Economic Potential of Smart Electricity Meters in Germany

ANALYSIS COMMISSIONED BY YELLO STROM GMBH

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Executive Summary

The widespread roll-out of smart electricity meters across European households is a key part of both national and EU energy policy. The latest EU electricity market directive requires Member States to introduce smart meters if the economic benefits are shown to outweigh the costs[1]. The overarching policy objective is to encourage energy efficient behaviour, and to enable consumers to become more active participants in the energy market. Subject to having the appropriate functionality, smart meters could make a significant contribution to these objectives by:

- providing consumers with immediate information about current and past energy consumption and the related costs, which makes it easier for consumers to identify potential **consumption savings**; and
- encouraging "**load shifting"** to reduce system costs at peak times by providing a mechanism to influence consumers' decisions regarding the time at which they consume electricity (for example through variable time of usage energy prices).

In addition, smart meters can potentially reduce operating costs, for example by reducing data management costs.

When assessing the costs and benefits of smart meters, we must distinguish smart meters from so-called "smart grid" solutions. "Smart grids" refers to intelligent grid control solutions, which should be assessed independently of the introduction of smart meters. [2]

However, the term "smart meter" itself is not used uniformly. Various technology options, which can have significantly different functions and effects, are broadly classed as smart meters. In general, smart meters have to fulfil certain minimum functional requirements (such as an interface to provide easy access to information) to be able to generate the benefits discussed in this report.

Governments may adopt various approaches to rolling out smart meters. For example, smart meters could be mandatory for all households, or only for a subset of households. Various technology options and communications solutions

1 The Directive requires all Member States to have carried out a full cost benefit analysis of a smart meter roll out by September 2012.

2 "Smart Grid" methods for intelligent grid control (e.g. through variable control of sub-stations etc) generate economic benefits for network operation in particular. However, these methods do not rely on the introduction of smart meters, since a particular metering solution is not essential for the centralized operation of grid components and technical devices. Further, in the context of broadly defined smart grid concepts, the benefits of smart meters are usually restricted to those described above, i.e. promoting energy-efficient behaviour, increased consumer involvement and the reduction of measurement operating costs. These are the benefits considered in this study.

could also be chosen. These choices will determine the total cost of a roll out, and are likely to result in different benefits for different types of household. A full and robust cost benefit analysis will inform the type of approach that should be chosen for a smart meter roll out.

A national roll out of smart meters in Germany would entail the replacement of approximately 40 million standard electricity meters. This would require an estimated investment of 3.8 to 5.7 billion euros (depending on meter features), as well as additional ongoing operational costs. Given the significant investment required, it is important to understand whether the expected benefits of a smart meter roll out justify these costs, and to assess which approach to the roll-out has the greatest economic benefit.

On behalf of Yello Strom GmbH, Frontier Economics investigated the economic potential of smart electricity meters for German households. This study assesses the overall economic benefit and the respective costs that would be generated by the installation of smart meters in various types of household. As part of this evaluation, the costs and benefits accruing to all relevant parties[3] were considered. In addition, we identify the minimum methodological requirements for conducting a cost benefit analysis of a smart meter roll out.

Details of the cost benefit analysis, and the results of the assessment, are presented in this report. Five broad conclusions can be drawn from our analysis and are summarised below.

Conclusion 1: The consumption structure and behaviour of private households are key to realizing the potential benefits of a smart meter and have to be accounted for in a cost-benefit analysis.

Our analysis shows that the benefits of smart meters for Germany result primarily from the associated reduction in electricity consumption in the household. Other benefits, including load shifting and reduced meter reading costs, make a comparatively small contribution to overall net benefits. The assumptions and analysis employed to determine the consumption reduction effect are therefore pivotal in determining the outcome of the cost benefit assessment.

The potential for any given household to reduce consumption is for instance dependent on:

- the size of the household;
- the functionality of the installed smart meter equipment; and
- the consumption pattern of the household.

3 Including customers, metering service providers, suppliers and, where applicable, grid operators.

The saving potential can be approximated based on the household's total electricity consumption. Our analysis shows that there is significant saving potential in Germany, particularly in households with annual consumption exceeding 3,300-3,500 kWh, and that this potential can justify the installation of a smart meter. However, this is dependent on the extent to which households are willing to participate actively and to respond to new information by reducing consumption.

The extent to which households are able and prepared to use the information provided by a smart meter is a decisive factor. As a result, cost benefit analysis based on assumptions regarding the impact of a smart meter on an average or "representative" household are insufficient. Instead, since the saving potential can vary significantly from household to household, a differentiated analysis of household's saving potential must be undertaken. This approach will utilise richer information and deliver more robust results.

Conclusion 2: Smart electricity meters have net economic benefits for a proportion of German households as the individual advantages vary significantly between households.

Our cost benefit analysis shows that the installation of smart electricity meters has net economic benefits for at most around 40% of German households (in the most favourable scenario). As described in Conclusion 1, the potential advantages that can be achieved in households with a smart meter differ considerably depending on household size and the functionality of the smart meter itself. As a result, the potential energy savings in households with low consumption, for example, do not justify the significant acquisition and maintenance costs of a smart meter.

Policy approaches which do not make the installation of smart meters mandatory for all households, but allow for selective installation in households with high potential benefits, are therefore recommended. By employing such an approach, investments could be focused on those households with a net benefit.

Our analysis shows that by adopting this kind of strategic approach, investment costs of up to 4.5 billion euros can be saved in comparison to a mandatory national introduction of smart meters. These savings could more usefully be invested in alternative methods for achieving policy objectives.

Conclusion 3: Net benefits will be maximised if households retain the freedom to decide whether to install a smart meter, and choose which technology to install

Ultimately, households themselves are best placed to identify whether the installation of a smart meter is worthwhile, and which technology option will be most effective. This is because:

- There are differences in the potential to save energy and the responsiveness to new information across different households (as described above). In addition, there are potential benefits gained through coordinating a meter installation with other activities. For example, households that have installed advanced heating systems that can interact with a smart meter may identify greater potential savings than houses with older heating systems. **Whether or not** installing a smart meter is worthwhile therefore depends on a number of heterogeneous factors – a 'one size fits all' approach is unlikely to be efficient.

- **Various technology options** are available, and the benefits from any given option are likely to depend on the individual circumstance of the household. For example, the use of an existing broadband connection for meter communications might further reduce costs, and alternative meter functionality is likely to generate different benefits for different households.

These arguments suggest that households themselves should have the **freedom to choose whether to install** a smart meter, and the **freedom to choose which technology** they prefer.

Although a uniform, nationwide introduction of smart meters is likely to entail cost savings through economies of scale, our analysis suggests such savings are not sufficient in Germany to outweigh the disadvantages of removing the individual household's freedom to choose the optimum solution. This is because installing uniform meters (so-called standard meters with similar functionality) does not fulfil the individual requirements of various households.

Further, giving customers freedom of choice regarding smart meter technology would enhance the potential for suppliers to compete for customers. Such competition generates further incentives for the technological development of smart meters, and for future innovations and cost reductions.

