jansen et al. (2007)). On the one hand, DSOs might need to be compensated for the negative impact following the penetration for DG. On the other hand, if DSOs benefit from the provision of ancillary services enabled by DG penetration, the DSO should compensate the DG operators. Netting both impacts implies that valuable economic signals are lost. Changes in regulation should therefore be targeted at either one, or both, described impacts.

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Glossary of abbreviations

ANM	Active network management
CAPEX	Capital expenditures
CF	Cash flow
DER	Distributed energy resources
DG	Distributed generation
DSO	Distributed system operator; also referred to as distribution network operator (DNO) in the UK
EU	European Union
O&M	Operation and maintenance costs
GSP	Grid supply point
MS	Member state
NPV	Net present value
OPEX	Operational expenditures
RAB	Regulated asset base
TOTEX	Total expenditures
TSO	Transmission System Operator
UK	United Kingdom
WACC	Weighted average cost of capital

Appendix A DSO Model input

Table A.1 presents all DSO input parameters and values as set in the base case analysis.

Table A.1 *Overview of DSO model parameters*

Parameter	Value	Unit
Debt ratio	60	[%]
Equity ratio	40	[%]
Return on equity	7.5	[%]
Return on debt	4.5	[%]
Weighted average cost of capital (WACC)	5.70	[%]
Depreciation rate	3.33	[%]
Tax rate on benefits	30	[%]
Value of distribution losses	40	[€/MWh]
Value of curtailed electricity	40	[€/MWh]
Load factor (non-intermittent)	60	[%]
Load factor (intermittent)	30	[%]

Appendix B Sensitivity analysis of DSO model results

This appendix contains an analysis of the sensitivity of DSO business model results to changes in model parameters. The parameters analysed on sensitivity include (i) the WACC, (ii) the investment trajectory, (iii) the value of curtailed electricity, (iv) the value of distribution losses, (v) the tax rate, and (vi) the depreciation rate.

B.1 Change in the value of the WACC

For the start of each regulatory period the regulator of each country as a rule will determine a new weighted average cost of capital (WACC) for DSOs. The WACC is the remuneration for making available equity and debt by financial institutions to the DSO. The WACC multiplied by the Regulatory Asset Base (RAB) should make it possible for DSOs to undertake capital expenditures (replacement and expansion investments) and to obtain a reasonable profit. In principal the WACC can be set at a higher or lower level, which depends mainly on developments in capital markets and to a less extent on the regulation method chosen by the regulator.

However, in the spreadsheet DSO business model only the debt remuneration is of direct concern, because the equity remuneration depends on the size of the resulting net profit. Therefore, the net profit varies only with the debt remuneration and the change of the return on debt therein. On the other hand, to determine the regulated profit the RAB has to be multiplied by the WACC, so differences in the return on debt as well the return on equity result in a change of the regulated profit.

The following figure shows the consequences of changes in the WACC values for the net profits only. In the base case the WACC is 5.7%, besides that we also tried values of 5.5% and 6.0%. The gearing (the degree to which an undertaking is financed by debt capital, expressed as a fraction of total capital) has in all cases the same value (60%). Changes in this gearing ratio only marginally impact the DSO business through the WACC and are therefore not extensively presented here. Hence the focus is on the level of return on debt and return on equity. The table below gives an overview of the chosen values.

Table B.1 *Input parameters for different values of the WACC*

Vanilla WACC (case) [%]	Return on debt (R_d) [%]	Return on equity (R_e) [%]
5.50	4.50	7.00
5.70	4.50	7.50
6.00	4.67	8.00

