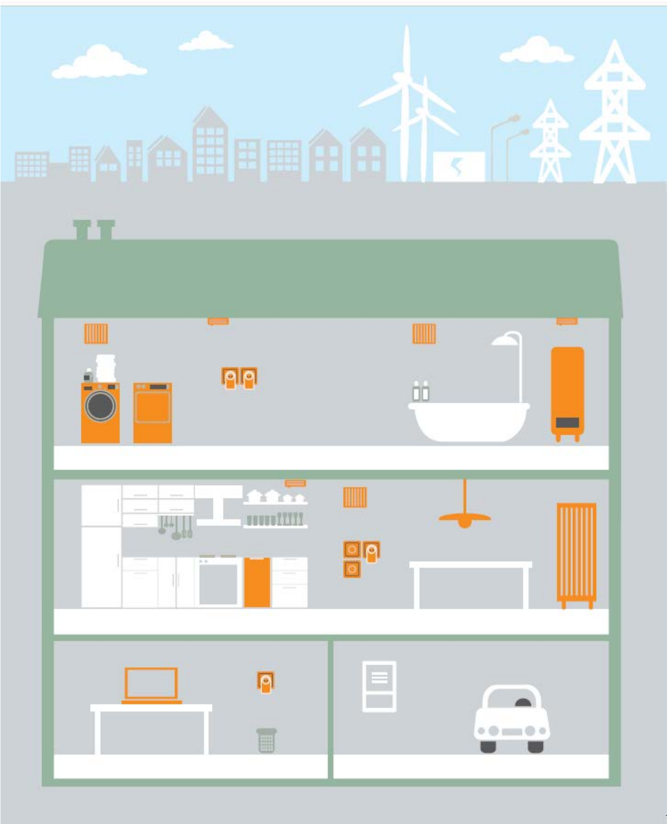
Second phase of the Ecodesign study on Smart Appliances (Lot 33)

MEErP Tasks 1-7, supplementary report



DRAFT FINAL REPORT

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AC	Air Conditioning
ADSL	Asymmetric Digital Subscriber Line
AMI	Advanced Metering Infrastructure
BACS	Building Automation and Control System
BAT	Best Available Technology
BAU	Business As Usual
BEMS	Building Energy Management System
BEV	Battery Electric Vehicle
BRP	Balancing Responsible Parties
CBA	Cost-Benefit Analysis
CEM	Customer Energy Manager
CEMS	Customer Energy Management System
CF	Commercial refrigeration products
CFL	compact fluorescent light
CHP	Combined Heat and Power
CSWH	hot water buffers; continuous water heaters
DHW	Domestic Hot Water
DOCSIS	Data Over Cable Service Interface Specification
DR	Demand response
DRES	Distributed Renewable Energy Sources
DSF	Demand side flexibility
DSO	Distribution System Operators
EC	European Commission
ECHR	European Convention for the Protection of Human Rights and Fundamental Freedoms
EEA	European Economic Area
EED	Energy Efficiency Directive
EMS	Energy Management System
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Service Company
ETS	Emission Trading System
ETSI	European Telecommunications Standards Institute
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FRC	Frequency Containment Reserves (or currently called primary reserves)
FRRa	automated Frequency Restoration Reserves (or currently called secondary reserves). FRRa is activated automatically
FRRm	manual Frequency Restoration Reserves (or currently called secondary reserves). FRRm is activated manually
GLS	general lighting service 'incandescent'
GPP	Green Public Procurement
GSM	Global System for Mobile Communications
GW	gigawatt
HEG	Home Energy Gateway
HEMS	Home Energy Management System
HEMS	Home Energy Management System
HEV	Hybrid Electric Vehicle
HID	high intensity discharge lamp
HVAC	Heating, Ventilation and Air Conditioning

ICE	Internal Combustion Engine
IoT	Internet of Things
K	Temperature expressed in Kelvin
KPI	Key Performance Indicator
LED	light emitting diode
LFL	linear fluorescent lamp
LLCC	Least Life Cycle Cost
LTE	3GPP Long Term Evolution (4G)
M2M	Machine to Machine
MEErP	Methodology for Energy related products
NEEAP	National Energy Efficiency Action Plan
NRVU	Non-Residential Ventilation Units
NSWH	Night storage water heaters
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PLC	power line communication
PV	Photovoltaic
RES	Renewable Energy Sources
RTE	Transmission network - Réseau de transport d'électricité
RVU	Residential Ventilation Units
SAREF	Smart Appliances REFerence ontology
SOC	State Of Charge
TD	Tumble dryer
TEU	Treaty on European Union
TSO	Transmission System Operators
TWh	TeraWatt hour
UMTS	Universal Mobile Telecommunications System
UPS	Uninterruptible power supply
VDSL	Very-high-bitrate Digital Subscriber Line
VRES	Variable Renewable Energy Sources
VRF	variable refrigerant flow

EXECUTIVE SUMMARY

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) analysed technical, economic, environmental, market and societal aspects of energy smart appliance. Throughout the study, new relevant aspects have come up. More specifically, the following issues needed further attention:

- Stakeholders - in particular Member States - emphasised several times the need to include chargers for electric cars in the preparatory study and to explore their technical potential and other relevant issues in the context of demand response.
- The modelling has so far not systematically included the EEA-countries. Given for example the specific situation of Norway (high shares of electrical heating and electric vehicles), it would however be useful to have data of these countries included in the modelling.
- The issue of interoperability explored and monitored by the study was more complex than expected and thus required technical follow-up beyond the first contract.

These elements are added to the scope of the Ecodesign Preparatory Study on Smart Appliances (Lot 33) in the second phase, and the new results that cover the raised additional issues are presented in this supplementary report.

The document structure follows the MEErP methodology (Methodology for Ecodesign of Energy-related Products) wherever possible.

The first part of the document (tasks 1 – 4) mainly focuses on the following aspects related to the inclusion of electric chargers for electric vehicles: standards, legislation, market analysis, user behaviour, and interoperability. The markets for EVs and EV chargers are not yet mature, and experience significant growth and innovation level. Nevertheless, on basis of the market analysis and trends, a number of relevant expectations and assumptions were made. Although certain relevant numbers are missing in the literature, such as estimation of share of smart charging, it was possible to obtain an engineering estimation from the expert judgments. The policy instruments at place are also lacking at the moment, which is related to the immaturity of market.

The second part of the document (tasks 5-6) contains the analysis of results for the inclusion of EEA countries, and extension by electric chargers for the base case, business as usual case (BAU), and 100% case. The quantitative results on flexibility value from smart enabled appliances give sufficient motivation to proceed with regulatory work on defining the policy recommendations to ensure the uptake of energy smart appliances[1] in the years to come.

The state of play related to the interoperability and standards is included at the end in the annex. To resolve the interoperability problem, a lot of organizations and consortia that develop standards are moving the focus from communication interoperability to information/semantics interoperability. At the application layer, interoperability is not yet mature. The work on data formats (in the form of information models and data models) has not seen the same level of consistency throughout various standardization groups. The need for a shared roadmap and commitment to work together seems evident.

[1] In line with the naming in the latest Energy labelling directive (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2017:198:TOC), appliances which are capable of adapting their energy consumption pattern as a response to external stimuli (e.g. price signal, control signal) will be called “energy smart appliances” in the remainder of this document. This replaces the name DSF enabled appliances which was used in Tasks 1 to 6 of this study.

CHAPTER 1 SCOPE

1.1. Context

The EU 2020 strategy to mitigate climate change aims to achieve shared goals by 2020, one of which is increased share of renewable energy sources (RES) in the generation mix. In terms of electricity generation, it is generally expected that the share of renewables will be much higher than the agreed 20% target (reaching between 30-35% of all generation sources according to most estimates). Of all renewable energy systems (RES) generation in 2020, wind and photovoltaic power generation are expected to represent almost 50% of the installed generation capacity. These types of RES are characterised by their intermittency, limited predictability (large forecast errors), lower controllability than conventional generation, and uneven geographical distribution. The increase in these types of RES will have significant and far-reaching effects on both the electricity market and on transmission and distribution grids.

The electricity markets are under pressure. As a consequence of the augmented introduction of RES, wholesale electricity prices are expected to decrease. Furthermore, prices will change much more from hour to hour, depending on the wind and solar injection. As a result, spot price volatility is expected to increase. Eventually, this will lead to increasing retail prices (price for the end-consumer) as the cost for balancing energy increases [1]. The intermittent generation may even create prices well above the expected prices under normal condition.

Furthermore, an effect on the balancing market is predicted. Large penetration of intermittent and in particular wind generation introduces additional requirements for balancing products and services, since wind generation has limited predictability. In order to cope with the limited predictability, i.e., forecast errors, larger amounts of flexible sources are necessary.

For all electricity transactions, the most efficient allocation is sought within the constraints imposed by the physical system. The introduction of high levels of RES will not only considerably affect the electricity market but also distribution and national transmission networks can be impacted. In areas with low demand in particular, where electricity generation from RES may easily exceed consumption, distribution systems have to be reinforced and extended. In a similar fashion, demand may increase significantly due to heat pumps and electrical vehicles. This could require considerable investment from distribution system operators (DSOs) and hence increase the need for flexibility as a possible alternative to grid reinforcement.

Within this context, flexibility becomes of key importance. Additional flexibility is needed to maintain system reliability as the variations in supply and demand grow to significant levels. Furthermore, as VRES displace certain traditional, supply side, flexibility providers, the available flexibility resources in the system are reduced. This dual effect of VRES integration creates a flexibility gap which will need to be covered by new flexibility options.

Flexibility, in this respect, can be defined as the “modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system [1].

The available flexibility can be deployed for different purposes including, contract optimization (dealing with increased price volatility), portfolio management (offering balancing services to a balancing responsible party (BRP)), ancillary services (offering services to the transmission system operator (TSO)) and congestion management (offering peak load reduction to the DSO). Hereby the consequences of increased intermittent production can be (partly) mitigated and even turned into an opportunity for both the grid and the electricity market.

Essential to these developments is the transformation of Europe's traditional grids into, so-called smart grids.

1.2. Objective of the Follow-up Study on Smart Appliances (Lot 33) and of Task 1

Throughout the preparatory study on smart appliances, new relevant aspects have come up which were not possible to be covered under the framework of the preparatory study.

More specifically, the following issues required further attention:

1. Stakeholders - in particular Member States - emphasised several times the need to include chargers for electric cars in the preparatory study and to explore their technical potential and other relevant issues in the context of demand response. The Commission services agree with this conclusion; however, this task could not be accomplished under the previous contract. Electric cars were not included in the previous contract, because transportation is not in scope of the ecodesign regulation.
2. The modelling has so far not systematically included the EEA-countries. Given for example the specific situation of Norway (high shares of electrical heating and electric vehicles), it would however be useful to have data of these countries included in the modelling.
3. The issue of interoperability explored and monitored by the study is more complex than expected and required a deeper technical follow-up beyond the scope of the previous study.
4. Due to the scale of the subject and the wide range of products potentially in scope, an unexpectedly comprehensive work had to be carried out to define the scope and the boundaries of the study (a non-foreseen "Task 0"), which required almost one year of work. At the same time, given the pioneer character and the heterogeneity of the products in scope, the development and assessment of policy options needed more time and differentiation.

The objective of the second phase of the study is to address all these points in a comprehensive way. This report presents the findings of the second phase of the study regarding the first three points: inclusion of EV chargers, inclusion of EEA countries, and interoperability. The last point is presented in an update of Task 7 of the original study, to which this report is a supplementary report.

1.3. Electrification of transportation

Transportation electrification seems to be one of the big candidates to tackle the energy and climate change challenges. Results obtained from different studies clearly show that the electrification of drivetrains can contribute to an abatement of pollutant emissions in the urban environment and thus reducing air quality impacts and external costs of the transport sector [7],

[8]. However, some challenges have to be overcome in order to turn these opportunities into reality.

Despite the fact that a lot of market driven difficulties are in place in the short term, electric vehicle market forecasts are optimistic [9]. As the market share of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) is expected to increase to substantial amounts, the impact on the power system will increase correspondingly [10], [11]. In particular, the charging of the electric vehicles (EVs) has a significant impact on the transmission and the distribution grid, when a local high EV penetration rate occurs [12]. The electricity generation and low voltage distribution infrastructure will have to be able to supply the additional energy and power capacity required for electrical transport. If the charging of electric vehicles is allowed to happen in an uncoordinated way, the electrification of transport may well affect the electricity grid in a negative way, resulting in both voltage issues and power congestion which are detrimental to the reliability and security of the distribution grid [13], [14].

Furthermore, if the residential evening power peak coincides with the start of the charging process for uncoordinated charging, insufficient generation capacity will be available at higher penetration levels of EVs [10]. Based on a survey conducted by Eurelectric, assuming 100% electrification of transportation, charged under a fit-and-forget strategy, the additional demand from EVs could raise the peak demand by 21.1% by 2035 according to the expected growth in the coefficient peak load by that year [17]. This effect on the peak load is depicted in Figure 1.