Conclusion 4: If smart meter installation is made mandatory, the obligation should be targeted at certain types of household, and should still allow for freedom of choice regarding technology options

Our cost benefit analysis demonstrates that, from an economic perspective, it is not appropriate for all households to be obliged to install smart electricity meters (see Conclusion 2). However, there may be political or other motivations for an enforced roll out. If an obligation is imposed, it should be aimed at those households for which we can anticipate significant benefits arising from a smart meter installation. For example, our analysis demonstrates that annual overall consumption could serve as a suitable criterion for identifying relevant households, since the potential benefits of installation outweigh the costs for such households. A targeted obligation can minimize the potential inefficiencies that result from a more widespread, mandatory installation.

However, should a targeted approach be taken, it cannot be expected that all participating households will achieve their full theoretical saving potential. Despite the obligation to install the smart meters, there is no guarantee that households will respond to new information. This fact reinforces Conclusion 3, since allowing freedom of choice regarding the meter technology installed allows households to identify and choose the technology that has the biggest impact for them.

Conclusion 5:If households can voluntarily install smart meters, the cost of reducing consumption by one kilowatt hour is significantly lower than in a mandatory nationwide installation scenario.

Since the saving potential varies considerably for all households, the energy savings achieved by installing a smart meter fluctuate significantly across households. Even if it was assumed that smart meters guaranteed energy savings, the ratio of required costs to the energy savings achieved is considerably less favourable for households with a lower saving potential than for households with a high saving potential.

Compared to a voluntary approach, additional energy savings can be generated with an obligatory nationwide installation of smart meters. However, the cost of a national roll out rise disproportionately to the energy saved. Our analysis suggests that the investment costs required to save one kilowatt hour of electricity per year under a voluntary roll out in Germany amount to only 0.30 € / kWh. If a national mandatory roll out is chosen, the average cost per kWh saved would be more than four times greater. The estimated savings associated with foregoing an obligatory installation amount to approximately 4.5 billion euros. This funding could be more effectively invested in alternative energy conservation measures.

1 Subject and approach of the study

1.1 Background and task

The widespread roll-out of smart electricity meters across European households is a key part of both national and EU energy policy. The latest EU electricity market directive requires Member States to introduce smart meters if the economic benefits are shown to outweigh the costs. The overarching policy objective is to encourage energy efficient behaviour, and to enable consumers to become more active participants in the energy market. Subject to having the appropriate functionality, smart meters could make a significant contribution to these objectives.

Governments may adopt various approaches to rolling out smart meters. For example, smart meters could be mandatory for all households, or only for a subset of households. Various technology options and communications solutions could also be chosen. These choices will determine the total cost of a roll out, and are likely to result in different benefits for different types of household. A full and robust cost benefit analysis will inform the type of approach that should be chosen for a smart meter roll out.

A national roll out of smart meters in Germany would entail the replacement of approximately 40 million standard, or "dumb", electricity meters. This would require an estimated investment of 3.8 to 5.7 billion euros (depending on meter features), as well as additional ongoing operating costs. Given the significant investment required, it is important to understand whether the expected benefits of a smart meter roll out justify these costs, and to assess which approach to the roll-out has the greatest economic benefits[4].

On behalf of Yello Strom GmbH, Frontier Economics investigated the economic potential of smart electricity meters in German households. This study assesses the overall economic benefits and the respective costs that would be generated by the installation of smart meters in various types of household. In addition, we identify the minimum methodological requirements for conducting a cost benefit analyses of a smart meter roll out.

This short report summarizes the main results of the analysis.

4 The latest EU electricity market Directive requires all Member States to have carried out a full cost benefit analysis of a smart meter roll out by September 2012.

1.2 Our method

The results presented in this report are based on a cost benefit analysis of the introduction of smart meters for German households. Below we outline:

- the basic modelling methodology;
- the framework we adopted for assessing the costs and benefits of smart meters; and
- the smart meter roll out scenarios we have modelled.

1.2.1 Basic modelling methodology

Our basic approach is to model costs and benefits for combinations of different types of household and different meter technologies. Differentiating customer types and types of smart meter enables us to identify the most suitable meter types for each household.

We differentiate households along the lines of:

- **Annual electricity consumption** – we estimate household consumption characteristics based on living space or the number of occupants.

- **Specific consumption patterns due to specific electricity uses** – households with special consumption patterns, e.g. storage heaters or heat pumps, are modelled separately.

- **Acceptance of meters and household motivation** – we consider indicative differences in the degree to which households accept or engage with a smart meter and respond to the information it provides. This allows us to model the fact that not all electricity customers use the functions of smart electricity meters to the same extent. Customers that voluntarily install a smart meter are more likely to use the information it provides to alter their consumption behaviour. In contrast, those customers who are obliged to install a smart meter might be less inclined to use it, or to respond to the information it provides.

Altogether more than 200 different types of household were identified in our cost benefit analysis. For each type of household we can then investigate:

- whether the installation of smart electricity meters is worthwhile; and
- which type of smart meter installation and technology has the greatest net benefit.

We are then able to perform detailed, disaggregated analysis of the distribution of costs and benefits over the various types of household in Germany. Compared to an assessment using more general assumptions and average values, the richness of this disaggregated assessment allows for more robust conclusions.

In reality, a variety of other different criteria for households can be observed and are likely to be relevant for assessing the costs and benefits of a smart meter. Although further differentiation across types of household is impractical, the fact that differentiation is likely to be relevant for a cost benefit analysis emphasises the importance of accounting for the heterogeneity of households in the modelling.

Within our analysis, various technology options for fitting households with smart meters were also considered. These technology options involve combinations of:

- different **basic technology and functions** of the meter - for example EDL-21 vs. EDL-40;
- different **communication connection** used - for example connecting through a power line vs. a broadband connection; and
- possible **special models** – for example integration of meter functionality with other systems and devices in the home.

The differentiation of customer types on the one hand and types of smart electricity meters on the other hand enables us to identify the most suitable meters types for each household. Our analysis demonstrates that any given type of meter can have different costs and benefits for different customers (for example, depending on whether a broadband connection is already available).

1.2.2 The cost/benefit framework

To assess the merits of various approaches and strategies for a smart meter roll out, the economic costs have to be compared with the economic benefits. This requires us to understand what the costs and benefits are, and to incorporate these appropriately into the model. We consider the following benefits and costs for the purposes of our analysis.

- The **benefits** associated with introducing smart meters include;
  - benefits from energy savings induced by the use of smart meters;
  - benefits generated by a shift in energy demand from periods with high electricity demand and thus higher system load (peak load) to periods with lower load (off-peak); and
  - other operational benefits, e.g. from simplified meter reading and communication with customers.

- the **costs** which result from converting to smart meters in comparison to retaining the current mechanical "dumb" meters:[5]
  - Costs of procuring an electricity meter including installation costs (capital expenditure);
  - ongoing costs for communication and maintenance of a smart meter, and possible additional support costs for customers with smart meters (operating costs).

Cost and benefit outcomes for all relevant participants can be aggregated to understand the overall impact of a given policy approach. The relevant participants for the purposes of our model are customers, metering service providers and suppliers. Grid operators are typically only affected by smart meters (and accordingly taken into account) to the extent to which they are active as meter operators or metering service providers.[6]

We investigate aggregate costs and benefits on an annual basis - i.e. we assess annual operating costs and annualised capital costs for the meter and communication infrastructure. Further, we simplifying assume that the installation of the meters occurs at once (rather than being stretched over a longer period of time).