Note: *(WACC formula applied is WACC = g * Rd + (1-g) * Re).*

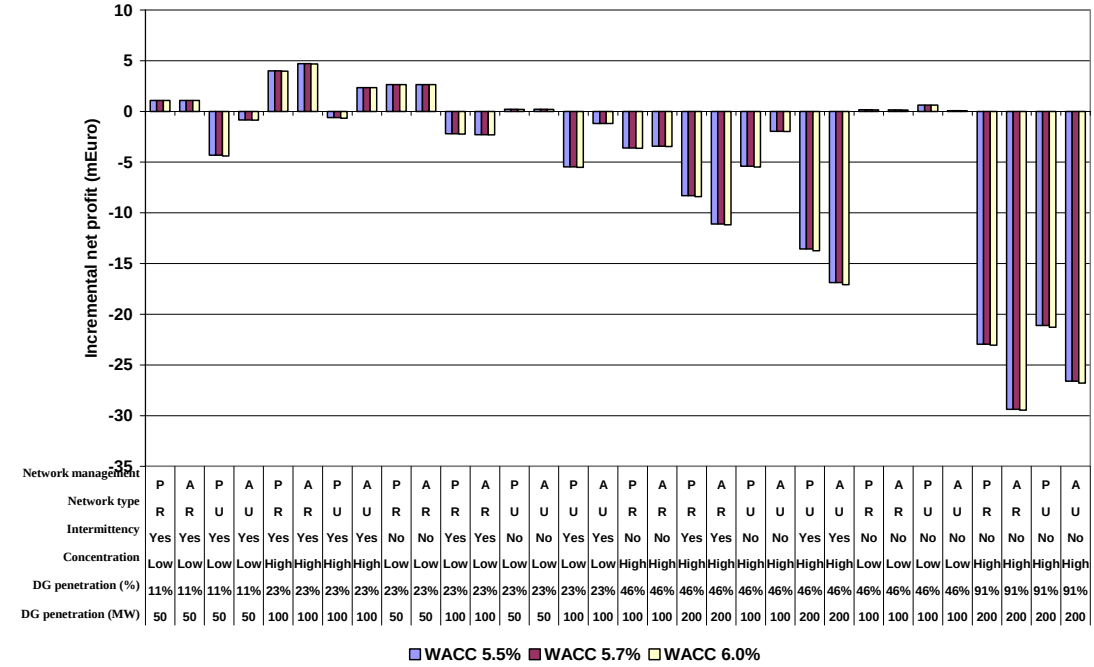


Figure B.1 *Results on model sensitivity to changes in the WACC*

Figure B.1 shows that an increase of the WACC results in a very small increase in losses. The increase only results from changes in the return on debt.) In this context, it is also interesting to compare the incremental net profit with the regulated profit because the WACC is the only parameter that changes the extent of regulated profits. The regulated profits at all times increase with an increase in the WACC. This effect is stronger than the increase of the net profit, so the proportion of net profits to regulated profits is a smaller fraction the higher the WACC is (see Figure B.2).