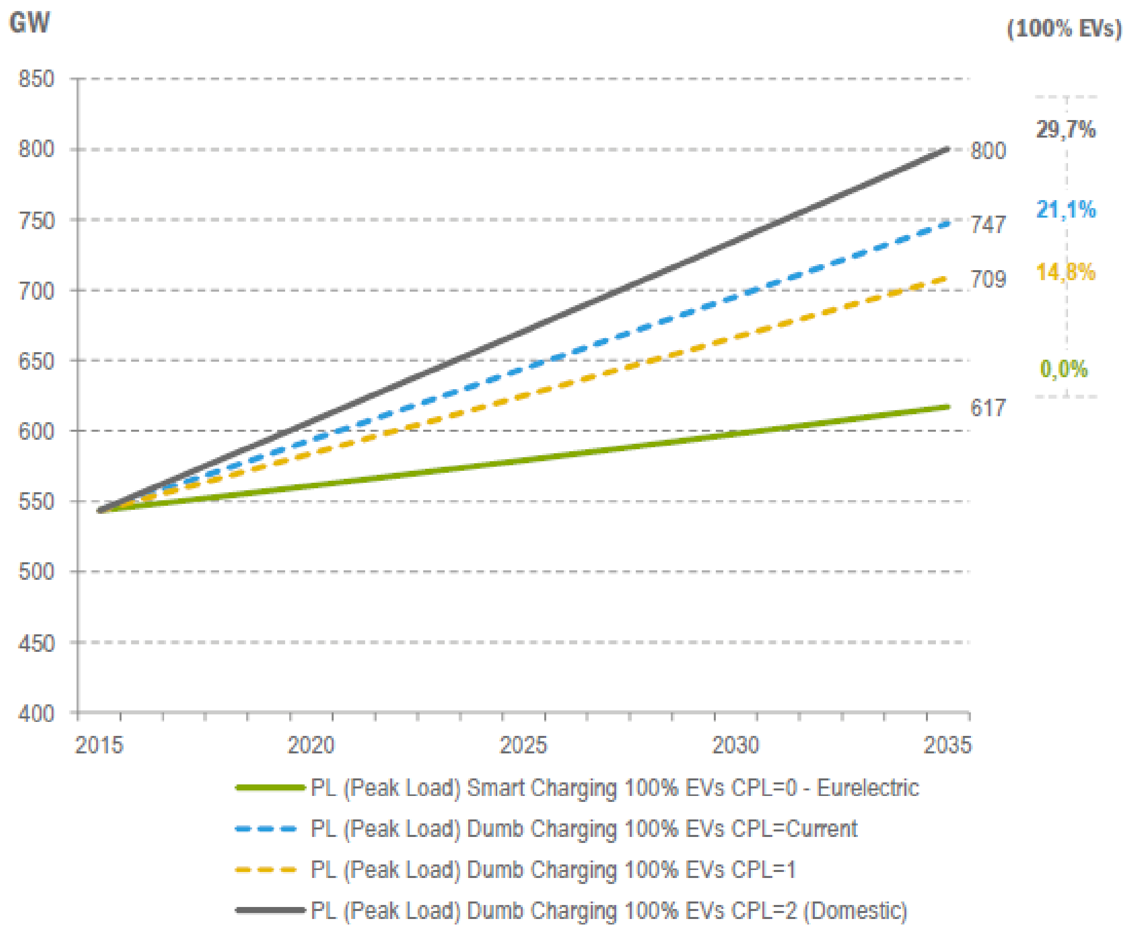


Figure 1 European peak load (GW) evolution in case of 100% EVs by 2035 and potential of smart charging to reduce the peak load between 15% - 30% [[17][2]

1.4. RESIDENTIAL GRID IMPACT

Clusters of EVs can be expected at the proximity of present load centres [29]. Charging a substantial EV fleet on residential level will then contribute to an increase of present loads, leading to multiple effects which can be manifested on different aspects of the distribution grid.

The power profile of the distribution system is affected as EVs are charged, impacting the technical lifetime of transformers and distribution feeders. The ageing of transformers is strongly connected to the hot spot temperature, which depends on the transformer and cable conductor currents. EV charging strategies can strive to smoothen out the load profile and thereby minimizing the accelerated ageing of distribution system assets.

[2] The coefficient of the peak load (CPL) is defined as the ratio of peak load to average load and is an indication of the flatness of the load curve.

Furthermore, in order to ensure a safe and satisfactory operation of grid-connected electric appliances, the voltage magnitude is required to stay within a specified range around the nominal value [30]. For this reason, nodal voltages in distribution systems are subjected to regulation. According to the mandatory EN50160 standard, the 10 min mean rms (root mean square) voltage deviation should not exceed ±10%, measured on a weekly base. For under voltage, a wider range is allowed in the measurement procedure: -15% to -10% for 5% of the time [31]. Within this context, the rationale for coordinated EV charging can be found. Peak shaving reduces the simultaneity of household and EV power demand, which has a beneficial impact on the voltage deviations.

1.5. SMART CHARGING

As networks were designed to meet demand at all times, the traditional "fit-and-forget" approach to distribution network development would imply building more lines and transformers. But this approach may no longer be the most cost-effective as it involves high technology adoption costs that might be burdening the national power systems and preventing e-mobility from truly hitting the mass market [17].

In order to receive the full benefits of EVs, an efficient integration of those vehicles is needed with regard to both generation and distribution of electricity. By coordination of the charging of a pool of EVs, the impact on the electricity distribution infrastructure can be largely mitigated by making more efficient use of the available capacity of the system while satisfying the requirements of the individual vehicle owner [15], [16]. Smart charging involves the intelligent charging of the batteries in electric vehicles: charging them in a way that avoids excessive and costly spikes in power demand and also – in the years to come – using the batteries of the cars as storage to deliver valuable services to the electricity system, as well as maximising local integration of renewable energy sources (RES) [17]. Smart charging as defined by CEN-CENELEC is described as "smart charging of an EV is when the charging cycle can be altered by external events, allowing for adaptive charging habits, providing the EV with the ability to integrate into the whole power system in a grid- and user-friendly way. Smart charging must facilitate the security (reliability) of supply and while meeting the mobility constraints and requirements of the user. To achieve those goals in a safe, secure, reliable, sustainable and efficient manner information needs to be exchanged between different stakeholders." [18].

With smart charging, the extra energy demand for EV charging may even be turned into an advantage for the grid. The EV flexibility can be activated for multiple purposes. Despite those many uses, with widely varying timing and technical requirements, the use of flexibility always boils down to efficiently maintaining the energy balance while efficiently guarding the grid capacity constraints to prevent and/or mitigate emergency situations. As a consequence, there are only three parties that are the end user of flexibility in the current European liberalised markets: TSO, DSO and BRP.

First, EVs can provide flexibility services to the power system with load management. With load management for electric vehicle charging, the charging process can be controlled by shifting the charging period to times of lower demand or of RES surplus, reducing or increasing the charging power, or interrupting the charge of the car's battery in case of emergency situations. The charging can also be scheduled to coincide with available RES, thereby promoting renewables integration. Within this context, the charging process of EVs can be steered in function of balancing the input from decentralized intermittent renewables such as solar and wind. Several concepts of using fleets of EVs for electric grid support have been discussed in literature [20], [24]. A specific coordinated charging strategy aimed at mitigating distribution grid constraints was treated. The authors in [13] propose a centralized approach of directly influencing the charging schedules of the electric vehicles. The aim of such a methodology is to postpone or potentially avoid distribution grid reinforcements and associated costs.

Secondly, the flexibility of EVs can be exploited to efficiently safeguard the energy balance. In this context, EVs can assist in day-ahead or real-time portfolio management of the BRP. The available flexibility can be used to optimize the day-ahead scheduling of production and consumption and/or the flexibility allows in real-time to match supply and demand in case of deviations from the original scheduling. Once the cumulative energy portfolio within the TSO control area[3] appears to be unbalanced, the TSO takes actions to restore the balance of the control area since he is responsible for the stability of the grid in real-time or close to real-time. In case deviations are detected, the TSO will activate the necessary ancillary services or reserves. EVs could participate in the market for ancillary services or reserves.

Since most of the EV charging will take place at home and work locations, it is very important that smart charging measures are made available and are embraced by the end consumers. Lack of consumer acceptance might present a barrier for smart EV charging and EV flexibility provision.

Smart charging is a process which can be driven by:

- Direct signals: automated, direct load control
- Indirect signals: flexible EV loads respond to price signals as time-of-use, dynamic hourly price of energy, price of maximum instantaneous power demand, etc.

The control mechanism can be enabled by the grid, by the charging point, or by the vehicle itself, while a communication system with the grid allows the charging process to take actual grid capabilities into account (intelligent algorithms can be distributed at all three levels) as well as customers preferences. The direct or indirect signals can be communicated through an ICT infrastructure in order to allow algorithms to take generation, the energy balance and grid constraints into consideration, as well as to enable the customers to benefit from price opportunities.

Research indicates that consumers are not keen on changing daily routines, so they seem to be more in favour of automated demand-response than manual control [21], [22]. Moreover, end users cannot be expected to be continually monitoring a price signal and react accordingly. Therefore some kind of automation is needed when complex tariff designs are applied [23]. In principle, the advantages of automation and remote control is that it allows for very quick responses and controllable levels of reduction, that it is available when system emergencies occur unplanned and when households are unable to take action.

Smart charging can represent an opportunity for all the involved stakeholders [17]:

- Customers: maximising customer convenience while reducing costs.

  Different studies have concluded that the majority of the EV charging will take place at home or at work, meaning that the residential low-voltage grids will likely be the primary charging point. Since the EV has the potential to double the power consumption of a household in some countries, significant upgrades of the low-voltage distribution grid

[3] The cumulative energy portfolio within the TSO control area is cumulative energy portfolio across all relevant BRPs in the control area.

might be imposed, which entails an increased cost. If charging is intelligently steered, customers can optimally use the moment when the charging process can be accommodated within the existing infrastructure. Customers could more easily accept a smart charging service if it is economically convenient. Smart charging could lead to significant cost savings if customers use cheaper electricity at "off-peak" time, which is possible when e.g., time-varying prices are applied. EV owners will be able to save on their energy bill and benefit from a lower total cost of ownership.

- Power system: optimising generation and grid capacity, cost efficiency by minimising network reinforcement costs, facilitating renewables integration and optimizing the energy balance.

  EVs represent a new mobile, power-dense and variable type of electricity load that will mostly be connected to the distribution grids at the low voltage level. As EVs were not considered at the initial stage of network planning, they could cause serious network congestion and assets overloads. Heavy investments could be required to upgrade the electricity cables connecting households to transformers and the transformers themselves. Investments in the upstream grid could also be needed. These investments may burden therefore the electric mobility technology adoption at national and international scale. Smart charging will therefore need to take into account network constraints in order to avoid overloading the grid. If the charging is coordinated to make better use of the available grid capacity at off-peak hours, smart charging has a potential to reduce the effect on the peak load to zero [17]. At the same time, the utilisation factor will improve. Thus smart charging has a strong potential to optimise the grid asset utilisation, thereby decoupling electricity capacity growth from peak load growth. Within this context the EV flexibility can be seen as a potential, cost-effective solution for avoiding unnecessary grid investments and reinforcement costs. Flexible EV demand will not only result in more efficient grid usage, but could also avoid unnecessary investment in generation capacity, resulting in longer asset lifetime.

- Society: reducing local and global CO_2 emissions and related costs, in addition to increasing social welfare.

  Smart charging will be an essential part of the transition towards a low-carbon economy and smarter electricity system. E-mobility's effectiveness in reducing large-scale CO2 emissions will rely on the decarbonisation pace of the power sector. If cars are coordinated to charge at times of lower electricity consumption, they can optimise the use of existing capacity and use less emitting power plants running outside peak hours which would be needed to meet what are otherwise infrequent spikes in electricity demand, maximising their integration in the electricity system. Moreover, with smart charging the time of charge can be coordinated to coincide with available renewable capacity such as wind at night, or solar at noon, bringing further benefits in terms of emissions reductions.

1.6. Scope of the supplementary report of the second phase of the study

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) analysed technical, economic, environmental, market and societal aspects of energy smart appliances. Throughout the study, new relevant aspects have come up. More specifically, the following issues needed further attention:

- Stakeholders - in particular Member States - emphasised several times the need to include chargers for electric cars in the preparatory study and to explore their technical potential and other relevant issues in the context of demand response.

- The modelling has so far not systematically included the EEA-countries. Given for example the specific situation of Norway (high shares of electrical heating and electric vehicles), it was concluded that it would however be useful to have data of these countries included in the modelling.
- The issue of interoperability explored and monitored by the study is more complex than expected and thus required technical follow-up (second phase of the study) beyond the original contract.

These elements are added to the scope of the Ecodesign Preparatory Study on Smart Appliances (Lot 33), and the new results that cover the raised additional issues are presented in this supplementary report.

The document structure follows the MEErP methodology (Methodology for Energy related products) wherever possible.

CHAPTER 2 MARKET ANALYSIS

The objective of Task 2 consists of the assessment of the stock of energy smart appliances defined in Task 1 within the EEA and CH and of the assessment of the stock of EV chargers in the EU28, EEA and CH area in 2014, 2020, and 2030.

An analysis has been made of current trends regarding the general Internet of Things market and more specifically the market for smart home and energy smart appliances within the EEA and CH. Although market reports give a good picture of general tendencies regarding the current and future supply of energy smart appliances within the EEA and CH, it was not possible to derive 'smart' shares of individual appliances for the various categories.

Energy smart appliances as defined in the original study, electric vehicles, and EV charging points have not yet (fully) seized the market and no figures are available specifically for this subcategory of 'energy smart' appliances. Therefore, the current stock data for all appliances - including non-communication/communication enabled and non-DR/DR enabled appliances – is given as a starting point. Expert judgment estimations have been made per appliance type of the current share of DR enabled stock as well as predictions for 2020 and 2030.

2.1. MARKET COMPONENTS FOR EVS

As indicated in the previous section, EVs may offer a huge flexibility potential. Different aspects influence the possibility and widespread introduction of smart charging, extensively described in literature. Many research and demonstration projects as well as position papers from industry have covered this topic the past years.

In order to provide a full review of the smart charging of EVs both a technology overview and market assessment must be performed. A useful instrument for identifying business models concerning electric mobility was created by F. Kley, C. Lerch and D. Dallinger [34]. The authors identified three main drivers for EV business models and smart charging, in particular:

- Vehicle and battery
- Infrastructure system
- System services which integrate EVs into the energy system

The further breakdown into market segments, based on the different characteristics and design possibilities, is provided in Figure 2.

Vehicle and battery

Characteristic		Design possibility				
Property	Vehicle	Customer	Independent provider	Energy utility	Battery producer	Vehicle manufacture
	Battery	Customer	Independent provider	Energy utility	Battery producer	Vehicle manufacture
Type of billing	Vehicle	Pay for equipment	Fixed rate	Pay per use		
	Battery	Pay for equipment	Fixed rate	Pay per use		
After-sales services provider	Vehicle	Customer	Independent provider	Energy utility	Battery producer	Vehicle manufacture
	Battery	Customer	Independent provider	Energy utility	Battery producer	Vehicle manufacture
Exclusiveness of use	Vehicle	One customer	More than one customer			
	Battery	One customer	More than one customer			

Requirement of technical & organizational change

Infrastructure

Characteristic	Design possibility			
Type of power supply	Conductive (wired)	Inductive (wireless)	Battery exchange	
Accessibility	Private	Semi-public (e.g. at employer)	Public	
Power connection	1-phase (Level 1)	3-phase (Level 2)	High voltage AC (Level 3)	High voltage DC (Level 3)
Connection type	Unidirectional	Bidirectional		
Information flow	None	Unidirectional	Bidirectional	
Information processing	Day-ahead	Intra-day	Real-time	
Operator of power supply	Private	State	Energy utility	Independent provider
Type of billing	No fee	Fixed rate	Pay per use	
Metering	No metering	At charging station	In vehicle	

Requirement of technical & organizational change

Systems services

Characteristic	Design possibility				
Type of systems service	No services offered	Load shifting	Back-feeding		
Number of participants	One participant	More than one participant			
Level of Grid Integration	Local/ stand-alone grid	Balancing group	Control zone	National	
Control	Uncontrolled	Indirect control	Direct control		
Type of power input	Public grid	Local generation	Renewable energies		
Provider	Private	Semi-public	Energy utility	Independent provider	Public
Billing/ compensation	No fee	Fixed rate	Pay per use		

Requirement of technical & organizational change

Figure 2: Components defining the EV market [34]

In the past the home automation industry was the only player to provide smart home functionality; but in 2015 several market actors are lining up to take a share of the smart home market:

- Telecommunication providers already have a platform at the customers' home, via the broadband router and are very well positioned to enhance this platform towards a smart home platform (E.g. Qivicon product range offered by Deutsche Telecom; in the US Cable TV, Internet & Phone provider Comcast Corporation steps into the smart home market);
- Energy providers are providing smart thermostats and energy boxes[4] to their customers to reinforce the customer-energy provider binding in a liberalized energy market. Some energy providers offer complete smart home solutions (E.g. RWE Smart Home products, Eneco's Toon thermostat, Eni's Anna thermostat);
- In the US, the home security industry is broadening their scope from alarm to smart home offerings. At the base, consumers value safety, but several consumer segments value energy management, especially when bundled with security and safety offerings (see Task 3);
- The traditional home automation industry, previously targeting the high-end market segment, are now offering slimmed down solutions for the middle-end market segment;
- The consumer industry, and especially some dominant and innovative actors like Google/Nest, Apple and Samsung are offering products or platforms for the smart home. These offerings may tie the customer to a particular ecosystem[5], though there are also open systems such as the Home Connect for white goods.