1.2.3 Scenarios

Within the framework set out above, we evaluate six different scenarios for the introduction of smart electricity meters in German households. The six scenarios can be grouped under two headings – scenarios where smart meters are installed across the whole nation, and scenarios where there is a partial installation of smart meters in German households (and therefore continued long-term operation of conventional meters in households without smart meters). The three scenarios under each of these headings are described below:

- Scenarios with **nationwide distribution** of smart meters:
  - **Mandatory rollout - EDL 40 (scenario 1):** Nationwide installation of a uniform smart electricity meter for all households. The mandated

5 Note, we do not account for "stranded" investments in our cost benefit analysis (i.e. we do not assess the economic value of "dumb" meters that are not yet fully depreciated).

6 A distinction must be made between smart meters and so-called "smart grid" solutions, which refer to intelligent grid control (e.g. through variable control of sub-stations etc.). Smart grids are associated with economic effects for the grid operator. However, smart grid solutions do not rely on the introduction of smart meters, since a particular metering technique is not essential for the centralized operation of grid components and technical devices. Insofar as smart meters can generate an economic benefit through customer participation as part of smart grid concepts, these effects are already accounted for in our generic methodology.

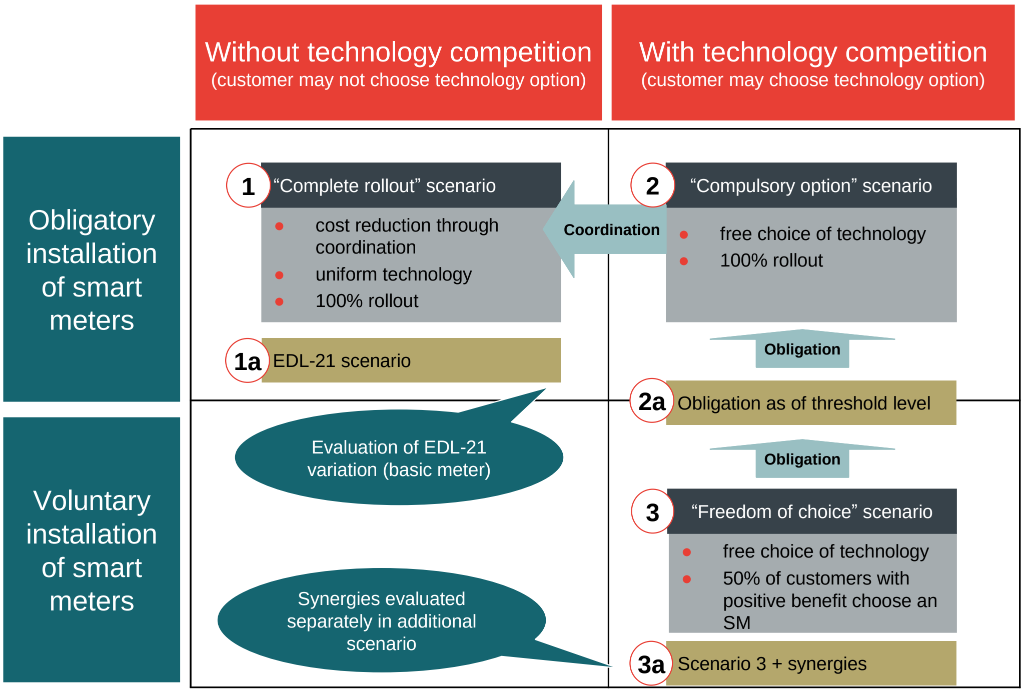
uniform technology is the "EDL 40" compatible meter with data transfer via the electricity grid (i.e. power line), which in our model offers the greatest overall benefit.

- **Mandatory rollout - EDL 21 (scenario 1a):** Nationwide installation of a basic "EDL-21" meter, the simplest and most affordable meter that is recognized as a smart electricity meter by the German regulator.
- **Compulsory option (scenario 2):** Obligatory installation of a smart electricity meter for all households while having the freedom to choose the type of meter.

- Scenarios with **partial distribution** of smart meters:
  - **Freedom of choice - without synergies (scenario 3):** Free choice for all households whether to install a smart meter, and if so what type.
  - **Freedom of choice - with synergies (scenario 3a):** Free choice for all households whether to install a smart meter, and if so what type. Additionally, the possibilities for reduced (installation) costs were analyzed based on synergy potential, e.g. if the installation of the meter occurs as part of other measures which would be taking place regardless of whether a smart meter is installed.
  - **Compulsory option over 5,000 kWh (scenario 2a):** Obligation for all households with an annual electricity consumption of over 5,000 kWh to install a smart electricity meter (with freedom of choice for technology options), while all other households may opt to have a meter installed or not.

Figure 1 provides a schematic overview of the six scenarios.

Figure 1. Schematic overview of scenarios



Source: Frontier

1.2.4 Methodical procedure

As outlined in section 1.2.1, we base our analysis on a disaggregated assessment of individual, differentiated households. Our process followed three stages:

- **First we place all German households into different categories** – The objective of our analysis is to determine the economic potential of smart meters in the household sector. In the first step, we categorize the approx. 40 million German households in accordance with the different features that are relevant for our model (e.g. size, consumption behaviour, affinity to using smart meters, see section 1.2.1).

- **We then calculate individual costs and benefits for each household type** – For each type of household identified, we analyse:
  - the benefits generated by a given type of smart meter[7];
  - the costs associated with the installation of a given type of meter[7]; and

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[7] Note: although our analysis is focussed on households, we consider all cost and benefit aspects of the installation of a smart meter, regardless of which participant these relate to.

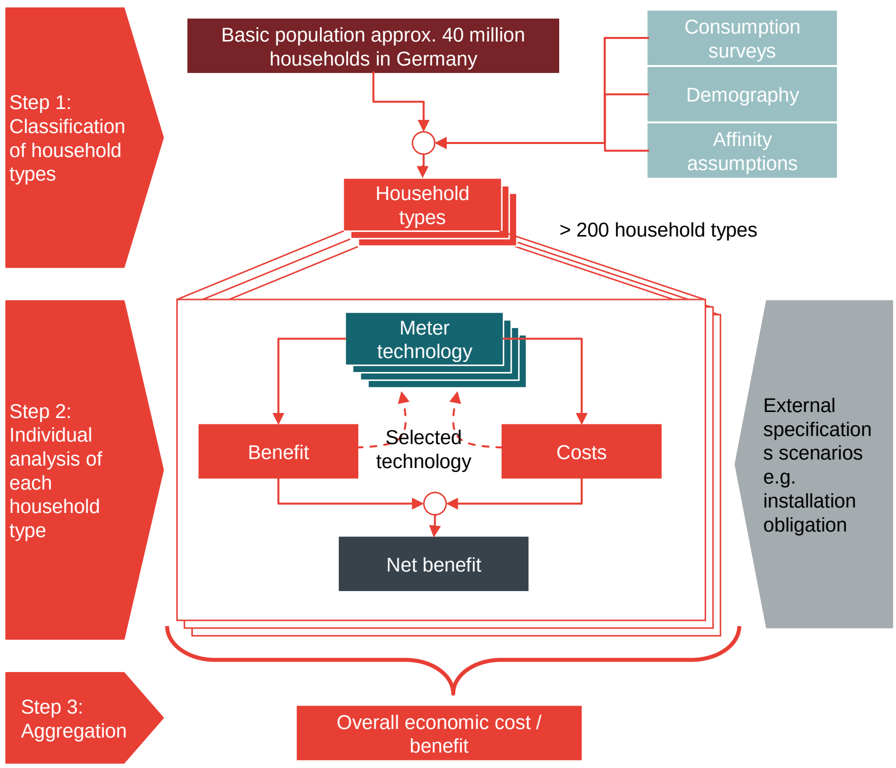
- the preferred technology option for the household, subject to restrictions determined in the scenario (i.e. in a partial roll-out scenario, households can also decide against installing a smart meter).