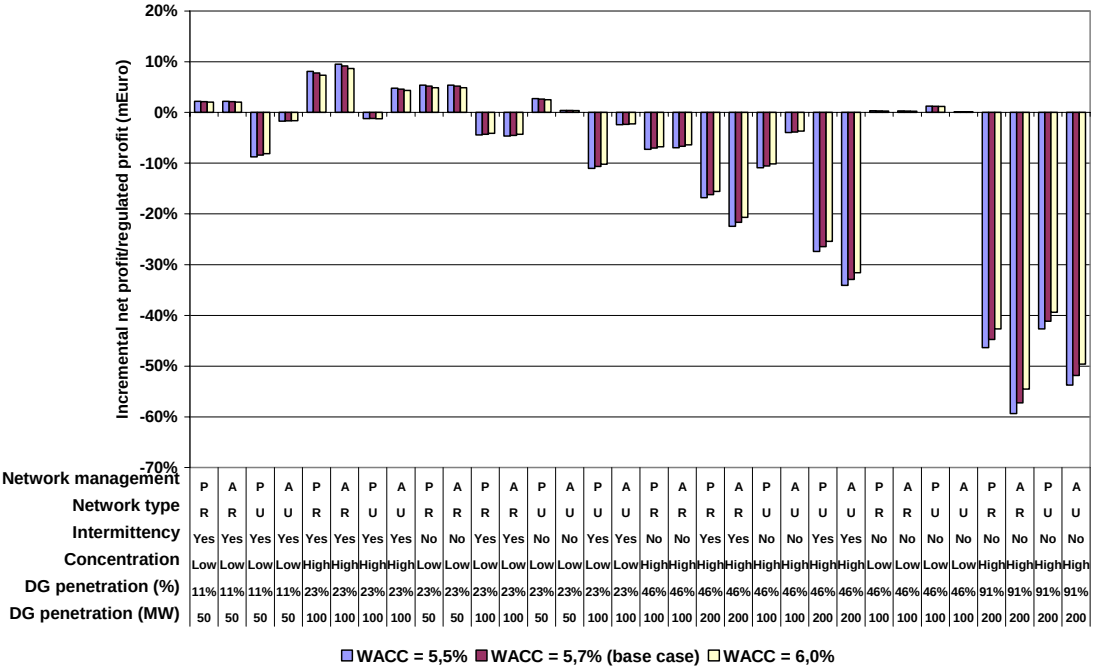


Figure B.2 *Results on model sensitivity to changes in the WACC and the impact on relative net incremental profit*

Regarding the sensitivity of results for changes in the WACC we conclude:

- Because the WACC is a composed variable of two input variables (return on debt and return on equity) the effects of a change of the WACC can be complicated.
- The effects of changes of the WACC on the incremental net profit are relatively small pro case.
- The proportion of net profit to regulated profit (also considered as 'regular' profit) decreases with the WACC and is limited.

B.2 Change in investment trajectory

In all cases the size of the investment depends on the DG capacity connected. We have checked four investment trajectories or paths:

1. Linear path (investment is equally spread out over time).
2. Concentrated path (investment is concentrated in one year).
3. Concave path (large investments early on).
4. Convex path (small investments early on, large investments in latter years).

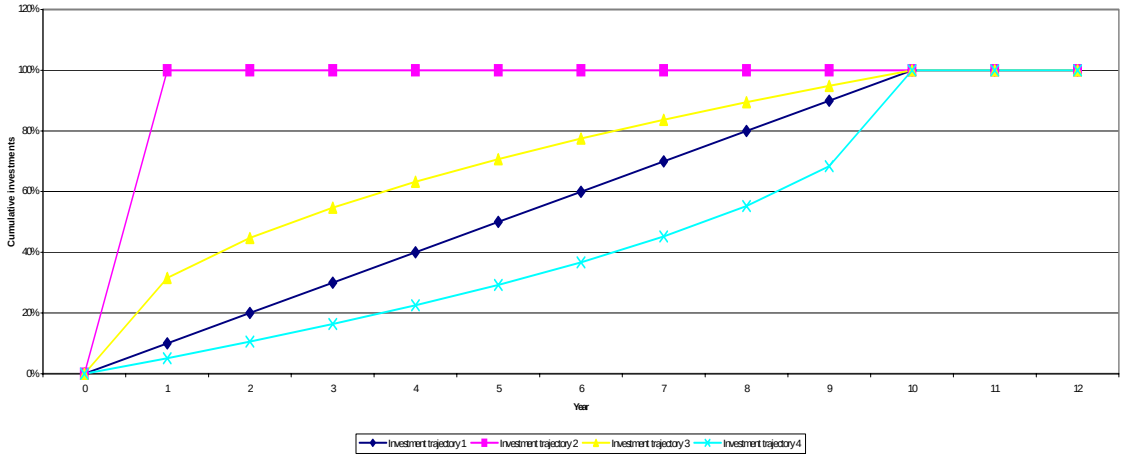


Figure B.3 *The investment trajectories as function of time*

In the first situation in each year an investment of 10% of the whole investment takes place. The second has the strongest outcomes, whereas the fourth scenario gives the least negative rates. The third one is stronger negative than the first one, but less than the second. This ranking is logical; how later the investments are situated in time, the higher the incremental net profit/regulated profit because the operational costs associated with investments occur from a moment later in time. However, the differences between different scenarios are bigger than expected.

