Committed to the Environment

The social costs and benefits of Smart Grids

Summary

(April 2012)

Introduction and key question

Although a reliable social cost-benefit analysis (SCBA) of large-scale introduction of Smart Grids is currently lacking, the rough-and-ready estimates available give the impression that the results of such an exercise would be positive. In the latter half of 2011 and in early 2012 a number of large-scale trials to explore Smart Grids were initiated in the Netherlands: the so-called ‘Pilots Smart Grids’. To identify and quantify the social costs and benefits associated with Smart Grids and assess whether large-scale introduction is indeed desirable, an SCBA needs to conducted. An additional question concerns the issue to be considered when rolling out large-scale trials aimed at improving the economic impact of Smart Grids in the Netherlands.

The key question posed by the commissioning party, the Dutch Ministry of Economic Affairs, Agriculture and Innovation, was to identify and quantify the costs and benefits, both direct and indirect, of a national roll-out of Smart Grids.

The present report deals with Phase 1 of the SCBA. In Phase 2 the results obtained in the Pilots Smart Grids will be incorporated in the SCBA, to reduce uncertainties and gain a more accurate picture of the social costs and benefits.

Scope

Although the notion of Smart Energy Grids can in principle encompass grids for all forms of energy and energy carriers, this study deals solely with the grid for electricity transmission and distribution (thus excluding Smart Thermal Grids). In line with the definition employed by the Dutch Taskforce on Smart Grids, we define a Smart Grid as being an ‘enabler’: a Smart Grid makes it possible to respond effectively and efficiently to future changes in the energy market. Incorporation of electric transport, distributed energy production (in many cases renewable), home automation (‘domotica’) as well as large-scale wind farms and the emergence of new services like ‘demand response management’ and ‘real time pricing’ are examples of such changes that dovetail with the Taskforce definition. In this study we have opted to restrict the concept to a communications infrastructure ensuring that grid connections and grid components meet demand for power transmission and distribution in a smarter and more secure manner.

Whole playing field investigated

This study assesses the implications of introducing Smart Grids over the period 2011-2050. Over this length of time, key data on core issues like the energy mix , energy demand and energy prices are hard to predict. It is as yet unclear whether the electrical power system will indeed move towards climate-neutrality over the coming decades, whether the share of renewables will rise substantially and, if so, to what extent that power will be generated centralised or decentralised.

To cover potential future trends in these core variables (climate-neutrality, flexibility and amount of distributed generation) three scenarios were considered. These scenarios are not blueprints for the future, but provide three pictures of the future energy system and electrical power grid based on a series of prior assumptions designed to ensure those pictures are internally consistent and coherent. By appending uncertainty ranges, this yields sketches of the future that can be deemed plausible based on current information. The relevance of these three scenarios is that they generate a better understanding of the consequences of Smart Grids in a multiplicity of situations that may arise over the coming years and decades.

The SCBA was run with the following three scenarios:
1. **Business As Usual** (limited CO_2 emissions reduction).
2. **Renewables & Gas** (80-95% CO_2 reduction).
3. **Coal-CCS & Nuclear** (80-95% CO_2 reduction).

The three scenarios are characterised as follows:

Scenarios	Busniness as usual (BAU)	Renewables & Gas (R&G)	Coal-CCS & Nuclear (C&KN
CO_2 emissions of E sector	High	Zero	Zero
Power demand (excl. ET, HP)	High	Low	Medium
- elecric transport (ET)	Zero	High	High
- electric heat pumps (HP)	Low	Medium	High
Distributed capacity	Low	High	Low
Central capacity			
- gas-fired	🟩	🟩	🟧
- coal-fired	🟩	🟥	🟩
- renewable (biomass)	🟧	🟩	🟧
- renewable (offshore wind)	🟥	🟩	🟥
Flexibility	🟩	🟩	🟧
Central storage capacity	🟥	🟩	🟥
Hydrogen production for transport	🟥	🟥	🟩