  Using this analysis we identify the net effect of a smart meter installation for each household (i.e. 'positive' if the benefit outweighs costs; 'negative' if the costs outweigh benefit; 'neutral' if no smart meter is installed or costs and benefits are balanced).

- **Finally, we aggregate the individual results to obtain an estimate of the total net impact** – the estimated impact of a smart meter for each type of household is multiplied by the total number of households of that type in Germany to understand the overall impact of a given policy approach. We calculate the aggregate net benefits, total energy savings etc. of different policy approaches and different smart meter technologies.

Figure 2 provides a schematic overview of our approach.

Figure 2. Schematic procedure



Source: Frontier Economics.

Using these calculations we can make statements regarding the overall effects for Germany of a smart meter roll out under the six different scenarios. We can also assess the distribution of effects across sectors of the population. As we demonstrate in this report, distributional effects are particularly significant for the discussion of economic potential.

1.3 Structure of this report

Five main conclusions can be drawn from our cost benefit analysis, and are set out in turn in the remainder of this report:

1. The consumption structure and behaviour of households determine the benefits of smart meters (section 2);
2. Smart electricity meters only have net economic benefits for a proportion of German households (section 3);
3. Net benefits will be maximised if households retain the freedom to decide whether to install a smart meter, and choose which technology to install (section 4);
4. If smart meter installation is made mandatory, the obligation should be targeted at certain types of household, (section 5);
5. A mandatory nationwide roll out of smart meters does not deliver environmental policy objectives in the most efficient way (section 6).

2 Consumption structure and behaviour of households determine the benefits of smart meters

In this section, we discuss the main advantages of smart meters. We demonstrate that the most important economic benefits of smart meters are driven by their impact on reduced energy consumption. We then outline the implications of these results for undertaking a cost benefit analysis, noting in particular that individual consumption behaviour must be modelled appropriately to achieve robust results.

2.1 Consumption behaviour differs considerably between households

The combined electricity consumption of all German households was approximately 139 TWh in 2009[8]. The household sector was therefore responsible for around a third of total annual electricity consumption in Germany. On average, each household consumes around 3,500 kWh of electricity per annum.

However, this average annual consumption masks important variations in consumption behaviour across German households. For example, differences can be observed along the following dimensions:

- **Annual household electricity consumption** – Electricity consumption fluctuates significantly between households depending on the household size, living space, installed electrical appliances, etc.

- **Specific consumption patterns due to particular electricity use** – Households with special electricity consuming appliances, e.g. storage heaters or heat pumps, also have particular consumption patterns (temperature dependency, consumption in certain time periods etc.).

- **Motivation to conserve energy** – Customers generally have varying levels of motivation or desire to take energy conserving measures and reduce energy consumption. In addition, consumption reductions typically require investments that not all customers are able to afford.

The level of household consumption linked with each prospective smart meter is therefore extremely varied. As a result, the potential for any given smart meter

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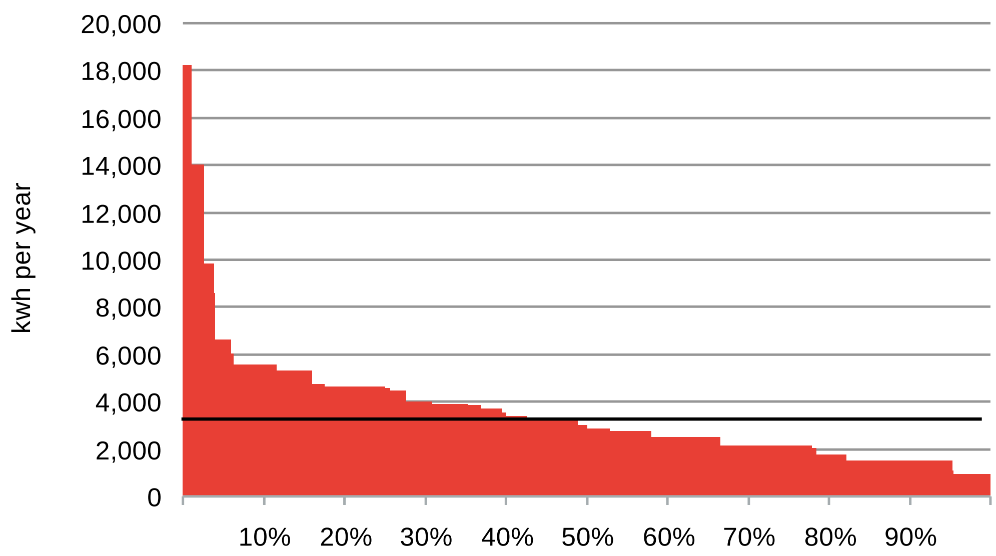
8 Arbeitskreis Energiebilanzen 2009.

installation to reduce energy consumption also varies depending on which household the meter is installed in. A cost benefit analysis which factors in this consideration by modelling heterogeneity explicitly will therefore produce richer and more robust results than an assessment based on average consumption values. We therefore analyse the distribution of consumption across the entire household sector, and incorporate this information into our cost benefit model.

Detailed electricity consumption data disaggregated by type of household is not available. However, a good proxy for the distribution of consumption levels across households can be obtained by combining demographic data regarding household size and living space with assumptions about electricity usage (e.g. for heating purposes).

An indicative estimated distribution of consumption patterns across household types, calculated in this way, forms the basis for our analysis. **Figure 3** shows that, given our assumptions, 60% of households actually consume less electricity than the average of 3,500 kWh per year.

Figure 3. Distribution of energy consumption across households in Germany



Source: Frontier Economics

2.2 Key advantages of smart electricity meters

The vast majority of the economic benefit of smart meters is generated by three areas which were analysed separately:

- **Incentives for reducing consumption** – Smart meters offer the opportunity to provide end users with immediate and clear feedback about

Consumption structure and behaviour of households determine the benefits of smart meters

current electricity consumption, and the associated costs. It is expected that customers will use this information to consume electricity more efficiently, and that overall energy consumption reductions can be achieved.[9]

- **Incentives for shifting consumption** – Through facilitating load- and time-variable tariffs, smart meters offer households incentives to strategically shift electricity consumption to those times where electricity is less costly to produce. Smart meters therefore deliver benefits through more efficient use of electricity generation capacity. Further, although electricity generation increasingly utilises renewable energy sources, load-shifting potentially reduces total system emissions.[10]

- **Other operational savings** – Through remote collection of data, smart meters are likely to generate savings by reducing meter reading and invoicing costs. However, smart meters potentially also entail additional operational expenses, e.g. due to increased requirement for customer support.

In **Figure 4**, the scale of the anticipated annual benefit of smart meters is compared for three example household sizes and scenarios. It is clear that energy savings drive the majority of the economic benefit of smart meters, accounting for approximately 50-54% of the overall benefit for these example households. The potential economic benefit of smart meters therefore results primarily from energy saving potential of each individual household.