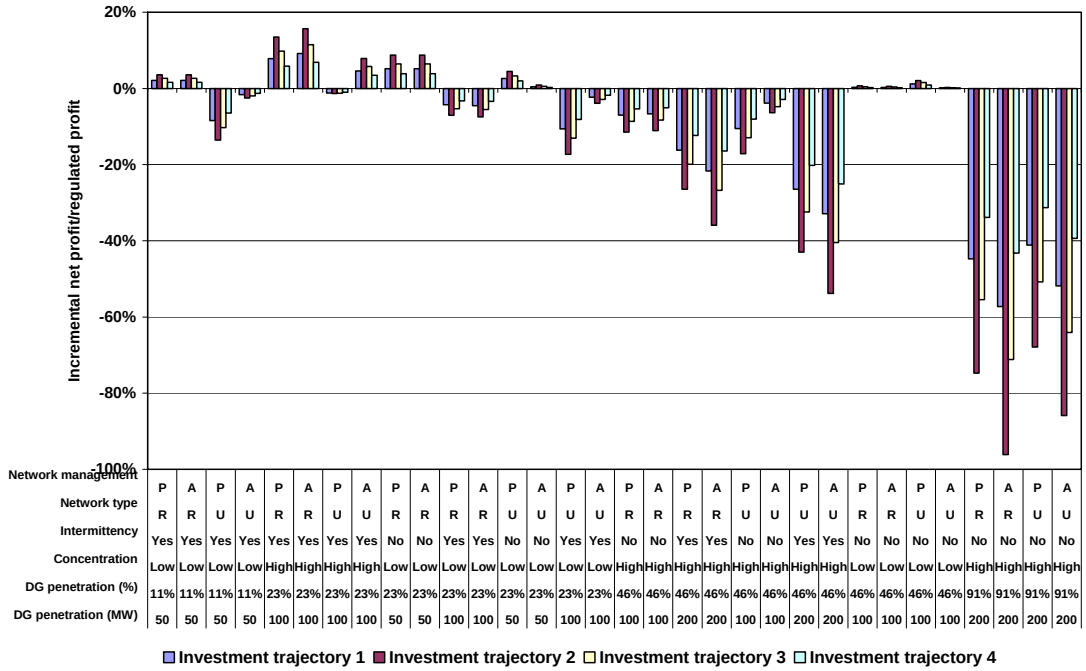


Figure B.4 *Effects of different investment trajectories on incremental net profit/regulated profit*

Regarding the sensitivity of results for changes in the investment trajectory we conclude that different investment trajectories do change the level of incremental net profit. The difference is larger for high penetration cases since the level of distribution network reinforcements are higher in those cases. The sign of the impact on DSO business remains identical: i.e. a change in assumed investment trajectories does not change the message of the results.

B.3 Change in the value of distribution losses

In the base case the distribution loss has been valued at 40 €/MWh. If the value of distribution loss is set on 30 €/MWh, the results are more favourable. There is a simple explanation for this: if the load on the network is lower, the distribution losses are smaller (and the value of distribution losses decreases); thereby net profits have to increase. In the situation that network density is higher, logically also distribution losses are on a higher level, so a change of the 'loss value' does raise net profit then by even more.

Moreover, with active management the losses are larger than under passive management since the active form of management implies the use of circuits with smaller size, which means more losses in circuits. The intermittent cases show smaller losses than the non-intermittent ones. Cao et al. (2007) explained this result from the lower occurrence of the worst-case situation of high output of DG at times of low demand in the intermittent cases compared to non-intermittent cases.