Regarding the path to the connected home, the Deutsche Telekom published the following conclusions in the 'How to Create Growth from the Connected Home' report [36]:

1. Connected devices will transform our homes over the next decade;
2. The market will be worth billions of euros;
3. The threat of disintermediation is very real with innovative players set to enter the home from adjacent markets;
4. Major players need to 'step up to the plate' in order to drive growth from IoT;
5. To engage consumers, focus on meeting their real needs;
6. The ultimate value for service providers, retailers and manufacturers will be in services;
7. The market is not homogeneous, it is distinct and regional and segment needs must be met;
8. Create a win-win relationship with partners;
9. No one standard will meet the entire needs of the market, and hence an open architecture will be a prerequisite;
10. Platforms that support multiple use cases will be the only ones that succeed.

2.2. MARKET TRENDS FOR EVS AND ELECTRIC CHARGERS

2.2.1. PERSONAL VEHICLES

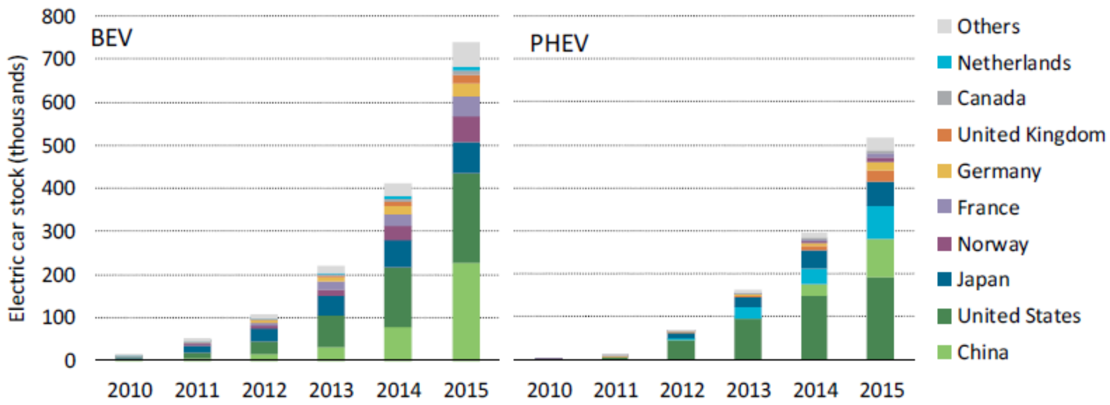
Personal electric vehicles

In 2015, the global threshold of 1 million electric cars (including battery electric, plug-in hybrid electric, and fuel-cell electric vehicles) on the road was reached. The global EV car stock comprised a total of 1.26 million vehicles that year, Figure 3 [24]. This positive dynamic is mainly the result of a

[4] Energy box is a popular name for home energy management systems (HEMS). Note however that the energy manager is a logic function, not necessarily a physical device.

[5] For instance a customer may decide not to buy a certain energy smart -enabled appliance because it cannot be integrated in a particular ecosystem at home. And the manufacturer of that particular ecosystem may decide ENERGY SMART -capability is not important for its revenue.

combination of ambitious EV targets and policy support which have substantially lowered the vehicle costs, extended the vehicle range and reduced perceived customer barriers in different EU countries. Substantial new implementation of electric vehicle supply equipment (EVSE) was also steering the EV market uptake the past years. Public policies are encouraging publicly accessible charging development through direct investment and public-private partnerships.



Note: the EV stock shown here is primarily estimated on the basis of cumulative sales since 2005.

Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2016), IHS Polk (2014), MarkLines (2016), ACEA (2016a) and EEA (2015).

Figure 3: Global EV car stock [24]

Looking into the additional EV registrations between 2014 and 2015 for both BEV and PHEV, EV sales increased by 70% year-on-year, with over 550.000 vehicles being sold worldwide in 2015 [24]. That year, as depicted in Figure 4, the car sales of eight main EV markets represented 90% of the total volume of new registrations, i.e. China, the United States, the Netherlands, Norway, the United Kingdom, Japan, Germany and France. In the Netherlands, EV sales more than doubled, reaching a market share of electric vehicles close to 10%, the highest in the European Union and the second-highest globally, after Norway (23%).

To deep dive into the European EV statistics, the European Alternative Fuels Observatory (EAFO) database is consulted. EAFO monitors the sales of BEV and PHEV across Europe. As can be observed in Table 1 and Table 2, the EV market in 2016 was concentrated on the Renault (Zoe) and Nissan (Leaf) segment for BEV and Mitsubishi (Outlander) for the PHEV market [35]. In total, the BEV market grew to over 91.000 new vehicle registrations in 2016, representing a 4% increase year-on-year. The majority of the BEV market remains concentrated on smaller cars [36]. With inclusion of PHEVs, the total volume of new EV registrations amounted to 209.151 vehicles in 2016 [35].

Table 1: BEV sales in Europe [35]

Ranking	Brand	Model	2016 Total	Share PEV market
1	Renault	Zoe	21338	10,20%
2	Nissan	Leaf	18614	8,90%
3	Tesla	Model S	12358	5,90%
4	BMW	i3	9739	4,60%

5	Volkswagen	e-Golf	6678	3,20%
6	Kia	Soul EV	4440	2,10%
7	Tesla	Model X	3708	1,80%
8	Volkswagen	e-Up!	2576	1,20%
9	Peugeot	iOn	1893	0,90%
10	Hyundai	Ioniq Electric	1113	0,50%
Others	/	/	8952	4,30%
Total			**91409**	**43,60%**

Table 2: PHEV sales in Europe [35]

Ranking	Brand	Model	2016 Total	Share PEV market
1	Mitsubishi	Outlander PHEV	21333	10,20%
2	Volkswagen	Passat GTE	13250	6,30%
3	Volkswagen	Golf GTE	11350	5,40%
4	Mercedes	C350e	10231	4,90%
5	Volvo	XC90 PHEV	9589	4,60%
6	BMW	330e	8702	4,20%
7	BMW	225xe Active Tourer	5940	2,80%
8	BMW	X5 40e	5394	2,60%
9	BMW	i3 Rex	5351	2,60%
10	Mercedes	GLC350e	1829	0,90%
Others	/	/	25137	12,00%
Total			**118106**	**56,50%**

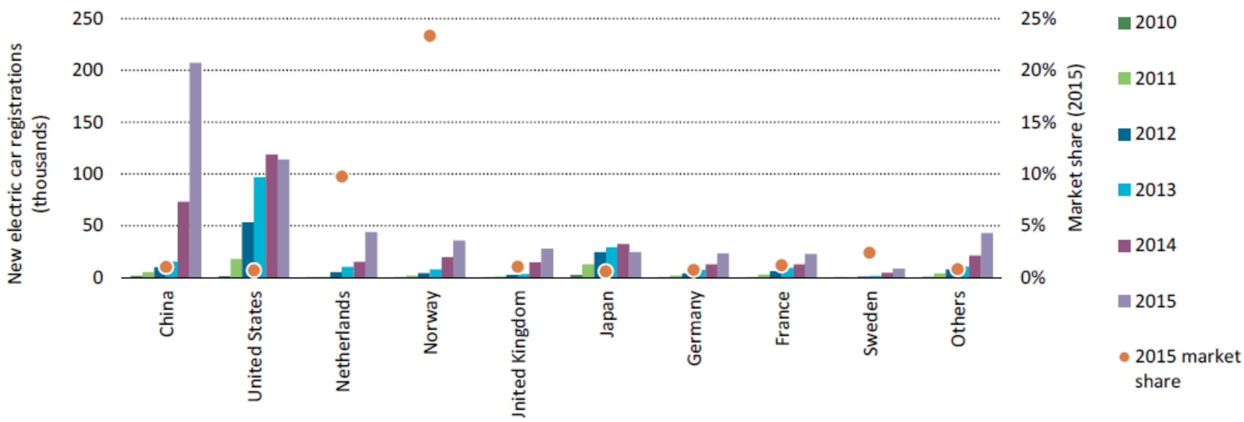


Figure 4: EV sales and market share in a selection of countries and regions in 2015 [24]

Extending the focus from new registrations to the whole European vehicle fleet, according to EAFO, the total vehicle fleet of pure electrically driven passenger cars amounts to 607.569 by the end of 2016 [35]. More in detail, the EAFO data assumes that the BEV market has approached 315.191 vehicles sold. For the PHEV, the market is stated to have reached a fleet number of 292.378 vehicles.

Studies indicated that financial incentives and the availability of charging infrastructure are the main drivers for the growth of the EV market share. In the frontrunners, Norway and the Netherlands, a range of measures were implemented, favouring the EV owners. In the Netherlands, electric vehicles enjoy very significant reduction on registration and circulation taxes, as well as privileged access to parking spots and some portions of the transport network, restricted for conventional vehicles. Norway provides i.e. strong incentives in the form of registration tax reductions and, for BEVs, the exemption from value-added tax (VAT).

Current market growth forecasts for EVs still involve a wide degree of uncertainty and depend on a variety of factors, including government policies, purchasing costs and customers' willingness to buy the new cars. For the estimation of the 2020, and further, global market development of EVs, different deployment scenarios can be considered, see Figure 5. To assess the market potential of the European EV market also here different studies and projections exist. Any forecast of figures is based on specific scenarios, described by key variables able to address policies, economy and energy, society and mobility, as well as industrial and technological issues. A general trend across the different studies within this topic is the expectation of an uptake of fast growth starting in 2021, possibly because cars with higher battery capacity of more than 300 km would by then become available on the market at a cost-effective level of €/kWh [17].

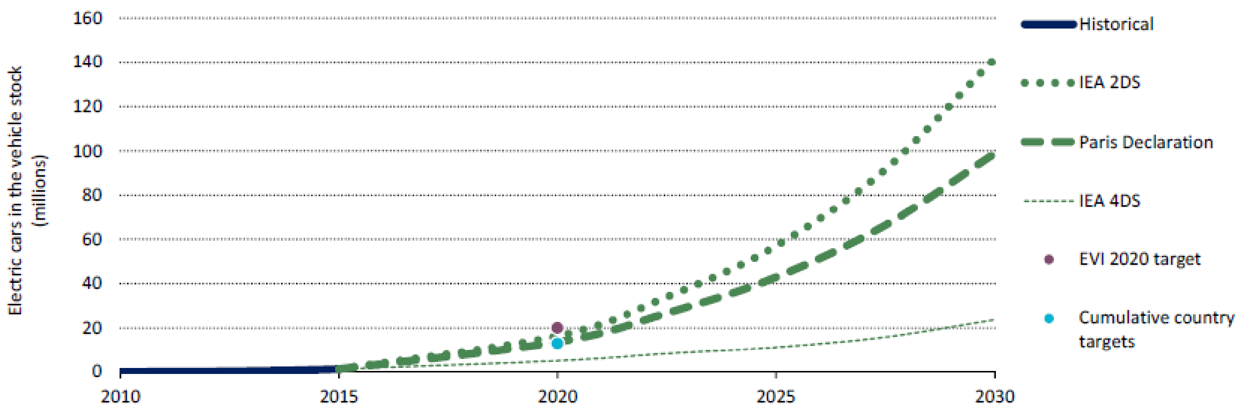


Figure 5: Deployment scenario for the global stock of EVs [24][6]

The Directorate-General for Internal Policies commissioned a study to identify the challenges for a European market for electric vehicles, including market forecasts of the EV fleet in 2020 and 2030 [38]. Within the analysis three scenarios were considered, differentiation on the variables; climate change policy, total cost of ownership and the marketing strategies of utilities and OEMs.

[6] Note: 2DS = 2°C Scenario; 4DS = 4°C Scenario.

- Scenario 1 assumes that there are no globally binding CO2 targets, a moderate increase of oil prices.
- Scenario 2 assumers that the key industrialized and emerging countries reach an agreement on climate policy, a continuous increase of oil prices and utilities investing in charging infrastructure.
- Scenario 3 assumes the enactment of globally binding CO2 targets and a thorough climate change policy. Oil prices increase to $200 a barrel and utilities as well as OEMs invest in charging infrastructure. Also different other stimulating policies for EVs are in place.

For each of these scenarios the study of the DG for Internal Policies established a forecast on EV sales by 2020. If the moderate scenario, Scenario2, is considered, the European EV[7] car stock is anticipated to reach a volume of 5.320.000 vehicles by 2020 [38]. This forecast is supported by the sum of all EU country targets for 2020 as described by the IEA [24]. If the country commitments of all EU countries are summarized, a European EV car stock of approximately 5.800.000 vehicles is anticipated. Therefore, for the further tasks, for 2020, Scenario 2 from Table 3 will be used.

Table 3: European market forecast EVs by 2020 [38]

Total volume in 2020	Scenario 1	Scenario 2	Scenario 3
ICE	55.142.000	51.205.000	42.545.000
HEV	10.470.000	9.975.000	12.700.000
PHEV	2.792.000	3.325.000	5.080.000
BEV	1.396.000	1.995.000	3.175.000

Countries with announced targets to 2020 or later	2015 EV stock (thousand vehicles)	2020 EV stock target (million vehicles)	EV share of all cars sold between 2016 and 2020	EV share in the total 2020 stock	Source
Austria	5.3	0.2	13%	4%	BMVIT, 2012
China*	312.3	4.6	6%	3%	State Council, 2012
Denmark	8.1	0.2	23%	9%	ICCT, 2011
France	54.3	2.0	20%	6%	MEEM, 2011
Germany	49.2	1.0	6%	2%	IA-HEV, 2015
India	6.0	0.3	2%	1%	LBNL, 2014
Ireland	2.0	0.1	8%	3%	SEAI, 2014
Japan	126.4	1.0	4%	2%	METI, 2016
Netherlands**	87.5	0.3	10%	4%	EVI, 2016a
Portugal	2.0	0.2	22%	5%	IA-HEV, 2015
South Korea	4.3	0.2	4%	1%	MOTIE, 2015
Spain	6.0	0.2	3%	1%	MIET, 2015
United Kingdom	49.7	1.6	14%	5%	EC, 2013 and CCC, 2013
United States***	101.0	1.2	6%	2%	IA-HEV, 2015
Total of all markets listed above	814.1	12.9	7%	3%	

Figure 6: EV car stock targets for 2020 based on country commitments [24]

[7] Both plug-in hybrid EV (PHEV) and battery EV (BEV) are considered.