Load shifting, on the other hand, contributes a lower percentage (33-37%) of the total benefit of smart meters. This is due to the relatively low potential for load shifting in households. Some large household appliances (washing machines, dishwashers etc.) offer consumption volumes which can in principle be shifted to a different time of the day. However, most components of household consumption (cooking, lighting etc.) cannot be shifted in this way, since they are always required at specific times in the day. As such, only a small proportion of household consumption can potentially deliver load shifting benefits.

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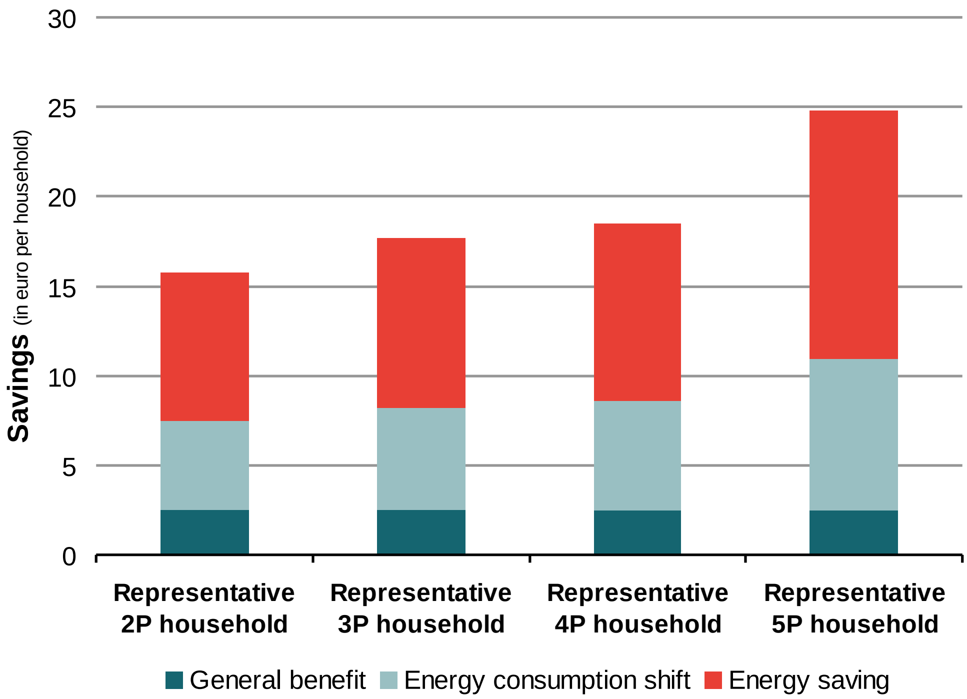
9 There are as yet not any reliable international figures available which enable a conclusion to be drawn regarding the saving potential in Germany. For the purposes of our analyses we use a value of 3%, which is at the top end of the figures used in various other studies (compare e.g. Senter Novem on behalf of ESMA, 2008, Report on Effective Customer Feedback Mechanisms Deliverable 6, Workpackage 2, Tasks 2 and 3.).

10 We estimate the total shift potential of households based on standard load profiles and evaluate the benefit based on the time-related price differences on the wholesale electricity market.

Consumption structure and behaviour of households determine the benefits of smart meters

Figure 4. Monetary annual benefit of smart meters for example households



Source: Frontier Economics

2.3 Individual consumption behaviour must be considered in cost benefit analysis

Figure 4 shows that the saving potential of individual households varies significantly. We might characterise two types of saving potential for a household:

- the **objective** saving potential; and
- the individual/**subjective** saving potential.

The **objective potential** depends on the customers' consumption structure, reflecting the household's size, devices and consumption pattern. As outlined in Section 2.1, electricity consumption, and hence the objective potential for consumption reduction, varies considerably between German households.

The energy saving potential also depends on the extent to which a household is prepared to alter their consumption behaviour in response to incentives to conserve energy (e.g. new price information provided by a smart meter). This **subjective possibility** is difficult to quantify accurately without detailed empirical analysis. However, when performing a cost benefit analysis this effect

Consumption structure and behaviour of households determine the benefits of smart meters

should be modelled, which requires an evaluation of individual households on a differentiated basis.[11]

Our analysis demonstrates the strong influence of individual household characteristics on the benefits that a household can anticipate from installing a smart meter. An assessment of the energy savings of a "representative household" is therefore likely to result in distorted conclusions.[12]

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11 We base our analysis on appropriate assumptions which provide an indication for the required differentiation. However, the subjective assumptions underlying the core conclusions in this report are not critical to the conclusions (i.e. differentiation of households based on the objective saving potential alone is sufficient to derive the results presented here).

12 As demonstrated in Section 2.1, assessments using national averages are unsuitable because the individual households are not necessarily symmetrically distributed around the mean. For example, even if it can be proved that a solution for households with average consumption would be beneficial, our analysis shows that in reality that is only applicable to less than 43% of households.

3 Smart meters only have net economic benefits for a proportion of German households

In this section we demonstrate that due to the variation in benefits of smart meters, the net benefits (i.e. benefits less costs) also fluctuate significantly for different households. The results of the six scenarios analyzed e.g. suggest that the installation of a smart meter is not worthwhile in many small households (i.e. the costs are higher than the potential benefits). As a result, government strategies which allow for the selective installation of meters are preferable to mandatory nationwide approaches.

3.1 There are households with negative net benefits in all scenarios

In Section 2 we demonstrated that the benefit of smart meters varies considerably between households. Households with high electricity consumption profit from smart electricity meters because they achieve greater consumption savings (in absolute terms) and can therefore reduce costs more than smaller consumers. At the same time, the procurement and maintenance costs of a smart meter are relatively similar for all households.[13] Ultimately, differentiating households allows us to identify, in all analyzed scenarios, those households for which a smart meter is not worthwhile because the costs are higher than the potential benefit.

We investigated six scenarios (see section 1.2.3) for the introduction of smart meters in German households, including three scenarios based on an obligatory nationwide roll out. **Figure 5** presents an example of the net benefits (i.e. the benefits after deducting installation and operational costs) per household in the "Mandatory rollout EDL 40" scenario (where all German households are obliged to have an EDL 40 meter installed[14]). The green area indicates those households for which the benefits would exceed the costs in this scenario. Net benefits are only positive in around 15% of households.[15] The red areas in **Figure 5** represent

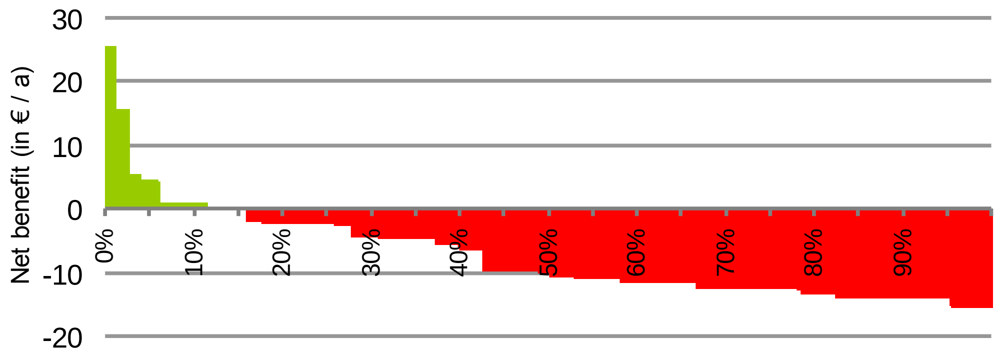
13 In section 4 we investigate possible differences in these costs, although these do not influence this basic consideration.