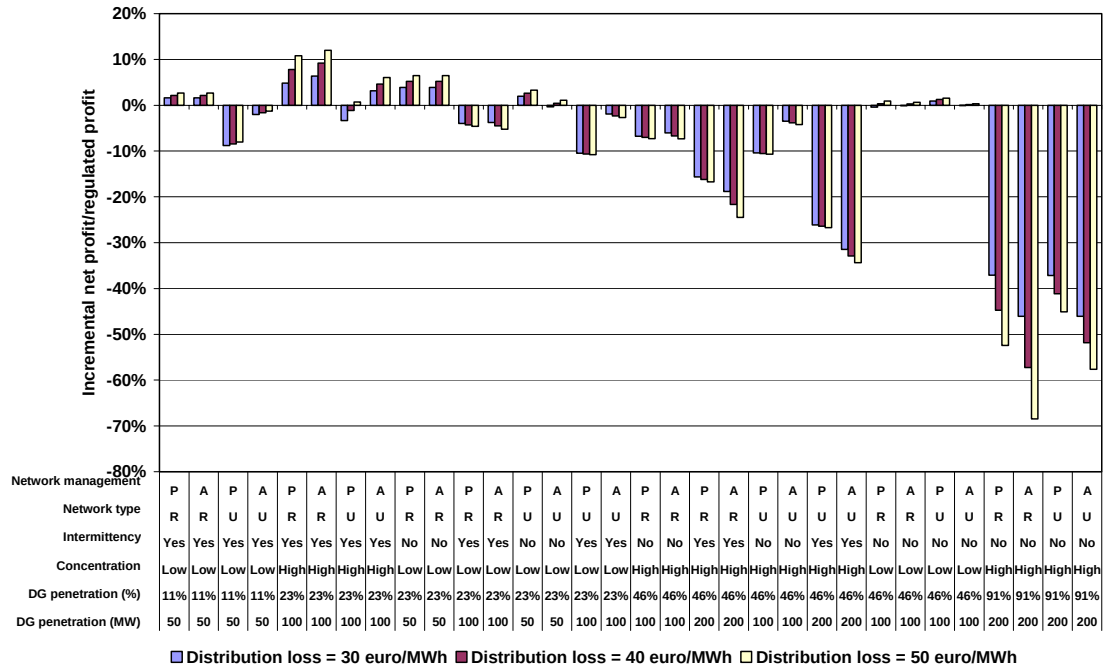


Figure B.5 *Effects of different distribution loss values on incremental net profit/regulated profit*

Regarding the sensitivity of results for changes in the value of distribution loss we conclude:

- Generally, the results vary as expected; however in some cases with high penetration and concentration the distribution losses are big, so a different loss value causes big differences in profits within such cases.
- Changes of both active and passive management cases are also in accordance with expectations: the relationship between changes in the value of distribution loss and changes in the profit indicator is linear in all cases.

B.4 Change in the value of curtailed electricity

Curtailment costs are the cost associated with the energy, which the distributed generator cannot produce when demand is low, because otherwise the voltage of the system will rise. In that way the size of curtailment costs depends on the time of day.

Curtailment arises from the presence of active management in the system, which means using circuits with smaller sizes. Combined with distributed generation active management requires in some cases curtailment, which is not necessary in passive management cases.

In the base case the curtailed electricity has a value of 40 €/MWh. If this changes to 30 or 50 €/MWh a few cases show little higher respectively lower net profits/regulated profits. In particular the change of profits of some non-intermittent cases stands out in the analysis. By the same reason as described in the former part the changes in comparable intermittent cases are smaller.