Further projections towards 2030 and 2050 indicate a rampant success of EVs in the coming decades. The Paris Declaration on Electro-Mobility and Climate Change and Call to Action, developed in the framework of the Lima-Paris Action Agenda and announced at COP21, targets more than 100 million electrically driven vehicles on the road in 2030, up from 1 million today [39]. Within the 2016 Energy Technology Perspective (ETP), published by International Energy Agency (IEA), the objectives of the 2° scenario sets a deployment target for electric vehicles exceeding the goal of the Paris Declaration with 140 million EVs by 2030 globally.

Downscaling to the European level, the study of the DG for Internal Policies provides a good estimate of the 2030 EV stock. Considering the moderate scenario, a forecasted number of 22,6 million EVs vehicles on the road will be electrically driven, see Table 4 [38]. This projection corresponds to the 'revolution scenario', anticipated by Eurelectric, Figure 7. Therefore, for the further tasks, for 2030, Scenario 2 from Table 4 will be used.

Table 4: European market forecast EVs by 2030 [38]

Total volume in 2030	Scenario 1	Scenario 2	Scenario 3
ICE	**55.315.000**	**45.548.000**	**13.980.000**
HEV	17.020.000	10.036.000	19.572.000
PHEV	**8.510.000**	**15.440.000**	**27.960.000**
BEV	4.255.000	6.176.000	8.388.000

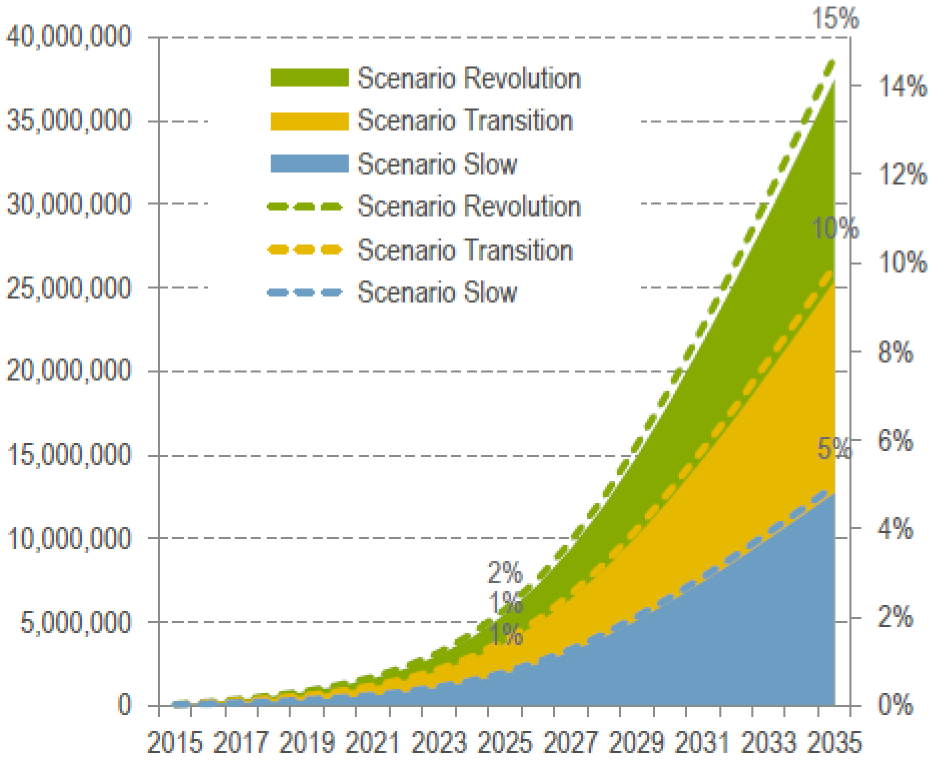


Figure 7: EV market uptake, accumulated market share (%) and sales [8]

[8] The relevant EV market share uptakes in three scenarios are displayed on the figure for 2025 and 2035.

Car sharing

New, innovative mobility concepts such as car-sharing or company vehicle fleets exploit the strategy of extending the user base at the lower operating costs of electric cars and this way spreading the capital costs over a greater number of heads.

Car-sharing schemes already exist for ICE-vehicles. These models are attractive to customers who make only occasional use of a vehicle, as well as others who would like occasional access to a vehicle of a different type than they use day-to-day. They are considered to be a future-proof model of transportation since they help reduce the number of vehicles on the road, counteracting the increasing traffic congestion severity.

It will enable participants to cover short journeys. In contrast to existing car-sharing, most car-sharing concepts for electric vehicles will allow the consumer to start a journey at one public pick-up point and leave the vehicle at another station. Different cities have already adopted this business concept including Brussels (Zencar), Amsterdam (car2go) and Paris (Autolib). The latter, Autolib, is the gold standard of electric car sharing. The construction of the first Autolib charging stations began in mid-2011. An initial fleet of 250 EVs served the city of Paris when the sharing system entered service. In the beginning the car availability was lacking as subscriptions exceeded the expectations. Currently, 4.000 ‘Autolib’ vehicles circulate in the Paris environment. Since Autolib was launched, more than 500,000 people have subscribed to one of our subscription plans.

Within the current analysis the possibility of car sharing is out of scope. Especially since the potential flexibility of the vehicles in this sharing schemes is limited. This is due to the fact that the aim is to reduce stand still times to the bare minimum, limiting to the time needed for charging.

2.2.2. BATTERY

In parallel with the positive battery cost evolutions, battery energy density needs to increase to enable longer ranges for lower prices, especially within the context of eliminating range anxiety. Range anxiety refers to the fear that the vehicle won’t have enough stored energy to handle daily driving. Because of the (perceived) insufficient battery performance, EV owners are anxious of being stranded in an electric car. Hence, for EVs to catch on, battery storage capacity and driving ranges need to be improved.

Technology learning, RD&D and mass production led to rapid cost declines and performance improvements in the past decade and hold the promise of continuing to progressively reduce technology costs in the near future. Recent improvements in the energy density of batteries allowed a larger electric range of commercially available EVs, making significant progress to address range anxiety issues. Based on an IEA analysis and US department of energy (DOE) data, Figure 8 provides an overview of the evolution of the battery energy density, including future projections. Between 2008 and 2015 the energy density of PHEV batteries improved from 60 Wh/L to 295 Wh/L, an enhancement of almost 400% [24], [25]. The 400 Wh/L target set by the US DOE to 2022 requires an additional 36% improvement to be achieved in the following years [25].

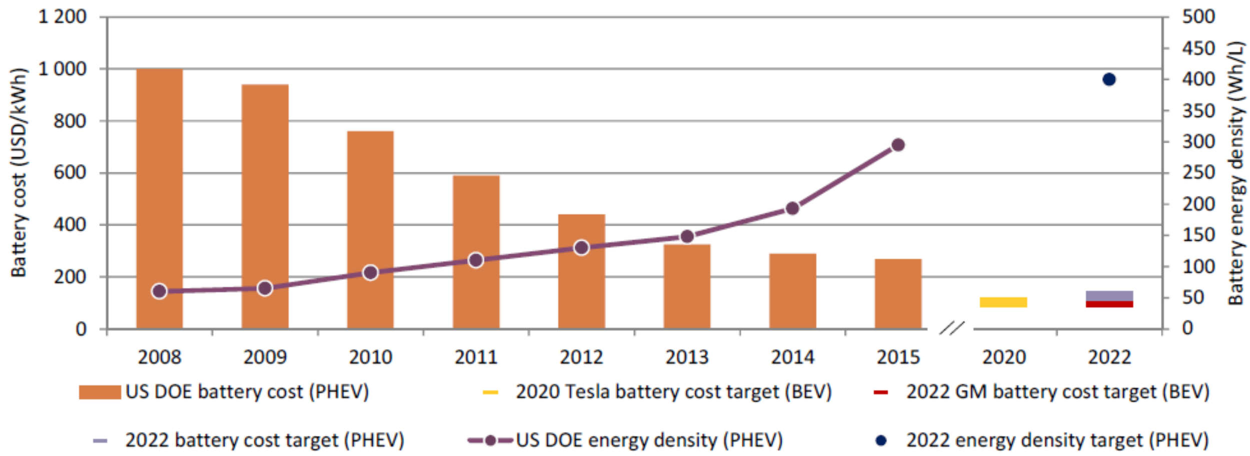


Figure 8: Evolution of battery energy density and cost [24]

As for the range, there is a positive trend in battery technology, which could see their capacity increase between 36 kWh and 43 kWh in 2025 [17]. These figures mean that an average car will be able to provide a higher autonomy of more than 300 km, thereby overcoming range anxiety. In this regard, recent carmaker announcements suggesting EV ranges that will soon be exceeding 300 kilometres (km), giving encouraging signals for the future. Tesla for example, launched orders for its new Model 3 in March 2016, committing to an electric drive range of nearly 350 km on a single charge by 2017. The first vehicles are scheduled for delivery to customers late October [28],[27].

For the determination of the average PEV battery size, the average battery size for each passenger car segment is calculated. This calculation is based on data from EAFO on the available BEV and PHEV models within each vehicle segment. The classification is founded on the distinction defined by the European Commission;

- A: City cars
- B: Small cars
- C: Medium cars
- D: Large cars
- E: Executive cars
- F: Luxury cars
- J: Sport utility cars
- M: Multiple purpose cars
- S: Sport coupes

The average battery size within each segment is displayed within Table 5.

Table 5: Average battery size for 2016 BEV and PHEV [35]

	BEV	PHEV
Subcategories	Average Battery Size (kWh)	Average Battery Size (kWh)
A	17,06	\
B	35	33

C	25,2	11,8
D	35,5	8,4
E	100	6,2
J	100	8,85
M	39,25	7,6
S	58,75	5,85

As can be derived from Table 5, the specifications of a battery changes significantly depending on the vehicle it powers as well as the drivetrain (BEV or PHEV). In order to make correct assumptions on the prevalent battery capacities of the European EVs on the road, the market spread of the European EV fleet across the different vehicle segments is determined on the basis of EAFO sales data of the top 15 selling BEVs and PHEVs for the period 2014-2016 in Europe. The distribution of sales across the different segments is depicted in Figure 9. A detailed overview of the 2016 sales data is provided in Table 6.

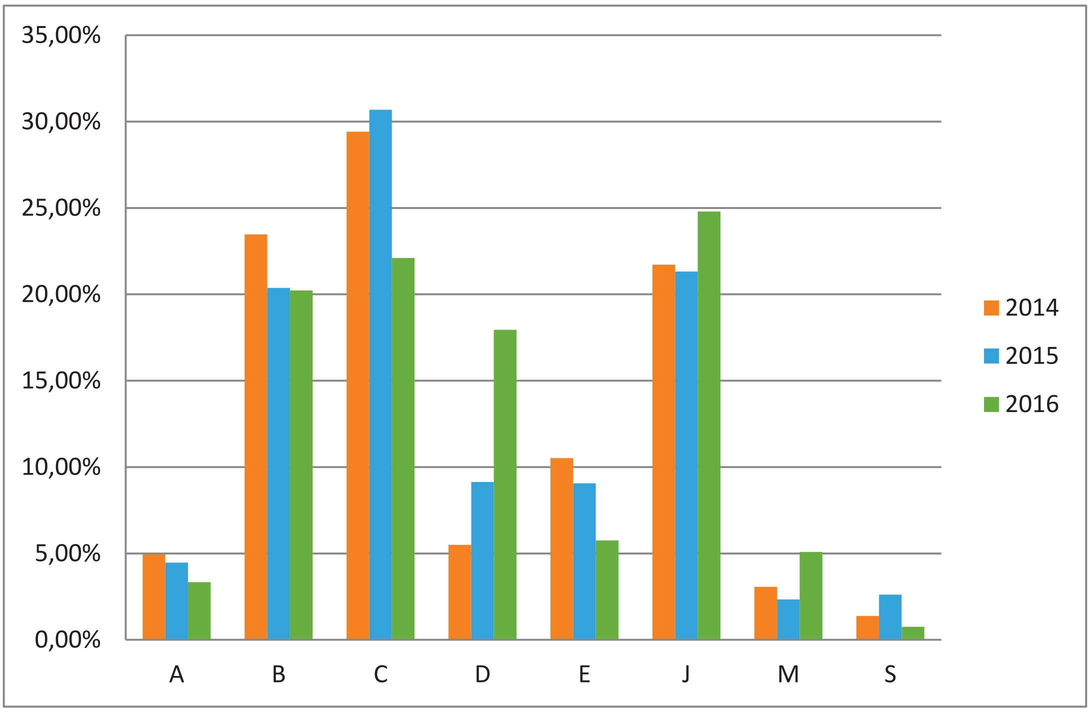


Figure 9: Annual vehicle sales by segment between 2014-2016 for Europe

Table 6: Market spread of EVs across vehicle segments in 2016

	BEV	PHEV	PEV
Subcategories	Market share	Market share	Market share
A	7,77%		3,33%
B	39,18%	5,99%	20,22%
C	30,35%	15,92%	22,11%
D		31,43%	17,95%
E	13,41%		5,75%
J	4,27%	40,20%	24,79%
M	5,01%	5,15%	5,09%
S		1,32%	0,75%

For the determination of the evolution of the battery capacity towards 2020 and 2030, assumptions have to be made on the design of the vehicles and the desired EV range for the EV users. It is anticipated that the battery capacity and entailing range will increase in the coming years but it is expected to stay below the range of ICE vehicles [40]. Within the study of Element Energy on the cost and performances of EV batteries, the current characteristics of EV batteries within the UK market have been projected to the future, based on expected vehicle energy consumption improvements. Element Energy defined the required range by considering user requirements, cost considerations and OEM marketing decisions.