14 The smart EDL 40 Powerline electricity meter uses the electricity grid for the purposes of transferring data. In our model, this meter proved to be the most beneficial option for nationwide installation.

15 This result is reached despite the assumption that the costs per installed meter are reduced through the economies of scale associated with nationwide installation.

the net loss in those households that are obliged to have a smart meter installed even though the expected advantages do not justify installation costs.

Figure 5. Distribution of the net benefit of obligatory installation of a smart meter (EDL40, Powerline).



Source: Frontier Economics.

This basic result is found in all three of the analyzed scenarios in which smart meters are mandated for all German households. These unfavourable net benefits reflect the fact that smart meters are only economically beneficial for a small proportion of households - at most around 43% of private households in Germany, depending on the scenario.

3.2 Selective introduction strategies for smart meters in Germany are advantageous

We also investigated scenarios which posit the selective installation of smart meters in only a proportion of households (see section 4 for more information about selective installation). **Table 1** compares key results for the various scenarios.

Smart meters only have net economic benefits for a proportion of German households

Table 1. Key results of various scenarios

Scenario	1	1a	2	3	3a	2a
	Nationwide Rollout		Compulsory option	Freedom of choice		Compulsory option
	EDL 40	EDL 21		No synergies	With synergies	over 5,000 kWh
Proportion of households with smart meters	100%	100%	100%	20%	21%	28%
Fixed capital (in € millions)	5,648	2,824	4,459	1,050	1,064	1,464
Net benefit (in € millions / a)	-251	-207	-218	71	73	55
Average benefit per household with smart meter (€ / a)	-6.23	-5.13	-5.41	8.70	8.73	4.81
Energy conserved in all households (in million kWh / a)	4,625	2,098	4,891	3,210	3,264	3,554
Average energy conserved per household with smart meter (in kWh / a)	115	52	121	394	391	312

Source: Frontier Economics

In contrast to those scenarios with national installation of smart meters, a selective procedure, i.e. the installation of smart meters only in households with a high benefit, can generate considerable economic advantages, including:

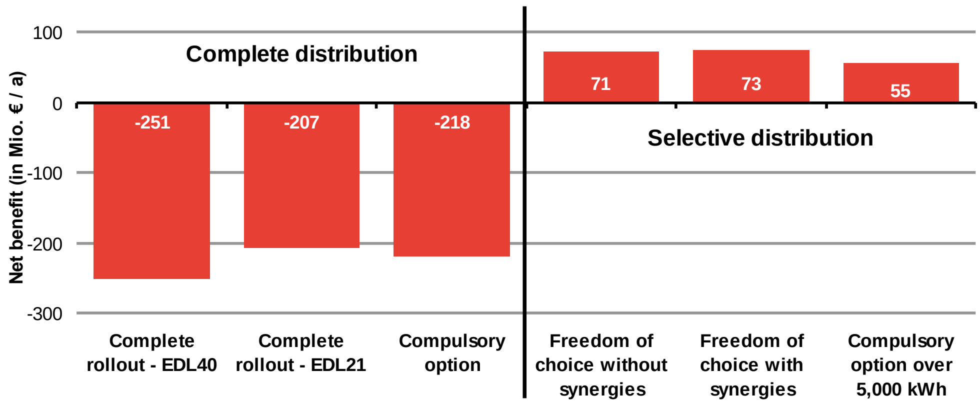
- **Significantly higher benefit to cost ratio** – In our analysis, only those scenarios with a selective procedure have net benefits. Mandatory national roll outs always result in a negative net benefit, ranging from -207 million €/annum to -251 million €/annum. Scenarios which allow households to selectively install smart meters lead to a positive net benefit of between 55 million €/annum and 73 million €/annum.

Smart meters only have net economic benefits for a proportion of German households

- **Significantly lower capital expenditure** – Our analysis shows that by using a selective approach, investment costs of up to 4.5 billion euros can be saved in comparison to a national roll out of smart meters.

The potential benefits of a nationwide installation of smart meters, for example cost reductions (per unit) resulting from a coordinated procedure for all customers, are taken into consideration in these results. These positive efficiency effects do not reduce costs sufficiently far to result in positive net benefits for customers who only have small potential benefits from installing a smart meter.

Figure 6. Net benefits of selective and compulsory installation of smart electricity meters



Source: Frontier Economics.

From an aggregate perspective, methods which do not insist on an extensive obligation for households to install smart meters and allow for selective installation only in households with a high benefit from smart meters are, in general, recommended. By employing such an approach, the investment required to roll out smart meters more widely could be focused on those households with positive net benefits.

Smart meters only have net economic benefits for a proportion of German households

4 Net benefits will be maximised if households retain the freedom to decide

In the previous sections we have demonstrated that the benefit of a smart meter roll out depends on consumption patterns, and the individual willingness of a household to alter its consumption behaviour. In this section we show that the best meter technology option also depends on the individual characteristics of each household. Our cost benefit analysis demonstrates that customers should retain the freedom to choose both whether to install a smart meter, and if so which technology to install.

4.1 Free technology choice can generate additional benefits

Households have two potential dimensions of choice with respect to smart meters:

- whether to install a smart electricity meter or not; and
- which smart meter technology to install.

As described in sections 2 and 3, scenarios where consumers have freedom to choose whether or not to install a smart meter are advantageous because smart meters do not have net economic benefits for all types of household.

In addition, there are already numerous smart meter variations and technology options available which differ with regard to their functionality (e.g. their ability to interact with other household appliances or the method of communication). The procurement and installation costs for these technology options also vary. Different technology options therefore entail different costs and benefits for different households. Examples of this effect include:

- **Benefits from additional application options** – Extended application options, such as the integration of a smart meter in automated household appliances, additional displays in the household, or links with "smart phones", can increase the benefit for some customers, but are unlikely to be beneficial for all customers. Enforcing standardized equipment specifications therefore inevitably leads to missed opportunities for energy saving benefits for some customers, and unnecessarily high costs for other customers.

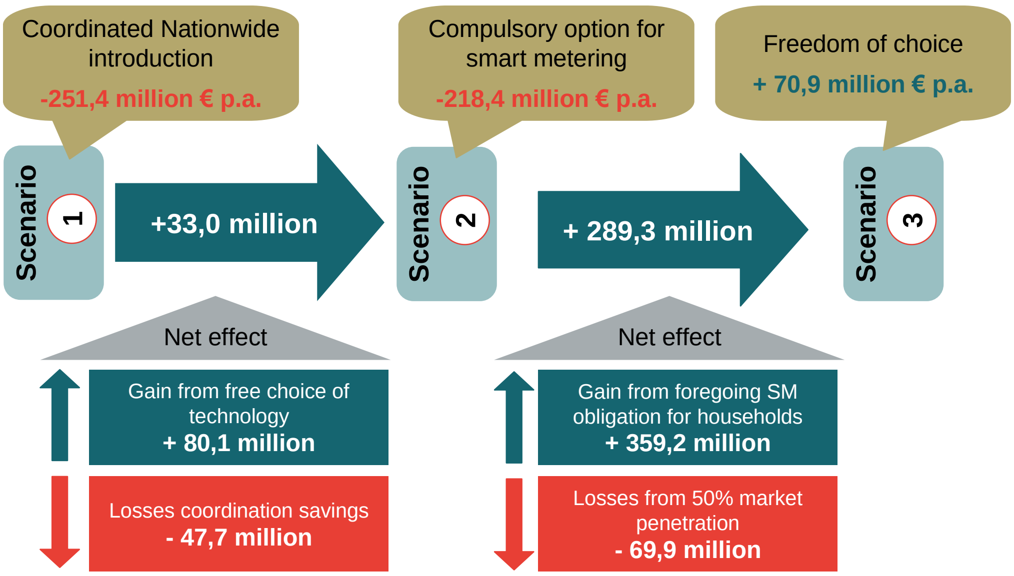
- **Lower costs due to synergy effects** – If customers are allowed free choice over smart meter technology options, customers can potentially take advantage of synergies which make the installation of smart meters more cost effective. This is particularly relevant for the communication connection technology used for smart meters. It is often possible to utilize an existing broadband connection for meter data transfer, and thereby save the costs of installing a special communication channel. With a uniform, mandatory communications technology, these potential synergies are missed.