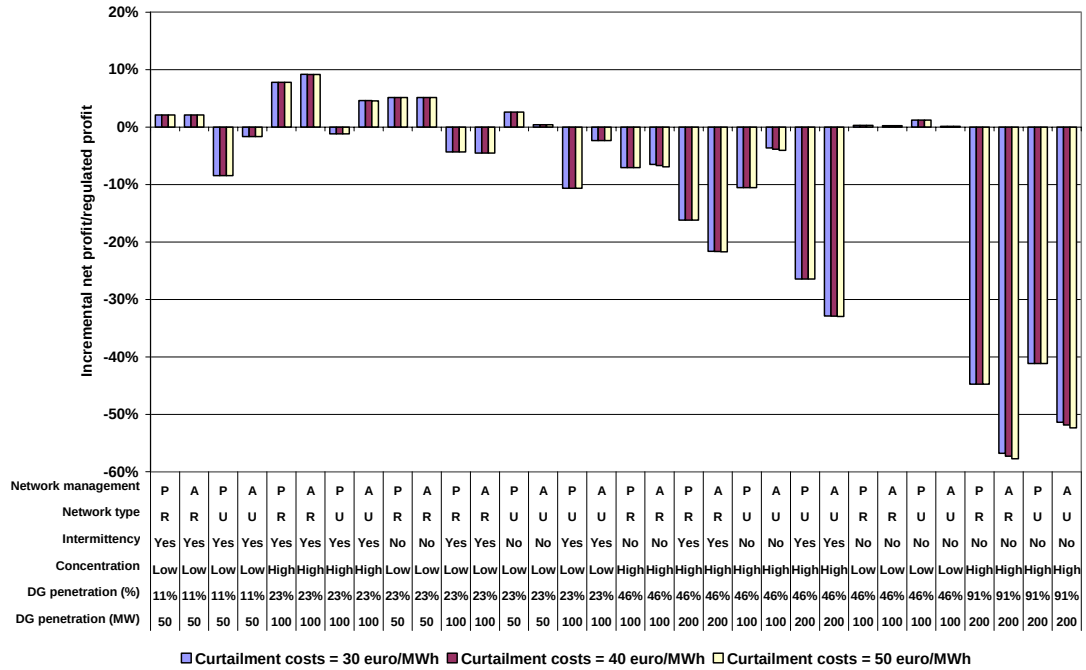


Figure B.6 *Effects of different curtailed electricity values on incremental net profit/regulated profit*

Regarding the sensitivity of results for changes in value of curtailed electricity we conclude:

- The size of the curtailment costs does not influence the profit indicator very much.
- Changes of active and passive management cases are in accordance with expectations: the relationship between changes of input and output is linear in some active management cases.

B.5 Change in the tax rate

The tax rates applied on the total revenues are in a range of 25% (Austria) to 43% (with regional taxes; Spain). We tried tax rates of 25% and 35% besides the base case tax rate of 30%. We think these values give the best impression, because in the future when DG investments take place international tax competition will have lowered the highest tax rates.

As in practice the tax rate is deducted on the net profit. A higher tax rate means of course lower profits. However, if net profits are negative the tax rate does not influence the net profits by assumption. At this point the model does not fully agree with reality, where in many cases the government compensates losses of companies through taxation. From a principle of caution we have not applied such a compensation of losses by taxation, which means that some cases, for instance those with a high concentration of DG, could show slightly better results in practice.