Table 7: Definition of BEV battery capacity for 2011 and projection towards 2030 [40]

Attribute	BEV 2011				BEV 2030			
	A&B	C&D	E&H	Van	A&B	C&D	E&H	Van
Range (km)	150	150	150	150	200	250	300	250
Energy consumption (kWh/km)	0.12	0.14	0.18	0.28	0.084	0.097	0.13	0.22
Max pack mass (kg)	240	300	460	500	110	180	360	400
Max pack volume (L)	180	270	360	550	100	130	280	375
Motor peak power (kW)	50	70	120	60	50	70	120	70
Assumed kerb mass (kg)	1270	1700	2300	2250	920	1280	1790	1800
Usable energy (kWh)	18	21	27	42	17	24	40	55

The projected evolution of battery capacity for both BEV and PHEV for the UK EV market can be consulted in Table 7 and Table 8. It must be noted that ‘usable energy’ refers to the required energy to achieve the target range. The total energy of the battery is actually greater than this value as batteries are generally not fully discharged/charged. Furthermore, the vehicle segment ‘H’, used in the analysis of Element Energy, corresponds to the vehicles segment ‘J’, commonly referred to in this report.

Table 8: Definition of PHEV battery capacity for 2011 and projection towards 2030 [40]

Attribute	PHEV 2011		PHEV 2030	
	C&D	Van	C&D	Van
Range (km)	30	40	80	80
Energy consumption (kWh/km)	0.15	0.3	0.11	0.24
Max pack mass (kg)	150	300	120	300
Max pack volume (L)	120	400	80	400
Motor peak power (kW)	60	60	60	80
Usable energy (kWh)	4.6	12	8.5	19.4

2.2.3. INFRASTRUCTURE

Different studies confirmed that the total number of public EVSE outlets increased with the growth of the electric car stock, confirming observations of a positive relationship between the adoption of EVs and the deployment of publicly accessible charging infrastructure. Within this regard, the IEA studied the ratio of electric vehicles per publicly available outlet for both fast and slow charging. Globally, there are 45 electric cars (of which 27 are BEVs) per each publicly available fast-charging outlet [24].

The total number of EVSE outlets available in 2015 reached 1.45 million, up from 0.82 million in 2014 and only roughly 20.000 in 2010, see Figure 10 [24]. The share of publicly available EVSE outlets stabilised after 2013 to about 13% of the total. Publicly available EVSE outlets increased to 190.000 in 2015 from 110.000 in 2014 and 50.000 in 2013.

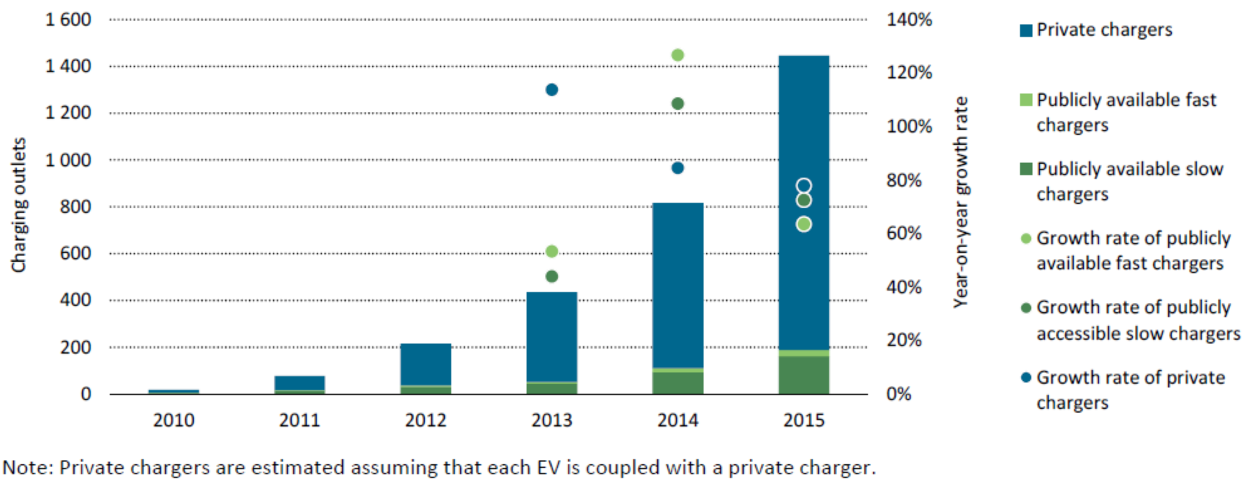


Figure 10: Global EVSE outlets, 2010 until 2015 (x1000) [24]

On a European scale, the EAFO maintains the overview of public charging infrastructure. In the last decade the number of EVSE outlets increased exponentially, Figure 11. In 2016, the total number of public EVSE outlets crossed the 100.000 milestone [41]. By the beginning of 2017, 112.681 charging infrastructure points are publicly available. A breakdown into the different types of charging infrastructure can be found in Table 9.

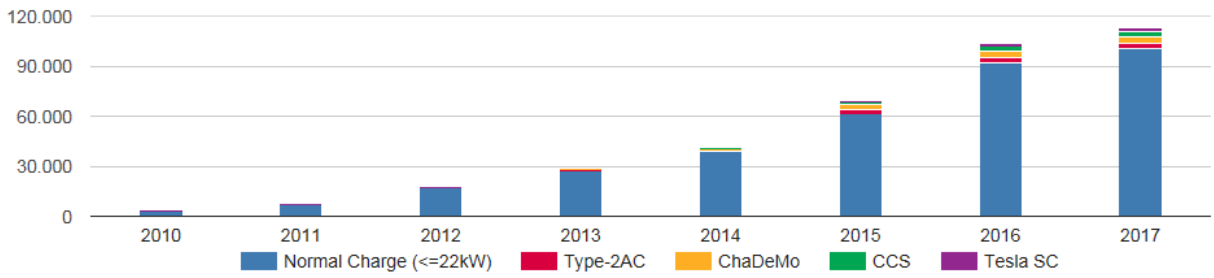


Figure 11: Total number of EV charging infrastructure points across Europe [41]

Table 9: Total number of charging infrastructure points distinguished by type [41]

Normal Charge (<=22kW)	Type-2AC	ChaDeMo	CCS	Tesla SC
100.292	**3.296**	**4.075**	**3.199**	**1.819**

In order to incentivise further EV adoption, national and local governments must support the deployment of the charging infrastructure that is indispensable to EV drivers, whether at home, at work or at public location. Global EVSE deployment projections can be assessed on the basis of the deployment targets identified for EVs, assuming current ranges of EV/EVSE average ratios. The EVSE deployment targets are depicted in Figure 12.

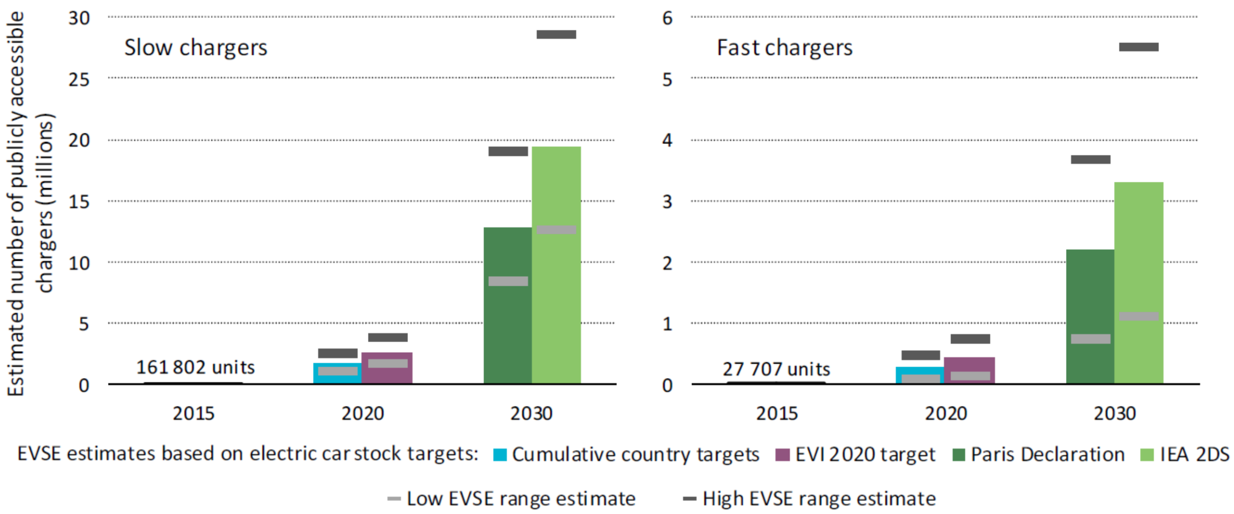


Figure 12: EVSE deployment targets implied by deployment targets for EVs, with EV/EVSE ranges maintained constant at 2015 level [24]

2.2.4. OVERVIEW OF UTILIZED ASSUMPTIONS

In this section, an overview of utilized assumptions on number of EVs in 2014, 2020, 2030 is presented, along with the assumptions on the share of smart EV charging in the total numbers.
For 2014, the number of EVs per country is obtained from EAFO webpage, and presented in Table 10.

Table 10 Number of EVs in 2014, source: EAFO

Number of EVs	2014
Austria	23.640
Belgium	34.536
Bulgaria	116
Cyprus	144
Czech Republic	2.260
Germany	147.812
Denmark	18.962
Estonia	2.370
Spain	19.230
Finland	5.710
France	166.686
United Kingdom	178.678
Greece	356
Croatia	690
Hungary	987
Ireland	3.485
Italy	17.990
Lithuania	280
Luxembourg	188
Latvia	522
Malta	188
Netherlands	224.016
Poland	1.785
Portugal	7.752
Romania	584
Sweden	58.710
Slovenia	1.024
Slovakia	412
Norway	40.000
Iceland	3.988
Switzerland	32.523
Lichtenstein	131

For 2020 and 2030, it is argued in section 2.2.1 that Scenario 2 from Table 3 and Table 4, respectively, will be used. As these numbers are for the total EU-28 area, they are distributed per country to preserve the distribution of share of EVs per land in total EU-28 EVs as it was in 2014. In Table 11, the assumed total EV numbers per country for 2020 and 2030 are presented.

Table 11 Estimated number of EVs per country in 2020 and 2030

Number of EVs	2020	2030
Austria	136.591	580.256
Belgium	199.548	847.704
Bulgaria	670	2.847
Cyprus	832	3.535
Czech Republic	13.058	55.473
Germany	854.054	3.628.124
Denmark	109.562	465.432
Estonia	13.694	58.173
Spain	111.110	472.010
Finland	32.992	140.155
France	963.107	4.091.396
United Kingdom	1.032.397	4.385.746
Greece	2.057	8.738
Croatia	3.987	16.936
Hungary	5.703	24.226
Ireland	20.136	85.541
Italy	103.946	441.574
Lithuania	1.618	6.873
Luxembourg	1.086	4.615
Latvia	3.016	12.813
Malta	1.086	4.615
Netherlands	1.294.359	5.498.591
Poland	10.314	43.814
Portugal	44.791	190.277
Romania	3.374	14.335
Sweden	339.225	1.441.068
Slovenia	5.917	25.135
Slovakia	2.381	10.113
Norway	250.000	1.560.000
Iceland	23.043	97.888
Switzerland	187.919	798.304
Lichtenstein	755	3.206

To the best of our knowledge, there are no estimations on the share of smart EV charging in future. Therefore, on basis of interactions with stakeholders, and educated guess is drawn. It is assumed that in 2014, no EVs were charged in a smart way, whereas in 2020 and 2030, it will be 50% and 75%, respectively. This is given in a table form in Table 12.

Table 12 Smart share of EV charging in different years

	2014	2020	2030
Smart share of EV charging	0,0%	50%	75%

2.3. MARKET TRENDS FOR ENERGY SMART APPLIANCES IN EEA COUNTRIES AND SWITZERLAND

The market trends for energy smart appliances are analysed in detail and presented in the report of the original study. These trends are extrapolated for periodical appliances and commercial refrigeration to the EEA countries and Switzerland proportionally to the number of households. For HVAC appliances, the stock is estimated on basis of bilateral discussions with stakeholders. The assumed quantities and installed power is presented in Table 13 and Table 14.

Table 13 Installed power of HVAC appliances in GW in EU-28 countries, Norway, Switzerland, Iceland and Lichtenstein

Installed power of HVAC appliances [GW]	EU-28	NO	CH	IS	LI
Electric radiators (without inertia)	279	25,1	1,9	0,2	0,01
Electric radiators (with inertia)	37	3,3	0,3	0,03	0,001
Heat pump (residential)	16	8,0	13,8	0	0,1
Heat pump (tertiary)	98	2,9	2,6	0	0,01
Boiler	10	0,9	0,1	0,01	0,0003
Air-conditioning (heat-pump, residential)	81	1,7	3,2	0,02	0,01
Air-conditioning (heat-pump, tertiary)	120	0,7	1,6	0,01	0,01

Table 14 Number of HVAC appliances in EU-28 countries, Norway, Switzerland, Iceland and Lichtenstein

Number of HVAC appliances	EU-28	NO	CH	IS	LI
Electric radiators (without inertia)	223.200.000	20.114.702	1.531.782	186.265	5.838
Electric radiators (with inertia)	18.500.000	1.667.213	126.962	15.439	484
Heat pump (residential)	3.200.000	1.600.320	2.760.000	0	10.000
Heat pump (tertiary)	3.266.667	1.600.320	2.760.000	0	10.000
Boiler	1.000.000	90.120	6.863	835	26
Air-conditioning (heat-pump, residential)	32.400.000	666.800	1.288.000	8.002	5.600
Air-conditioning (heat-pump, tertiary)	2.400.000	14.749	32.552	144	142

The HVAC heat-pump based appliances are split in two categories for the purposes of this study: HVAC heat pump based appliances with thermal storage, and HVAC heat pump based appliances without thermal storage. The market share of the HVAC heat pump based appliances without thermal storage (air-air based technologies) is assumed to be 65%, and the remaining 35% of market share is taken by the HVAC heat pump based appliances with thermal storage (air-water based technologies).

The extrapolation of the HVAC market to the future years (2020 and 2030) is assumed to be the same as in the original study. The amount of smart enabled appliances is assumed to increase in the future according to the same assumptions as in the previous study.

The number of periodical appliances is assumed to be proportional to the number of households in the EU-28, as well as in the EEA and CH. The number of households in 2014, which was used to assign the number of periodical appliances in all the countries, is given in Table 15. The same distribution was used to calculate the number of supermarkets for obtaining the flexibility value of commercial refrigeration.

Table 15 Number of households in 2014 for each of the modelled countries, sources: Eurostat, statista.com and www.ssb.no

Country	Number of households
Austria	3.882.534
Belgium	4.679.672
Bulgaria	3.009.974
Cyprus	315.742
Czech Republic	4.576.238
Germany	40.491.250
Denmark	2.687.369
Estonia	597.520
Spain	18.592.353
Finland	2.600.720
France	30.119.230
United Kingdom	28.092.678
Greece	4.538.505
Croatia	1.512.880
Hungary	4.289.769
Ireland	1.710.083
Italy	26.430.061
Lithuania	1.332.894
Luxembourg	231.800
Latvia	830.743
Malta	158.283
Netherlands	7.665.913
Poland	14.078.420
Portugal	4.000.408
Romania	7.373.696
Sweden	4.848.055
Slovenia	859.158
Slovakia	2.006.907
Norway	2.316.600
Iceland	124.000
Switzerland + Lichtenstein	3.399.604

The total number of the periodical appliances and m^2 for the EU-28 region and combined EU-28, EEA and CH region in 2014, 2020, and 2030 is given in Table 16, Table 17, and Table 18, respectively.