Given this heterogeneity in costs and benefits across households, a 'one-size-fits-all' technology solution is unlikely to maximise the net benefits of smart meters. It might be argued that a uniform roll out of a single technology could be associated with economies of scale, which would be lost were customers allowed to make heterogeneous choices of technology. However, the market for smart electricity meters is increasingly international, and as such we would assume that economies of scale can be achieved regardless of the policy approach in this regard.

4.2 Indicative value of freedom of choice

The scenarios analyzed enable us to estimate the value of both dimensions of customer choice. **Figure 7** compares the results of selected scenarios.

Figure 7. Merit of freedom of choice



Source: Frontier Economics

Three basic scenarios can be determined from the combination of the two freedom of choice dimensions:

- **No freedom of choice** – a nationwide obligation to install a uniform technology precludes freedom of choice for households along either dimension. Our analysis suggests that a nationwide installation of uniform

Net benefits will be maximised if households retain the freedom to decide smart meters would enable installation cost reductions of approximately 48 million euro per annum through economies of scale. However, these advantages would be cancelled out by the negative net benefits associated with installing smart meters in households which cannot achieve significant energy consumption reductions or load shifting. Overall, this scenario represents a poor outcome in our analysis.

- **Pure technological freedom of choice** – A scenario which plans the extension of the current obligation to install a smart meter from the exceptional cases (new build, renovation) to all households is conceivable. In this scenario, households would have no choice as to **whether** a smart meter is installed, but they could select the most appropriate technology. Our analysis shows that, although the cost reductions associated with a uniform and coordinated installation would be lost, this would be more than compensated for by the advantages associated with technology choices which maximise the impact of a smart meter for each type of household. This scenario therefore represents a better overall net benefit outcome than scenarios without freedom of choice for technology options. However, since all households are obliged to install a smart meter the total annual balance remains negative (-218 million €/annum).

- **Complete freedom of choice for households** – The highest net benefits in our analysis are generated by those scenarios in which households are granted complete freedom of choice. These scenarios benefit from the fact that due to the significant heterogeneity across households, individual households are best placed to decide whether a smart meter is worthwhile and which technology option will deliver the greatest benefit. In this scenario, no investment is made in smart meters that are not economically viable. The result is a total net benefit of 71 million €/annum.

The results of our static evaluation already demonstrate that freedom of choice would represent a significant economic advantage. Further, our assessment has not accounted for the likelihood that freedom of choice would have positive effects for supplier and technology competition which would enhance the degree of innovation and technological development in smart metering. Based on current information, a reliable quantification of this effect is not possible as part of this analysis.

Net benefits will be maximised if households retain the freedom to decide

5 If smart meter installation is made mandatory, the obligation should be targeted

As described above, scenarios in which German households are obliged to install smart meters have negative net benefits (see section 3). Below we analyze whether an obligation which targets specific types of household delivers higher net benefits than a national roll out.

5.1 Annual consumption as example limitation criterion

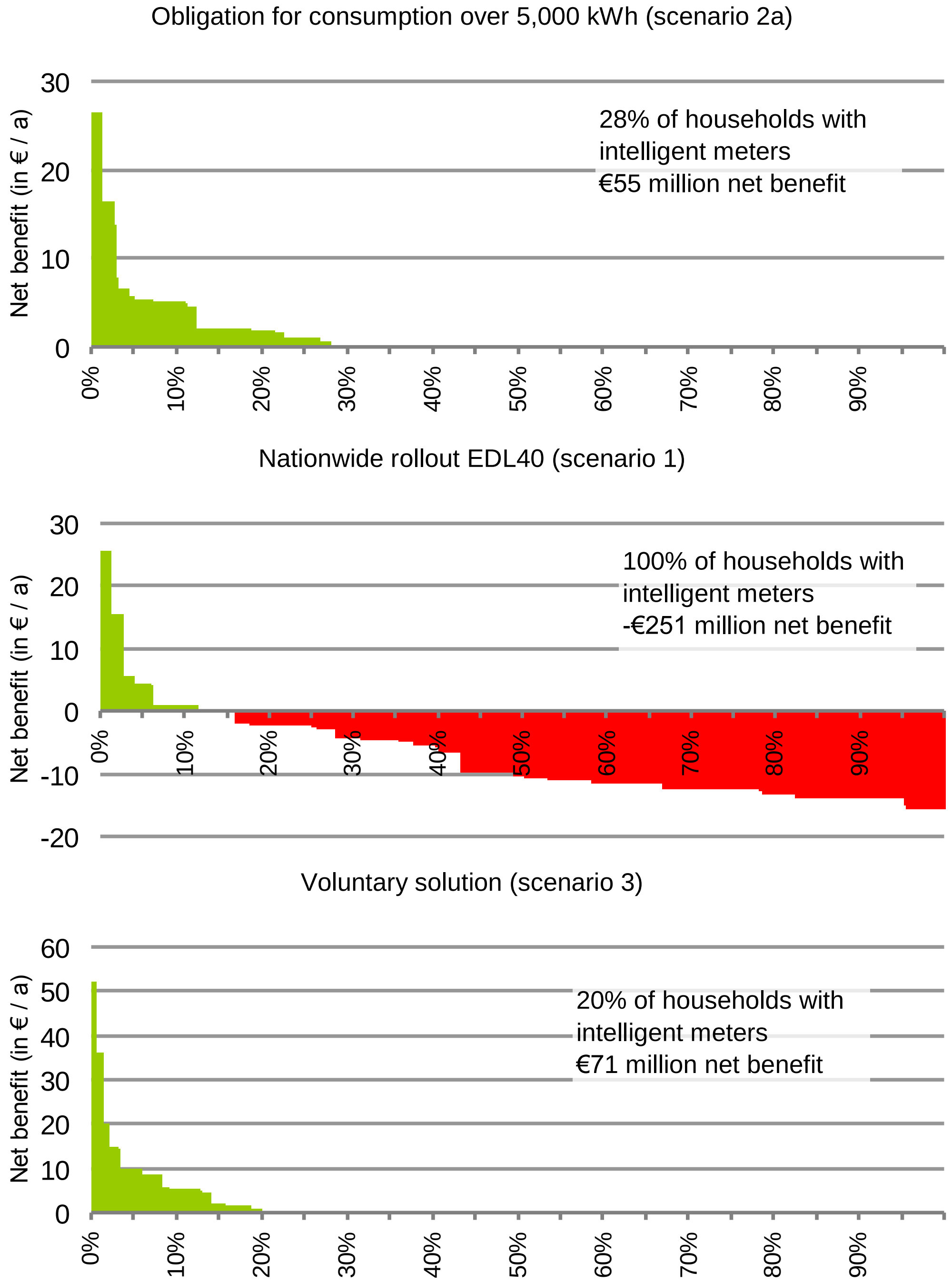
As demonstrated in section 4, smart meters have the greatest net benefits for households with high electricity consumption. In principle, annual household consumption is an indicator of the saving potential of a household. [16]

The largest 10% of households account for 47% of overall demand in the household sector. We therefore analysed a scenario in which households with an annual energy consumption of over 5,000 kWh are obliged to install a smart meter (with no restriction on the meter type).[17] We model all other households as free to choose whether to install a smart meter, and if so which type. The results are presented in **Figure 8**, in comparison with a nationwide roll out scenario and a fully voluntary scenario.