🟩 = yes
🟧 = (very) limited
🟥 = no

Baseline

For each scenario a baseline was defined in which no Smart Grids are rolled out. This baseline comprises the following:

- **Introduction of smart meters**, as foreseen under current Dutch policy. In the zero alternative, smart meters are installed before 2020 at all small-scale users.
- **Active grid management:** more efficient utilisation of the power grid is a process that proceeds automatically and can thus be subsumed under ‘existing policy’ of grid operators, given the direct financial gains accruing. On these grounds, automation of key grid components like local and regional substations are included in the baseline. At the same time, though, these grid components are essential for the functioning of a Smart Grid as a

system concept, i.e. they are key to improved coordination of supply and demand dynamics within such a grid.

- **Simplified control strategies** aimed at achieving a better spread of the load profiles. Given the direct financial interests involved, the baseline already includes simple measures to shave peak loads. This amounts to a fixed ('non-smart') control strategy for spreading loads without allowing for specific daily dynamics or weather conditions.
- **Greenhouse horticulture and heavy industry** are already fully equipped for Smart Grids, so that no additional costs and benefits have been included for these sectors in the project alternative.

Neither the costs or benefits of these four aspects are thus included in the project alternative.

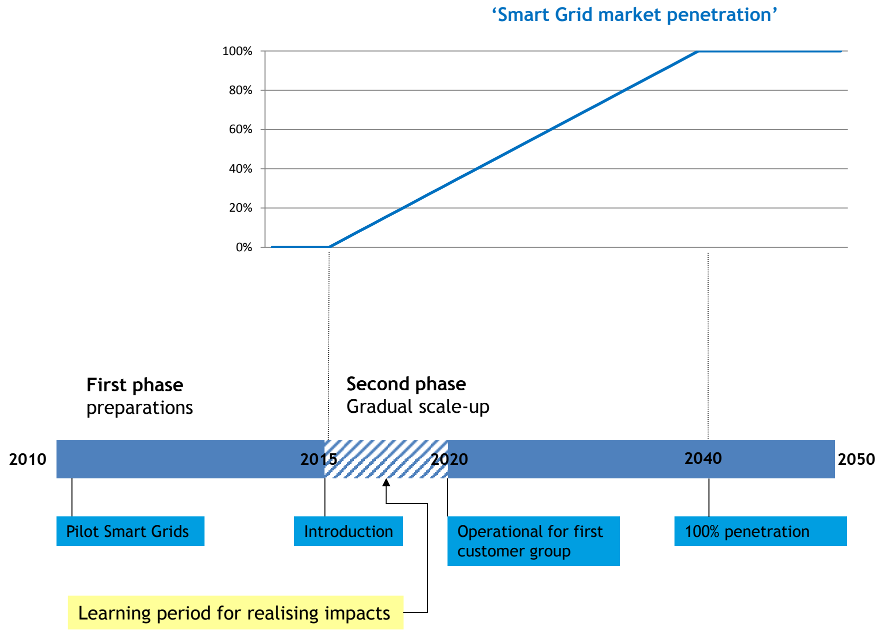
The project alternative

The project alternative can be characterised as follows:

- In **2015** the introduction of Smart Grids is initiated, at which point the first investments will have to be made. These investment costs will increase linearly as the Smart Grids are scaled up. In **2040** 100% of the connections will have access to a Smart Grid.
- Following a five-year learning period, Smart Grids will be operational from **2020** onwards, with scale-up proceeding linearly. On balance, this will mean a gradual expansion of the number of connections with access to new Smart Grid-based services. The effects will thus lag five years behind investments.
- Investments in connections (homes, offices, business premises) as well as the associated grid components (local and regional substations) will take place in a coordinated manner.

The timeline is summarised in Figure 1.