Table 16 Number of periodical appliances and areas of supermarkets in converted square meters for EU-28, and for the broader area (EU-28 with EEA and CH) in 2014

2014	Total EU-28	Total EEA-32
Dishwashers	98.345.000	100.937.874
Washing machines	196.821.000	202.010.201
Tumble dryers, no heat pump	45.572.060	46.773.571
Heat pump tumble dryers	22.445.940	23.037.729
Refrigerators and freezers (residential)	303.200.000	311.193.892
Electric storage water heaters, day	53.000.000	54.397.349
Electric storage water heaters, night	20.000.000	20.527.302
Commercial refrigeration (m2 stores)	104.489.483	107.244.357

Table 17 Number of periodical appliances and areas of supermarkets in converted square meters for EU-28, and for the broader area (EU-28 with EEA and CH) in 2020

2020	Total EU-28	Total EEA-32
Dishwashers	115.036.000	118.068.933
Washing machines	200.805.000	206.099.240
Tumble dryers, no heat pump	35.900.500	36.847.020
Heat pump tumble dryers	35.900.500	36.847.020
Refrigerators and freezers (residential)	308.000.000	316.120.444
Electric storage water heaters, day	50.000.000	51.318.254
Electric storage water heaters, night	19.000.000	19.500.937
Commercial refrigeration (m2 stores)	115.014.660	118.047.030

Table 18 Number of periodical appliances and areas of supermarkets in converted square meters for EU-28, and for the broader area (EU-28 with EEA and CH) in 2030

2030	Total EU-28	Total EEA-32
Dishwashers	148.553.000	152.469.612
Washing machines	204.744.000	210.142.092
Tumble dryers, no heat pump	3.888.900	3.991.431
Heat pump tumble dryers	73.889.100	75.837.192
Refrigerators and freezers (residential)	317.600.000	325.973.549
Electric storage water heaters, day	45.500.000	46.699.611
Electric storage water heaters, night	17.200.000	17.653.479
Commercial refrigeration (m2 stores)	140.202.229	143.898.671

In line with the literature research on market uptake and policy and regulatory circumstances, it is assumed that a significant number of home batteries is only present in Germany. Hence, in the EEA countries and Switzerland, no home batteries are modelled.

Table 19 Percentage of smart enabled appliances per year and type for the BAU scenario

Energy smart appliance	2014	2020	2030
Dishwashers	0,0%	2,0%	8,0%
Washing machines	0,0%	1,0%	4,0%
Tumble dryers, no HP	0,0%	2,0%	16,0%
Heat pump tumble dryers	0,0%	2,0%	16,0%
Refrigerators and freezers (residential)	0,0%	5,0%	20,0%
Electric storage water heaters	0,0%	5,0%	20,0%
Tertiary cooling (stores)	0,0%	10,0%	50,0%
HVAC residential and tertiary heat pump cooling and heating, with and without thermal storage	5,0%	18,0%	54,2%
HVAC residential and tertiary Joule heating	0,0%	3,0%	21,1%
EV chargers	0,0%	50%	75%

2.4. SUMMARY

In this chapter, firstly, market analysis for electric personal vehicles, batteries, and charging infrastructure is presented. Based on the market analysis, it is concluded that the study will proceed with the personal EVs and home/work charging, whereas concepts such as car sharing and fast charging will be left out of scope due to very limited flexibility.
On basis of the market analysis and trends, the assumptions on the number of EVs per country and different scenario year are drawn. Although certain relevant numbers are missing in the literature, such as estimation of share of smart charging, it was possible to deduce expert judgment estimations for EVs. The chapter also presented an extrapolation of the energy smart appliances market from EU-28 area to Switzerland, Norway, Iceland and Lichtenstein.

CHAPTER 3 USER ANALYSIS

Task 3 is about describing and quantifying the current situation for the users which will be impacted by making the electric chargers energy smart enabled.
The first part of this Task report handles end-user behaviour of owners of EVs, in particular the driving behaviour of personal EV cars. Furthermore, an in-depth analysis of possible system services for which the EVs apply is provided.
The findings that addresses data protection, data security and consumer rights equally apply to the EVs as to the other energy smart appliances, and was discussed in the task 3 of the original study. It is not repeated here.
Note that the core focus of this Task report is on the impact of the use of EVs on the end consumer and the resulting flexibility generated to feed into the use cases, making abstraction of any specific energy market structure. The findings presented here are further used in Tasks 6 and 7 for quantification of benefits from EVs. In the last section, an overview of the main drivers and barriers in taking up energy smart appliances is given along with possibilities to overcome the barriers and raise consumer's acceptance

3.1. DRIVING BEHAVIOUR

Within the Green eMotion project, a lot of information on driving profiles was collected. The Green eMotion project monitored both electric vehicles and charging points. Therefore different data is collected, such as the starting charging time, from the point of view of the electric vehicle and the point of view of the charging infrastructure. The project participants were contacted in order to obtain some insight into the relevant driving behaviour within the different pilots. Due to confidentiality issues it was impossible to receive disaggregated data which appeared in a non-public deliverable.

As an alternative, based on Norwegian data and calculation model, the distribution of charging behaviour over a one-day-timespan is used to simulate the EV charging behaviour, depicted in Figure 13 for 2014 and in Figure 14 for 2030. The Norwegian calculation model is a top-down model that takes into account the number of vehicles, their driving length and average energy use. This model is utilized to obtain charging profiles in each of the considered countries.
The assumptions to obtain charging profile for each of the countries are listed as follows. The number of EVs and the share of smartly charged EVs are already presented in section 2.2.4. The driving length is assumed to be 13.000 km/year for all the countries expect for Norway, where it is assumed to be 12.300 km/year, and United Kingdom, where it is assumed to be 12.700 km/year, on basis of assumptions that we obtained in bilateral discussions with the research institutes of these countries. Finally, average energy use is assumed to be the same for all the countries: 0,2 kWh/km. The amount of the annually drive kilometres and average consumption per kilometre are the same for all the considered years.

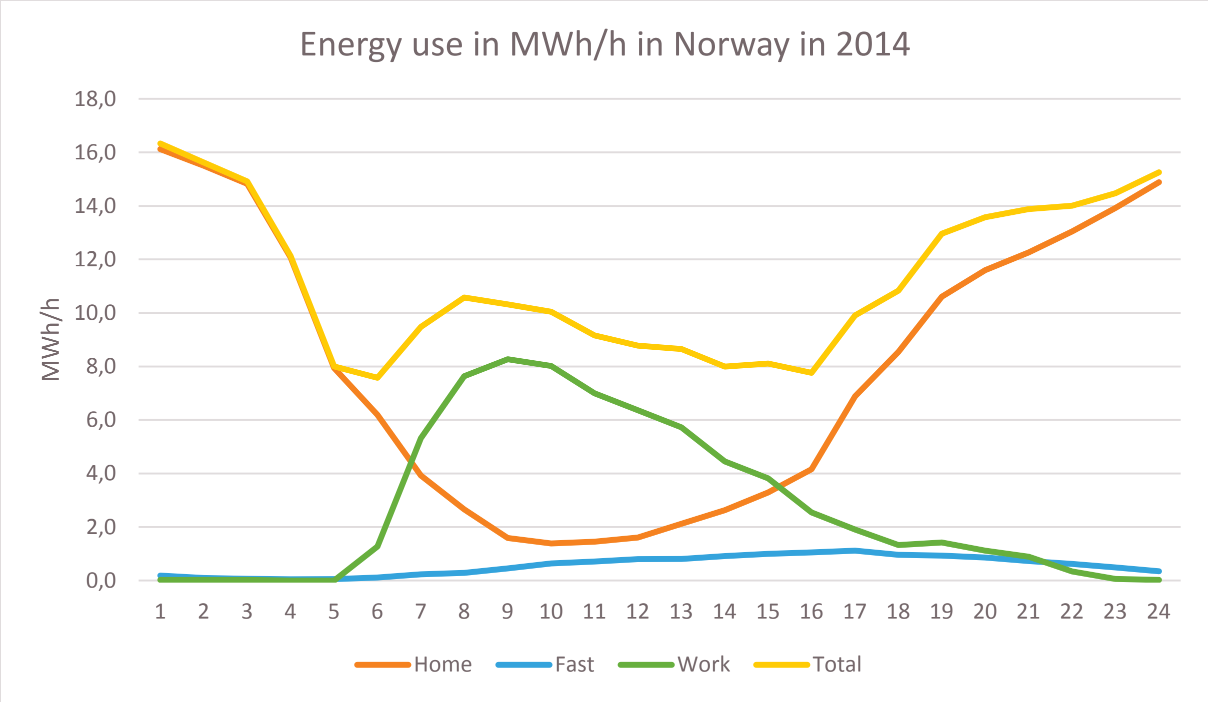


Figure 13 Estimated charging pattern of EVs in Norway in 2014

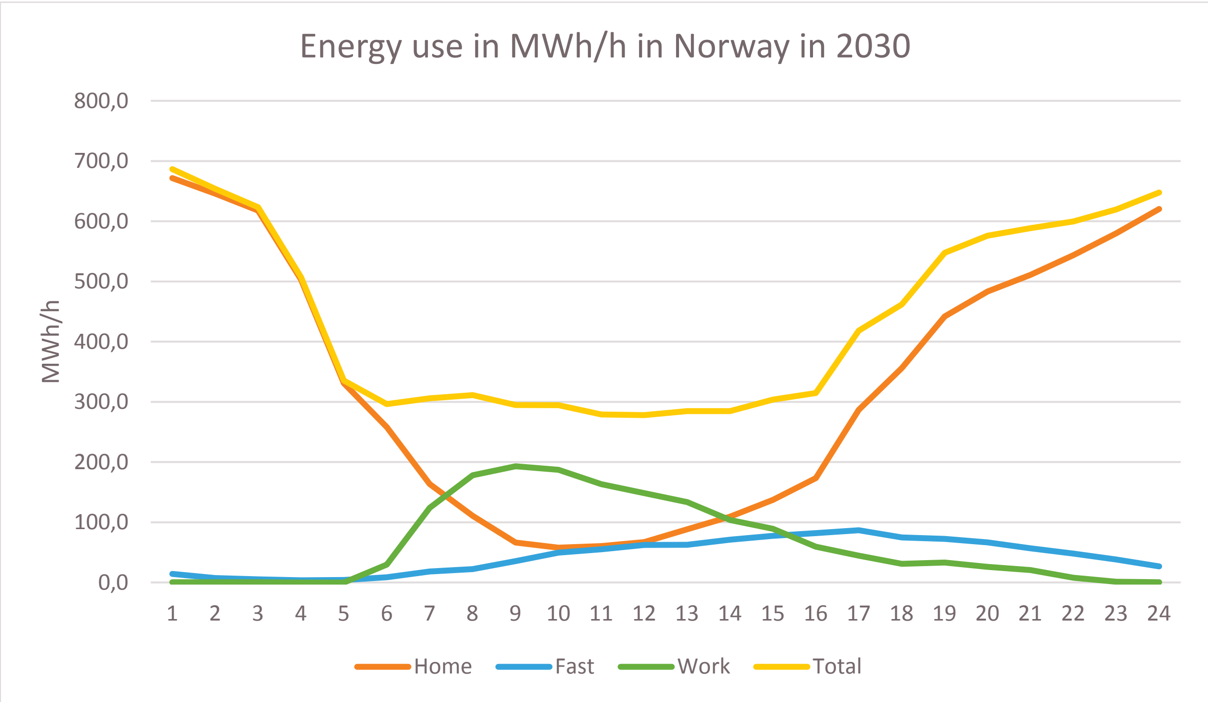


Figure 14 Estimated charging pattern of EVs in Norway in 2030

3.2. System services

In the context of electric mobility and smart charging, the topic of business cases seems to be taking on a central role. This is even more applicable when new value-adding services are introduced to the EV charging market, causing a cost reduction for the customer and improving the customer acceptance by generating benefits. Therefore, new mobility concepts and business models are required which transform the technological advantages of electric vehicles into value added for the customers. These new mobility concepts are very complex since most of the business models entail the emergence of completely new stakeholders, who have not been part of the current value chain for ICE- vehicles (e.g. energy suppliers, network operators, aggregators). The tendency towards new EV charging concepts induces the current energy market to change rapidly.

To reduce the environmental and health impact of individual transport in urban areas, an integrated approach is needed for a conversion to a sustainable electrified transport system, based on local renewable energy sources (RES). This transition must be associated with a user-friendly, grid-efficient and cost-effective integration of EVs.

Bidirectional power flows from the electrical grid towards the cars as well as from the cars towards the electrical grid are a technical possibility. Electric vehicles will mostly be connected to the grid for a relatively long period, but only need to be charged during a relatively small portion of that time. The electrical energy that is present in the car batteries can be used for several *ancillary services* at times when the car does not need the energy. The offering of these ancillary services is meant with the Vehicle-to-Grid (V2G) concept, a schematic overview of this V2G concept is pictured in Figure 15.

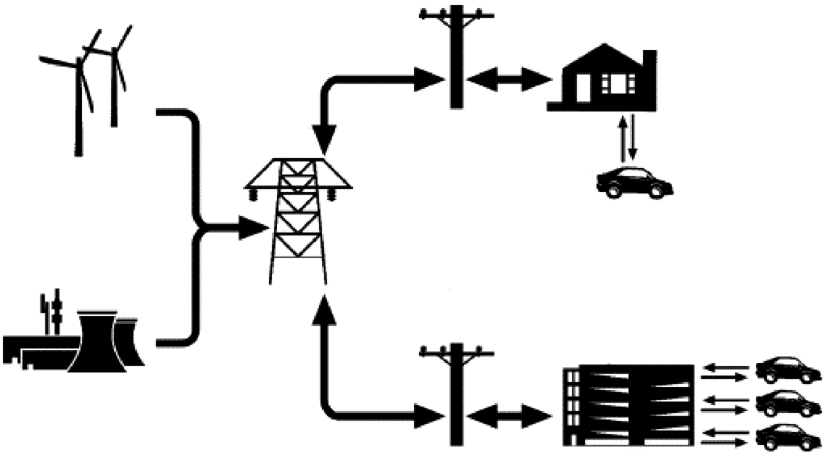


Figure 15: Schematic overview of the Vehicle-to-Grid (V2G) concept

It is not yet clear what the implications of V2G are for the lifetime of the car batteries, as constantly charging and discharging a car battery might proof to be very unfavorable for the lifetime of batteries. The question is then what the minimal price a car owner has to receive, in order to make the offering of car-energy a profitable business case.