16 Although we note that energy consumption is only an *indication* of the objective saving potential, and does not represent a household's actual willingness to reduce consumption. Further, we have not considered the extent to which households have already implemented energy efficiency measures.

17 In practice, implementing this type of obligation would be problematic because actual annual consumption could be influenced by additional meters, connection variations etc.

Figure 8. Comparison of benefit distribution of various scenarios



Source: Frontier Economics

If smart meter installation is made mandatory, the obligation should be targeted

5.2 Target-oriented obligation more advantageous than nationwide

Figure 8 shows that a targeted approach has greater net benefits than an obligatory national roll out. Similar levels of benefit are achieved for households in both scenarios[18] (green areas equally large or larger), but, unlike a national roll out, a targeted scenario does not involve the installation of meters that are not economically viable (red area). A targeted obligation therefore delivers higher net benefits, and would be preferable to a national approach.

Figure 8 also shows that smart meters are installed in a greater number of households under a targeted approach in comparison to a fully voluntary roll out[19]. However, it can be assumed that a smart meter is more likely to impact consumption in households which voluntarily install the meter (i.e., on average the share of theoretical saving potential that is actually realised is higher in households which choose to install a smart meter). Our analysis therefore suggests that the total net benefit of a targeted obligation is lower than that generated by a fully voluntary roll out.

An obligation to install smart meters may be deemed preferable for non-economic (e.g. political) reasons. Should the German government choose a mandatory approach, our analysis shows that this should be restricted to those households where there is a reasonable expectation that the installation will have net benefits. However, a targeted approach would require appropriate criteria to be defined to identify those households which would be obliged to install a smart meter.[20]

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18 Note: a scenario with free technology choice generates greater benefit than a uniform installation procedure (see section 4).

19 This depends on the assumption that households with an annual energy consumption of over 5,000 kWh have smart meters installed in a targeted scenario.

20 For example, we doubt that the current partial obligation for new buildings to install smart meters, as stipulated in the EnWG §21b, is an economically sensible criterion.

If smart meter installation is made mandatory, the obligation should be targeted

6 A mandatory nationwide roll out of smart meters does not deliver environmental policy objectives in the most efficient way

Our analysis shows that it does not make economic sense to introduce smart meters on a nationwide basis in Germany. However, support for a national roll out is often based on environmental policy rather than on economics. In other words, it is considered that the overwhelming policy objective is to induce significant energy savings, and smart meters are considered an effective way of doing this.

As well as having negative net benefits, we do not consider a national roll out of smart meters to be the most cost-effective way to achieve the overriding policy objective of energy efficiency. This section outlines two arguments:

- the cost per kWh of energy saved for a national roll out of smart meters is significant; and
- the capital investment required for a nationwide introduction of smart meters could be more effectively invested in alternative energy efficiency measures.

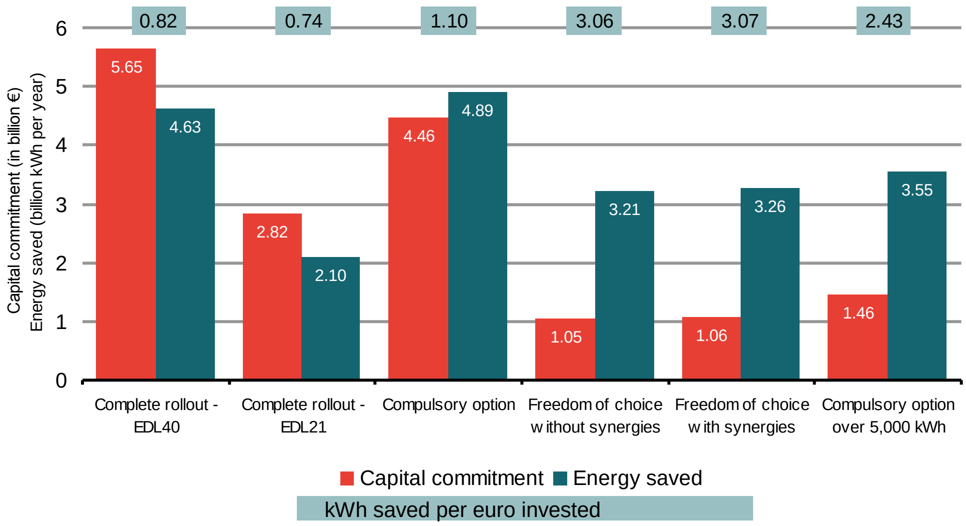
We would therefore recommend a fuller evaluation of alternative measures to a nationwide introduction of smart meters to achieve the environmental policy objective.

6.1 High capital commitment per kWh saved

Figure 9 compares the energy savings realised through a smart meter roll out with the respective investment required in each of our scenarios. With the exception of a nationwide installation of the simple smart meter EDL21, obligatory installations result in higher total energy savings than voluntary installation scenarios.

However, greater energy savings come at a high price. Capital investments of between 4.5 and 5.6 billion euro would be required for a nationwide installation of smart meters. This investment would deliver energy savings of between 4.6 and 4.9 billion kWh/annum. In contrast, the required investments for a voluntary installation would be between 1 and 1.5 billion euro, but would still deliver energy savings of between 3.2 and 3.5 billion kWh/annum.

Figure 9. Energy saving, capital investment required and the annual kWh saved per euro invested



Source: Frontier Economics cost benefit analysis of smart electricity meters

6.2 Alternatives to nationwide introduction of smart meters to be evaluated

Figure 9 shows that for every euro invested under the obligatory installation scenario, between 0.7 and 1.1 kWh/annum can be saved. In contrast, an investment of €1 for voluntary installation generates energy savings of between 3.2 and 3.5 kWh.

A mandatory nationwide roll out requires additional investments of between 3 and 4.5 billion euro over and above a voluntary approach. It is questionable whether the expected incremental energy savings of approximately 1 billion kWh justify this additional expenditure. In particular, this investment could be directed towards other energy saving measures, which could generate considerably higher savings per euro spent.

In other words, a voluntary approach results in both the best net economic benefits, and the best value for money in terms of energy saved per euro spent. It is very likely the additional funds required for a mandatory nationwide roll out of smart meters could generate significantly greater environmental policy outcomes if they are spent elsewhere.

A mandatory nationwide roll out of smart meters does not deliver environmental policy objectives in the most efficient way

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