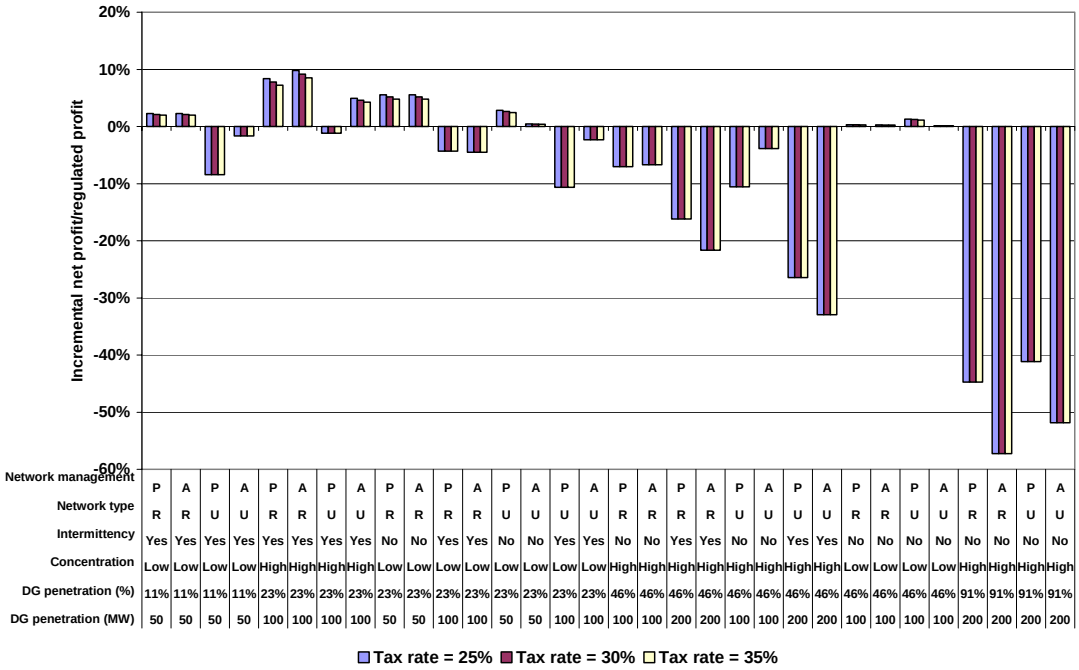


Figure B.7 *Effects of different tax rates on incremental net profit/regulated profit*

Regarding the sensitivity of results for changes in tax rates we conclude:

- Changes in profit run parallel to changes in tax rates.
- Losses are not affected through changes in tax rates by assumption.

B.6 Change in the length of depreciation period

In order to account for differences in depreciation periods between assets an average depreciation period for all assets of 20 to 40 years has been used. In the base case a period of 30 years is assumed. A prolonged period of depreciation means a decrease of the amount of depreciation per year, which means lower capital expenditures and higher net profits.

More generally, in cases of high density and concentration of DG more investments in assets are needed and therefore depreciation values are higher. Because of that in these cases the changes in net profits as a result of changes in depreciation period are much bigger.

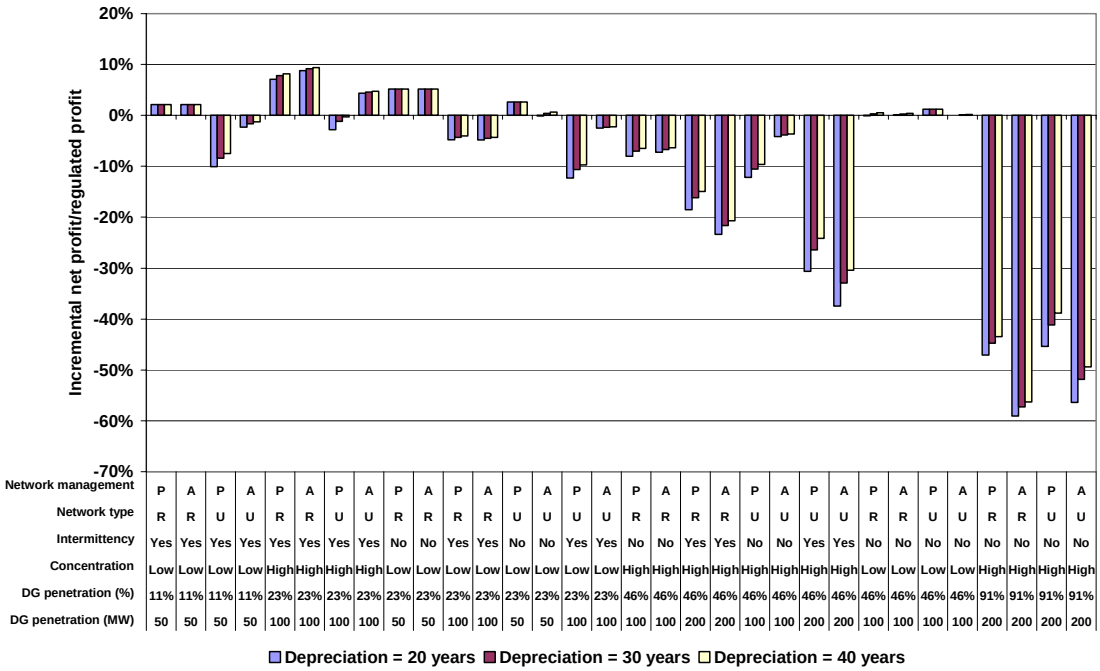


Figure B.8 *Effects of different depreciation periods on incremental net profit/regulated profit*

Regarding the sensitivity of results for changes in the depreciation rate we conclude:

- The differences as a result of different depreciation periods are relatively small.
- The results show that a longer or shorter period of depreciation means a decrease/increase of the amount of depreciation per year, which means higher/lower net profits.