V2G technology is extensively investigated at the University of Delaware by Professor Kempton. The University of Delaware is making a small number of BMW Mini-E EVs available for lease as part of an ongoing vehicle-to-grid (V2G) demonstration project [53]. The Grid on Wheels program will lease the vehicles for $3,600 per year, for two years. If the car is kept plugged in most of the time when not driving, owners can earn payments of roughly $100 per month [53]. In response to signals from the grid operator, a vehicle can discharge its battery in order to help keep the grid stable. BMW built a few hundred units of the Mini-E, which uses a powertrain from AC Propulsion, in 2009-2010. The company moved on to the ActiveE and its new production EV, the i3, but the Mini-E is handy for V2G applications, because it was built with a bidirectional charger [53].

3.3. DRIVERS AND BARRIERS FOR THE UPTAKE OF EV CHARGERS

(To be added in intro if this section to be added:

An overview of the main drivers and barriers in taking up energy smart appliances is given along with possibilities to overcome the barriers and raise consumer's acceptance.)

3.3.1. BARRIERS IN VIEW OF ECONOMIC ASPECTS AND REGULATORY FRAMEWORK

Some barriers are listed as follows.

- The active involvement of EV users is necessary for uptake of EV flexibility provision. The active involvement in smart charging is expected to be possible if it is mandatory, or if a clear financial incentive is provided. In the former, the policy regulation enforces the provision of EV flexibility instead of leaving it over to the market. In the latter, the customer participation needs to be remunerated or must be compensated via an energy bill reduction in order to make smart charging attractive.
- Price of EV and more in particular the battery cost in terms of €/kWh are considered to be high by an average consumer. It is expected that this barrier will be removed by technological advances and economies of scale, which are in turns expected to drive the investment costs down. This barrier could also be removed or reduced earlier by carefully thought of legislation (e.g, tax benefits) for the transition period towards the mature markets,
- Range anxiety, which is enforced by limited electric storage capacity of electric vehicles and the lack of sufficient and dispersed charging infrastructure, is also one of the barriers. Technological advances and accurate information system provided to the consumer are expected to remove this barrier.
- Electric vehicles and electric chargers are not part of (eco-design or labelling) legislation. This is due to the immature market. However, as there are currently no instruments at place, it is challenging to create policy options for energy smart electric vehicles and electric chargers.

CHAPTER 4 TECHNICAL ANALYSIS

The objective of Task 4 is to perform a technical analysis of EV charging possibilities. The focus of the Task 4 report will not so much be the products themselves (for which assessments have been carried out in the previous tasks) but that it will specifically address the implications that go along with the interoperability.

4.1. Technologies for EV chargers

Batteries can be charged at different rates depending on the requirement. There is however no consensus with regard to the terminology used to identify the different charging rates, see Table 20. All expressions used, are listed in the following table. In this report the term 'slow charging will be used for charging at < 7kW and 'fast charging will be used for charging > 22kW.

Table 20: Charging rate terminology, own elaboration

	3-7 kW	7-22 kW	22-50 kW	20-250 kW
UK	Standard	Fast	Rapid	
Ireland	Standard	Public	Fast	
Japan	Home		Quick	
China	Standard		Fast	Quick
Eurelectric	Medium power	Medium power	High power	High power
Other suggestions	Normal Slow	Accelerated	Fast	Ultra-fast

Charging times vary depending on different elements, being the current level of battery charge, the total battery capacity, the charging station's capacity and settings and the connection constraints. Furthermore, charging times will depend on the country in which the charging is performed. For an EV with a range of 160 km, it will require around 6-8 hours in Europe to charge at a regular socket (slow charging). At a charging station the charging time can be reduced to 1-4 hours. With fast charging the EVs can be 100% charged in 20 minutes.

Slow charging

Batteries of EVs can be slowly charged. Slow charging means charging at medium power rating (<7kW) which is at low voltage and current and part of the distribution grid.

Medium power charging would generally take place in:

- This type of charging mostly takes place in domestic settings like home, when the vehicles are parked at the garage or at a parking lot, which is mainly during the evening and overnight.

- Slow charging could also occur near office buildings, at small and medium enterprises (SMEs) or at the parking lot of a large company during the day.

Generally, no special equipment must be installed for charging these type of vehicles, since the vehicles can be plugged into a standard electric outlet [42]. However the installation of a wallbox at home can be recommended for safety reasons. These wallboxes are needed to avoid situations where the standard electricity outlets get burned. This wallbox entails a larger investment cost.

When charging at work, the charging points must be equipped with vandalism- and theft protection which results in a larger infrastructure cost.

In order to enable the provision of EV flexibility a controllable wallbox is necessary, requiring a minimum intelligence to allow for bidirectional communication.

Fast charging

The electric vehicle concept may gain more consumer acceptance when fast-charging infrastructure is created since it enables longer range travel for EVs. Conventional refuelling stations may choose to install high-power fast charging points to offer recharging EV similarly to refuelling gasoline and diesel vehicles. This may be an option for service stations that already have high power supplies, such as where they are built beside a garage or industrial complex.

Motorway service stations would be likely to adopt this model before service stations in other locations, as this would allow EV users completing long journeys to recharge their vehicles during rest stops. It is also likely that drivers stopping for breaks at motorway service stations would accept a recharging time of about an hour, as they may wish to stop to eat at the same time, while drivers stopping at other service stations may not wish to wait more than a few minutes where fewer facilities are available.

There are three possible impediments to fast charge stations [43]:

- the ability of the battery to absorb charge in a short time,
- the ability of the local supply system to cope with the high instantaneous loads
- the difficulty of ensuring an efficient and “user-friendly” connection between the grid and the battery.

There would be significant challenges to overcome if a service station was to offer fast charging to multiple vehicles at the same time, as this would cause a significant voltage drop in the distribution system. This would reduce transmission efficiency and create high transient loads. Hence, thought should be given to the deployment of fast charging to avoid costly upgrades in the existing power grids.

Fast charging stations entail even higher investment costs then general charging station.

Electric vehicles can be charged via different modes; i.e. conductive charging, inductive charging and battery swapping. With conductive charging a physical connection is made with the electric vehicle to charge the battery. Inductive charging uses an electromagnetic field to facilitate the exchange of energy. Battery swapping entails the full replacement of a depleted battery with a fully-charged battery. All charging models are briefly described in the following sections.

4.1.1. CONDUCTIVE CHARGING

EV charging infrastructure can be found in a variety of locations, from a EV owner's home to a workplace to (semi-)public locations. The charging method of electric vehicles will heavily depend on where customers want to charge their vehicles. A strict, future-proof categorization is difficult. However, most actors involved have established a general view on how they imagine the allocation of the different charging methods. In the mature market, the ideal number, location, and type of charging infrastructure will depend on the demand for different types of PEVs, their use, and their geographic distribution.

Figure 16 shows six categories of charging-infrastructure deployment, ranked in a pyramid that reflects their relative importance as assessed by the National Research Council [46]. The term intercity refers to travel over distances less than twice the range of limited-range BEVs, and interstate refers to travel over longer distances.

It should be noted that the presence of charging infrastructure and the elaboration of a charge point strategy is of more importance for BEV than for PHEV. PHEVs do not require electric charging for range extension because drivers have the option of fuelling with gasoline. BEVs, which have only electricity as a fuel option, are much more affected by the availability of charging infrastructure.

Furthermore, it should be taken into account that moving along the pyramid of possible charging locations there is a decreasing amount of flexibility. The charging behaviour at home locations concerns arrivals in the late afternoon and evening and departures are commonly in the morning, leading to long sojourn times and thus large flexibility frameworks [48]. Work charging entails vehicles being plugged in during working hours. In this case sojourns average around 8-9h, resulting in daytime flexibility, particularly compatible with night-time flexibility, available via home charging [48]. Public charging behaviour exhibits shorter stand still times and thus entail a limited volume of flexibility.

Figure 16: EV charging infrastructure categories ranked by importance [46]

Fortum, a large power company in the Nordics, is also a leading full service EV charging operator in Nordic countries. Fortum suggested a preferred charge point roll-out strategy, depicted in Figure 17 [47]. Within this charging model it is assumed that simple EVSE outlets will be deployed at home, both single- and multi-dwellings, and at work. Furthermore, they foresee public charging at street-side parkings and retail locations. Next to normal charging, fast charging infrastructure is envisioned, providing a similar concept as conventional gas refuelling stations.

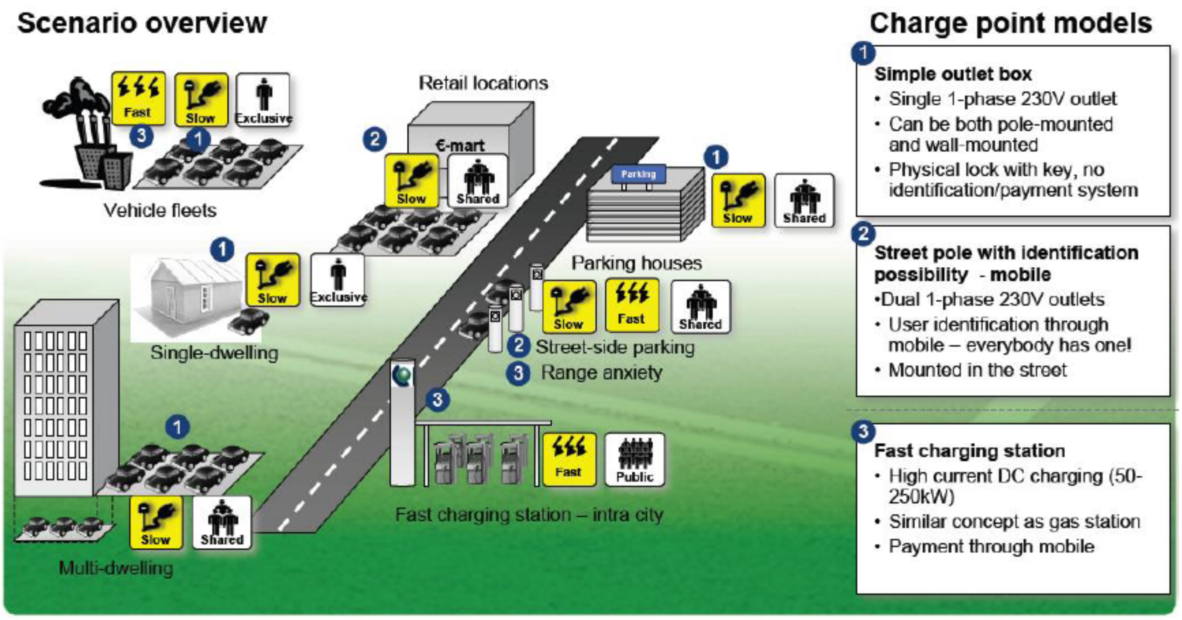


Figure 17: Fortum charge point roll-out strategy [47]

Within the Grid for Vehicles project, ECN conducted a survey concerning user preferences for charging locations in eight EU countries [45]. Respondents to the questionnaire indicate a preference for a combination of home/work charging spots and public charging spots. People living in smaller communities (less than 100.000 inhabitants) favour home/work charging while people living in large cities appear to be more afraid of being 'stranded'. Hence, fast, public charging infrastructure can help to reduce this fear of city dwellers.

Home

There is a general consensus (in both academic research and pilot projects) that the vast majority of vehicle charging will be undertaken at home. Even when people do not have access to a private parking place, home charging is preferred.

In applications whereby only one vehicle user requires access to a charge point, the domestic charge point is a sensible option. These are scaled down versions of the street side charge post and are typically limited to the basic safety and functional elements to provide mode 3 charging[9] of an electric vehicle.

Work

Another frequently visited charging location is workplace charging infrastructure. This charging location is considered the most important secondary charge point after home charging, especially

[9] With Mode 3 charging, the vehicle is connected directly to the electrical network via a specific socket and plug and a dedicated circuit. A control and protection function is also installed permanently in the installation.

since with a limited market uptake of EVs, the roll out of (semi-)public charging infrastructure can be very costly and a slow process. Work charging locations are particularly suited to providing charging facilities for users who need to recharge on a daily basis e.g. longer distance commuters. It also builds range confidence as it extends the driving range.

Private charging infrastructure at workplaces is likely to be funded by the businesses or organizations. Especially since taking care of the operating costs can be a perk to attract and retain employees. The Employer EV Initiative suggests clear benefits for the employer [49];

- Work charging can be a tool to recruit and retain a talented employee
- It can also contribute to an environmental friendly corporate image
- Given the lower operating costs of EVs, the employer can realize costs savings by switching to electrified company vehicles
- Certain EV privileges (e.g. designated driving lanes, preferential parking) can entail shorter commute times and increase productivity
- Employers can have an extra incentive to encourage electric commuting due to regulations

The benefits for the employee, the EV driver, are obvious. Range anxiety is decreased by allowing the employee to charge at work and increase the daily driving range. It also allows a broader range of drivers to switch to an EV since the driving range can potentially be doubled.

(Semi-)public

Public charging points, especially within cities are designed for supplementary use; it is generally accepted that EV drivers will rely upon their charging point at home 80-85% of the time. The concrete requirement for public and semi-public charging infrastructure remains an area for speculation. For marketing purposes a charge point might be installed on certain highly visited locations to raise awareness and provide a visible promotion of electric vehicle adoption. However, the question is for how long this objective will be applicable. A well-though deployment strategy for public charging infrastructure needs to be worked out.

One commonly accepted purpose of public charging is the facilitation of longer journeys in an EV with fast charging. Fast charging points, high powered units that can recharge an EV’s battery to 80% capacity in less than half an hour, are placed along the road or motorways to enable a fast refill of a depleted battery. In fact, EVs are ideal for urban commuting where travelling is limited to shorter distances. Since the average daily travelled distance for 80-90% of EV drivers is limited to 50 km most of the charging sessions can be limited to home and work locations. However, if EVs are to be normalized and pushed into the mainstream, (semi-)public charging infrastructure is crucial.

On-street fast chargepoints are installed as a safety blanket for when an EV driver either forgets to charge at home or needs a top up. The presence of this back-up plan of public charging points gives the EV driver an extra assurance if they should run out of charge, countering range anxiety. Since range anxiety is often mentioned as one of the fundamental aspects hampering the widespread market penetration of EVs, the presence of public, fast charging points can create a paradigm shift.

Fast chargers are not compatible with all EVs as a dedicated DC connection point is required to interface to these chargers. They are physically quite large and expensive so are only really suited to public applications whereby a large number of users are likely to benefit.

4.1.2. BATTERY SWAPPING

An alternative and faster means of replenishing a vehicle's range than charging would be to replace a depleted battery with a fully-charged battery. Better place for example, proposed a network of battery swapping stations, at which standard vehicles could have a battery swapped by a robotic system in a number of minutes.