Figure 1 Smart Grid investment timeline (project alternative)



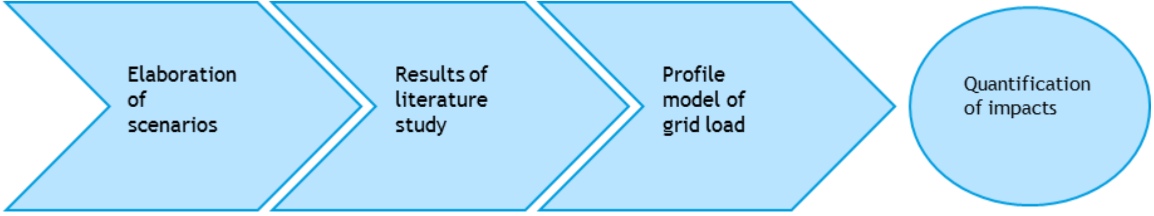
For each scenario, the following costs and benefits of implementing Smart Grids (project alternative) were then determined:

	Cost	Benefits
Direct effects	Investments in smart grids	1. Avoided grid investments
	Smart Grid operation and maintenance (O&M)	2. Avoided grid losses
	Cost on location for equipment	3. Avoided investments in central generating capacity
		4. Avoided investments in large-scale storage
		5. More efficient use of central generating capacity
		6. Additional energy savings
		7. Reduced imbalance
Indirect and external effects	Welfare losses due to shift in functional energy demand (pending)	8. External effects
		9. Welfare gains due to new services (pending)

Estimating the effects

On the basis of a literature study the potential changes in consumer behaviour with respect to usage patterns were charted with and without the support of a Smart Grid. Focus is on potential shifts in electricity consumption over time and the potential achievable energy savings. In each scenario the magnitude of these behavioural changes were then calculated using a simple profile model in which the impact on grid load and on the merit order of central capacity was determined. This is summarised in Figure 2.

Figure 2 Procedure for quantifying impacts



Behavioural changes (demand response) can occur as a result of improved usage information (feedback via home displays), tariff differentiation and remote capacity control by the grid operator for example. From the literature study it is concluded that improved usage information is an essential enabler for a Smart Grid: without appropriate information, no control. Smart meters and the demand response to which these give rise cannot therefore be allocated to the Smart Grid. In the Netherlands we do not anticipate ‘hard control’ on the part of the grid operator (user disconnection) without this being financial compensated. There will always be a 'priced in' shift via a contract. Ultimately, this is also a form of behavioural change, i.e. demand response, triggered by means of a financial incentive.

Tariff incentives can engender three kinds of behavioural change: *absolute savings* (not all peak savings are shifted to other times), *daily peak shaving* and *incidental peak shaving*. The difference between *daily* and *incidental* peak shaving is that the latter occurs at critical times of scarcity when there are strong price incentives at play, which is on only a limited number of occasions per year when demand is exceptionally high. The following table shows the magnitude of the behavioural effects as found in the literature. These can be regarded as conservative estimates[1].

Savings and shifts in consumption as percentage of peak capacity at Time of Use (TOU) and Critical Peak Pricing (CPP)

User group	Absolute savings (TOU)	Daily peak shaving (TOU)	Incidental peak shaving (CPP)
Households	4%	4%	16%
Utilities	4%	15%	30%
Industry	4%	15%	30%

Note: Only median values are presented here.

These impacts were quantified using a profile model that calculates grid loads and central capacity requirements based on stylised load profiles. These profiles were constructed for various user categories (households, utilities, industry, etc.) and types of equipment (heat pumps, electrical transport, solar panels, etc.).

Uncertainties in demand response

There are major uncertainties when it comes to how consumers and businesses will respond to tariff incentives and new Smart Grid-based services. The results reported in the literature are by no means unambiguous for all types of demand response. It is also to be queried whether results of practical trials in other countries can be translated one-on-one to the 'average Dutch consumer' and in particular to the context of the Dutch energy system (in terms of controllable capacity, for example, which in some countries are more substantial due to the share of electric heating).

It is also unclear how exactly the benefits of the system will be passed on to consumers and what tariff incentives will be needed to indeed realise the envisaged changes in behaviour (the chicken-and-egg problem). In some scenarios it is not unfeasible that tariff incentives for supply and transmission will be adversely and thus reduce the effectiveness of the envisaged demand response (high wind-power output leads to low tariffs). Since the grid operator is deemed to always have sufficient grid capacity available, these opposing incentives only have to occur several times a year during a peak event for problems to arise.

Results of cost-benefit analysis

In each of the three scenarios for the Netherlands' future energy system, the balance of costs and benefits (net present value) proves positive. In other words, this positive balance is robust for each of the energy scenarios, even a system with no substantial CO_2 reduction (BAU 2050) or with a high share of renewables (R&G 2050). For the climate scenarios the balance is considerably more positive than for the BAU 2050 scenario. This means that regardless of how the energy system develops, rolling out Smart Grids is an economically sound choice for society as a whole and represents an attractive investment.

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[1] Compare, for example, the European Climate Foundation's Roadmap 2050, in which scenarios were run to assess the impact of these investments when a figure of 20% is taken for demand-side flexibility (i.e. demand response).

The costs and benefits of the three scenarios are as follows:

NPV (€ billion)	BAU 2050	C&N 2050	R&G 2050
Benefits	€ 7.1	€ 14.1	€ 12.5
Costs	(€ 4.6)	(€ 4.6)	(€ 4.6)
Balance (benefits-costs)	€ 2.5	€ 9.5	€ 7.9
Internal interest rate	13%	28%	31%

- In all the scenarios Smart Grids yield economic benefits for society as a whole. One surprising result of this study is that Smart Grids are cost-effective not only in the scenario with substantial distributed generation of intermittent solar and wind power (R&G 2050) but also in the scenario with central generation and limited flexibility (C&N 2050). While the former (R&G 2050) was to be expected and was already forecast by the Smart Grid Taskforce, for example, the latter (C&N 2050) can be taken as a new finding. An important observation is that in a scenario with substantial central generating capacity (C&N 2050) a modest spread of capacity loads (in this case medium-voltage, MV) is attractive, particularly from the perspective of avoided investments in central capacity.
- The net gains delivered by Smart Grids are due to various benefit items, particularly the lower grid investments and of centralised generating capacity. In the R&G scenario the benefits accrue less from central capacity, but above all from avoidance of imbalance.
- The greatest grid savings occur in the MV grid.
- The benefits are due above all to direct effects and only to a very limited extent to indirect effects such as welfare impacts, reduced emissions, etc.

From the sensitivity analysis the following conclusions can be drawn:
- The savings on grid costs are due to a shift in demand in time, leading to a flatter user pattern and to absolute energy savings. This means a more favourable balance between energy volume and maximum capacity. This derives from permanent relinquishment of functional energy demand at times of high prices rather than from savings arising through improved feedback of user information due to smart meters.
- Consumer behaviour, i.e. demand response, has a substantial impact on the benefits of Smart Grids and is thus the key to unlocking the financial gains potentially available in the overall system (production, transmission and imbalance). At the same time, the tariff benefits can only be ‘passed on’ to consumers if there is also indeed greater efficiency of supply and transmission, i.e. if there are substantial systemic gains. This is a classic chicken-and-egg problem.
- The benefits accrue roughly evenly to small and medium-sized businesses (SME) and households, but with far lower costs to the former. This makes it more appealing to start with SME and only then move on to households.
- The ‘balance parameter’ used in this study reflects the degree to which local production and demand are balanced at a local level, and is thus an indicator for the remaining load that is ‘forwarded’ to a higher grid level. Although the net present value of Smart Grids remains positive when this parameter is adjusted, the sensitivity analysis indicates that the magnitude thereof has a substantial influence on the benefits. It is therefore important to gain practical experience with the magnitude of this parameter in the Pilots Smart Grids.

Conclusion

In all the scenarios, Smart Grids have a major contribution to make to creation of a future energy system. This study leads to the expectation that Smart Grids will have economic benefits for the consumer, which will ultimately translate to lower delivery prices and lower grid tariffs for consumers and industry alike. To a certain extent this means the results are robust for various trends in the development of the energy supply: with and without climate policy, with a greater or lesser amount of distributed capacity, with or without central power storage, and with greater or lesser flexibility of central capacity.

In all of this, the key element will be the demand response of consumers engendered by flexible supply and transport tariffs. This response will lead to savings on the costs of grid construction and power generation. There are considerable uncertainties in the SCBA analysis, however, including uncertainty as to the magnitude of certain cost items and the degree of demand response that will be achieved through flexible tariffs. Whether and to what extent this demand response indeed occurs is a key issue that needs to be investigated in the Pilots Smart Grids. In Phase 2 of this SCBA this uncertainty will be reduced as the results from this Pilots are factored in.

Recommendations

The results of this SCBA lead to the following policy recommendations for large-scale roll-out of Smart Grids.

Time/site-dependent tariffs an essential precondition

Economic benefits will only arise if price incentives indeed manage to engender a shift and/or savings in power consumption and if grid operators succeed in designing their grids accordingly while achieving the mandatory degree of reliability.

A revision of grid tariffs as well as supply tariffs, with a time-dependent and perhaps even site-dependent component (not every sub-grid will be heavily loaded at the same time) is an essential premise for realising the benefits, as well as for passing on the costs.

A share of the benefits will accrue to energy consumers by way of these revised tariffs, while some will accrue to third parties marketing services and products to help energy consumers shift and/or reduce consumption.

The analysis shows that Smart Grids can play a useful role in incorporating distributed generating capacity in the energy system. It cannot be concluded, though, that such capacity will be stimulated by Smart Grids, as this was not part of the study's scope.

To respond to the growing demand for electricity in all potential future scenarios, grid operators will have to expand the power grid at all voltage levels, but by adding 'smartness' this can be done with demand and maximum capacity standing in a different relationship than has been the case to date. However, grid operators will only undertake such a step if there is substantial certainty that energy consumers will indeed change their usage behaviour. It is therefore recommended to give high priority to developing the required legislation and time/site-dependent pricing to ensure that Smart Grids are indeed (cost-)effective. In the Pilots Smart Grids it is important to carefully elaborate the price incentives for the various user categories and gain an understanding of their impact. This also holds for the new services that can be marketed to energy users. Finally, the overall working of Smart Grids will need to be examined in broader detail, including the interaction between tariff incentives for transport and supply.

Who is to invest?

A Smart Grid must be 'smart' in terms of both its connections and its components. This will involve a variety of parties: energy consumers, grid operators and market parties offering consumers services and control concepts to energy users, and coordination of grid investments (grid operators) and investments in control 'behind the meter' (consumers and new service providers) are therefore essential. Such coordination is feasible in a regional approach for renovating existing housing, for example.

At what speed?

There is also a timing issue: when should (coordinated) investment be started? The Dutch power grid was constructed largely in the 1960s and '70s. Besides the capacity expansion required, then, in the period through to 2020 the grids are also up for replacement. Once laid, though, a 'thicker cable' will mean the envisaged savings are no longer feasible and it will have to once again do its job for a 50-year period, proving with hindsight to have been overdimensioned. Savings by means of a 'lighter' cable are only possible if demand response is achieved in timely fashion, i.e. before the new cable is planned. This shows that timely investment in Smart Grids (well before 2020) appears to be more urgent than recommended by the Taskforce, particularly because effective tariff differentiation aimed at achieving active consumer participation is not something that can simply be elaborated overnight.

What route?

In the sequence in which smart connections are rolled out there is also scope for further increasing the economic gains, by starting with SME, office buildings, small-scale industry and greenhouse horticulture. Particularly when it comes to medium-voltage connections there is potentially major shiftable capacity available. The literature study clearly shows that there is substantially greater financial willingness (elasticity) to shift demand in industry than households, which also implies a more favourable NPV for the former than the latter.

The full report 'Maatschappelijke kosten en baten van Intelligente Netten' is written In Dutch and downloadable on www.ce.nl > Publicaties.

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