This would achieve a similar refuelling time to that of a conventional vehicle. In addition, this would reduce the transients on the grid if batteries could be charged more slowly over longer periods of time. This model would not only provide a refuelling time equivalent to that of a ICE-vehicle, but a successful battery swapping station infrastructure could potentially eliminate range anxiety, remove the issue of battery life as a concern for the consumer and separate the cost of the battery from the cost of the vehicle [51].

The charging of the depleted batteries however, would have to be intelligently managed. An adequate supply of fully-charged batteries must be available when consumers arrive at the station, but without having to carry an excessive stock of batteries to meet the demand.

A key point is the fact that this model requires a significant change in the warranty structure of batteries compared to conventional vehicles as the responsibility for maintaining batteries must lie with the swapping station company rather than the manufacturer or vehicle owner.

Another issue herein is interoperability. This system requires, on the short term, a lot of standardization of the battery and the location within the vehicle. Due to this fact, several (vehicle and battery) manufacturers are sceptical towards the battery swapping model.

Due to the various uncertainties and the limited amount of good examples, this charging concept is out of scope in this analysis.

4.1.3. INDUCTIVE CHARGING

Inductive charging is yet to become a mainstream product. Inductive power transfer (IPT) requires compatible coils mounted in the road and under the vehicle along with a communications and alignment system to monitor and control the energy transfer. Presently these systems are bespoke and a complete system from one manufacturer is required.

When considering inductive charging, a distinction can be made between stationary and dynamic charging. Stationary inductive charging consists of an on-board unit, which is directly mounted on the vehicle underbody structure. To start the process of charging the vehicle has to be parked above the stationary unit, which can be placed at the central position of a parking lot, i.e. directly beneath the parked vehicle. Dynamic inductive charging is referring to the charging process where electric vehicles are charged while driving.

The big issue with inductive charging is the ability to guarantee interoperability of inductive charging systems of different suppliers and vehicle manufacturers.

The key advantage of inductive charging is the increased connectivity and thus larger timespan the EV flexibility is available to the system. This is due to the fact that once the vehicle is parked correctly, the EV is automatically connected to the inductive charging system.

4.2. Interoperability of EVs and EV chargers

Electric vehicles can play an important role in the market of "demand side flexibility" and many market actors are interested in the valorisation of these services from their specific point-of-view. The purpose of Task 1 was not to describe the market and business models itself, but when talking about interoperability it is unavoidable to take the market and business models behind it into account.

Interoperability needs to be considered on different levels: from the technical level (hardware and software) up to the organisational level. Many choices have to be made when new products and services are being developed and put into the market. The market of electric mobility is growing but can still be considered as a relative new market in which many new products and services are being developed and introduced at the same time. This requires huge investments and to make sure that the public and private money is spent wisely, it is crucial that we strive for an open market in which new products and services can be introduced easily and at the lowest cost. Interoperability is not only crucial from economic point-of-view, but even more important for the easy-of-use of the end customer.

Public charging infrastructure is a good example of a relative new market in which plenty of choices had to be made which have an impact on the interoperability between the installed charging infrastructure networks. On the hardware level choices have to be made e.g. on the needed type of plugs and on the required power levels (AC or DC, normal or (ultra) fast, …). On the software level choices had to be made e.g. on the type of authentication systems (RFID card, SMS, apps, …), billing systems (subscriptions prepaid and post-paid, ad-hoc, …) and all communication systems and protocols between the different electric mobility products and market actors.

Many public and/or private initiatives have been set up to stimulate the roll-out of a European-wide public charging infrastructure. Most initiatives took into account the "interoperability challenge" by addressing some of the aspects to strive for an "open and easy accessible market" for the market actors and for the end customers.

Governments from all levels (European, national, regional and city level) tried to play an enabling role in stimulating the roll-out of charging infrastructure. On the European level initiatives like the "Clean Power for Transport" directive stimulated the national governments in setting up "national action plans" describing the ambitions and supporting actions for rolling out extra public charging infrastructure. These national action plans needed to be submitted to the EC in November 2017 and 17 member states managed to keep this deadline. An assessment by the EC will follow later.

Via FP7 and H2020, many projects focussing on electric mobility have been funded and some of them worked on interoperability related issues like Green eMotion (http://www.greenemotion-project.eu/). The main objectives of Green eMotion were:

- Setting a framework for pan-European interoperable electromobility which is commonly accepted, user-friendly and scalable.
- Integrate smart grid developments, innovative ICT solutions and different types of EUs various urban mobility concepts.
- Enable a European wide market place for electromobility to allow for roaming.
- Providing a unique knowledge base.

Also in the more recent H2020 call "GV.8-2015. Electric vehicles' enhanced performance and integration into the transport system and the grid" a lot of attention was given to smart charging related aspects.

The project ELECTRIFIC "Enabling seamless electromobility through smart vehicle-grid integration" (http://electrific.eu/) targets on the third domain of the call: Integration of the overall cycle of EV energy management into a comprehensive EV battery and ICT-based re-charging system management, providing ergonomic and seamless user support. Abstract: ELECTRIFIC will revolutionise how electric vehicles are integrated into power grid and users' life. The fundamental premise on which the project will work that significant improvements to electromoblity can be unlocked by increasing coordination of all the actors in the electromobility ecosystem. To this end, the project will deliver novel techniques and ICT tools for enabling such coordination at all levels of the ecosystem. At the grid level, the project will develop new smart charging stations capable of dynamically controlling charging rate, maximizing the use of renewables and making as grid-friendly as possible. At level of EV users, the project will develop advanced driver assistance services that help and motivate the users plan travel and charging in a way that is convenient and yet respects potential constraints on charging capacity.

Also the project NeMo "Hyper-Network for electroMobility" (http://nemo-emobility.eu/) is tackling some of the smart charging related aspects. Abstract: Electromobility is a major factor towards transport decarbonisation. However a number of challenges (limited charging options, lack of interoperability, absence of a unified identification/payment process, energy grid overload, expensive charging tariffs) limit the potential for interoperable and seamless electromobility services to a wider of actors and geographic area, hindering electromobility adoption. These challenges stem from lack of standardisation in electromobility data and services. NeMo addresses all issues through a pan-European eRoaming Hyper-Network that allows seamless and interoperable use of electromobility services throughout Europe. In addition it provides an Open Cloud Marketplace, where third parties can provide services (B2B2C) aiming to increase EV attractiveness. The NeMo Hyper-Network is a distributed environment with open architecture based on standardised interfaces, in which all electromobility actors, physical (i.e. CPs, grids, EVs) or digital (i.e. CPOs, DSOs, etc.), can connect and interact seamlessly, exchange data and provide more elaborate electromobility ICT services in a fully integrated and interoperable way both B2B and B2C. The connection will be based on dynamic translation of data and services interfaces according to needs of the specific scenarios and involved stakeholders. NeMo is not just another proprietary platform for electromobility but a full open eco-system allowing continuous and uninterrupted provision of data and services. NeMo will raise awareness, liaise with standardisation bodies and contribute to the evolution of protocols and standards by developing public Common Information Models which incorporate all existing electromobility related standards and constantly update them to reflect standards evolution. NeMo will also propose sustainable business models for all electromobility actors opening new opportunities for SMEs and EU Industry.

But industry related initiatives also started to work on interoperability and "pre-standardisation" like eMI3 (http://emi3group.com/). Under the umbrella of ERTICO – ITS Europe, the eMobility ICT Interoperability Innovation, eMI³, is an open group of significant actors from the global Electric Vehicles market who joined forces to harmonize the ICT data definitions, formats, interfaces, and exchange mechanisms in order to enable a common language among all ICT platforms for Electric Vehicles. The eMI³ core objectives lie in the development, publication, sharing and promotion of ICT standards.

Standardisation is an important part to reach interoperability and many EU working groups are dealing with EV charging within the framework of CEN/CENELEC, IEC, … However, electric mobility is not only taking place in Europe and since most OEMs are active worldwide these standardisation activities like SAE, IEEE, … also have to be taken into account. We also see that standardisation groups like OpenADR and EEBus, with a broader scope than electric mobility, are starting to have an interest in the role that electric vehicles van play in the energy market. OpenADR has a specific Residential Electric Vehicle (EV Charging) DR Program: A demand response activity by which the cost of charging electric vehicles is modified to cause consumers to shift consumption patterns. EEBus is a non-profit organization for interoperability and is Europe's leading initiative in the area of the Internet of things. With a consistent focus on standardization, EEBus wants to make cross-domain and technology independent interoperability possible for everyone. EEBus has its roots in the sector of smart and renewable energy. Originated in the beacon and research project ("E-energy") funded by the German government, a global initiative has arisen which brings the leading stakeholders of the energy, telecommunications, electronics and automatization industries together. EEBus is focusing on the use cases of the sectors of energy smart, smart home & building, connected devices (domestic appliances, heating and air conditioning), connected car and open up the new market of smart connectivity.

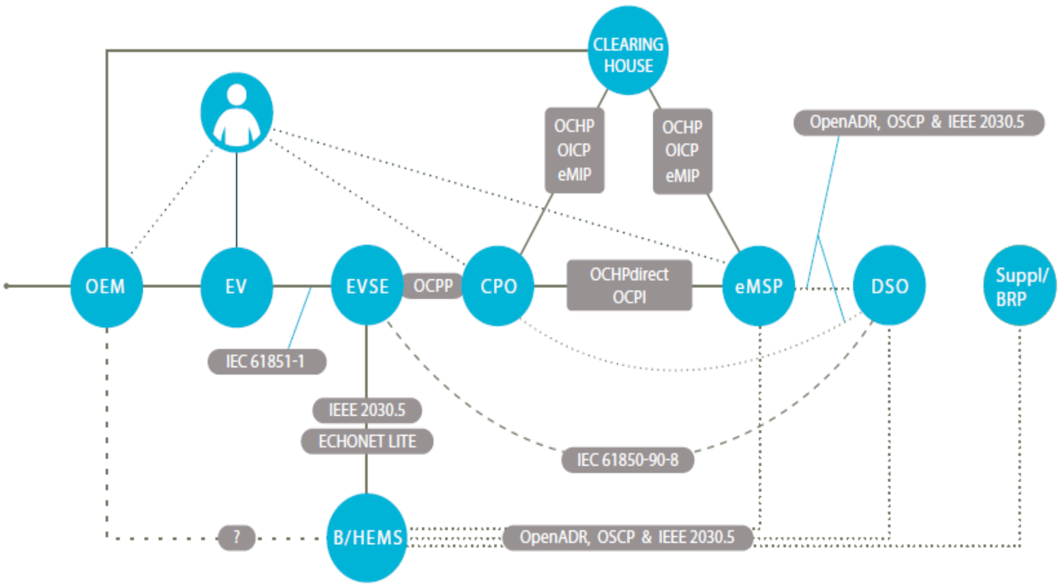


Figure 18 Overview of protocols in "EV related protocol study" from ElaadNL

A very interesting overview on the different protocols used between the different electric mobility market actors (EV, EVSE, DSO, Clearing Houses, …) can be found in the "EV related protocol study" from ElaadNL (https://www.elaad.nl/). It is a recent document from December 2016 giving an overview of the different functionalities we can expect from all existing protocols on the market today. From ElaadNL's role as a knowledge and innovation center in the field of EV charging, this study aims to give more insight in a set of protocols that is currently in use in Europe and to clarify their relationship to the electricity grid. The study addresses the question which (set of) protocol(s) is best applicable for which functionality in different types of situations. The report has been reviewed by a number of protocol experts (for some protocols even the original authors) to make sure the functionalities mentioned in the report are correct and up-to-date. The study gives a good overview how the market is evolving since it identifies for each of these protocols which functionalities it supports and how it scores on interoperability, maturity, market adoption and openness.

PROTOCOL	OSCP	OpenADR	OCPI v0.4	IEEE 2030.5	OCPP	61850-90-8	OCHP	OCPI 2.1	OICP	eMIP	IEC 61851	ISO 15118
	SMART CHARGING				CS <> CP		ROAMING				EV <> CP	
Authorize charging session			•		•		•	•	•	•		•
Billing					•		•	•	•	•		
EV Charging											•	•
Handle registration		•		•				•				
Manage grid	•	•		•	•	•						
Operate Charge Point					•	•						
Provide charge point information			•				•	•	•	•		
Reservation			•		•		•	•	•			•
Roaming			•				•	•	•	•		
Smart Charging	•	•	•	•	•	•	•			•	•	•

Figure 19: Overview supported use cases per protocol (Source: ElaadNL)

Addressing "demand side flexibility" from the EV home charging perspective is just one small part of the whole "interoperability puzzle". In the "EV related protocol study" from ElaadNL it is clear that "smart charging" is getting more and more attention. This involves charging in the public, semi-public and private domain.

The Netherlands is setting up a national "Living Lab Smart Charging" platform (https://www.livinglabsmartcharging.nl/nl/) in which companies (from multinationals to small tech start-ups, both national and international), universities, local and regional governments and grid operators cooperate to develop and test new products and services. Already 325 municipalities (including Amsterdam, Rotterdam, Utrecht and The Hague) have joined the Dutch Living Lab Smart Charging scheme, representing 80 percent of all public charging stations.

A lot of the experiences from the public charging infrastructure domain can be translated to the home charging domain, but also some specific new challenges can be found when addressing "demand side flexibility" at EV home charging level. Many individual EV owners need to be involved and this will be a much more intensive process for "aggregators" than when addressing "demand side flexibility" at big fleet owners. Fleet owners will have more electric vehicles in portfolio and are paying more attention on the economic costs of handling this fleet. Total-Cost-of-Ownership is not new for them and companies are more susceptible for the potential economic benefits of demand side flexibility. For individual EV owners it will be more difficult to make them invest in a "smart charging ready" (and thus more expensive) wallbox, since buying an EV is already a big investment for them. However, investing in a "smart charging ready" and connected wallbox is a first way to address the "demand side flexibility" (DSF) an EV offers. A second way to involve the DSF of an EV is via the EV OEM back-office itself. A third way can be via a HEMS (Home Energy Management System) especially for EV owners that also invested in local renewable energy production like solar panels or other "energy smart appliances".

As mentioned before, there are many different ways how to address the "demand side flexibility" when charging an electric vehicle. Due to the eCall system which will be introduced in all new cars in 2018, more and more vehicles will be "connected" and this also offers a potential for a lean solution for smart charging. Mobile phone applications are being developed to allow its users to earn money by using this technology to charge the car automatically e.g. in the middle of the night when wind power is generated but there is little demand for it and prices could be low. An example of such a mobile phone app is e.g. Jedlix, an active partner in the Dutch "Living Lab Smart Charging". They launched their smart charging app for iOS and Android early 2016, connecting over 1.000 public charge stations for all full electric and plugin-hybrid cars. The app manages the charging of the electric car and selects the optimal charging moments. How does it work? The EV driver defines the car model and departure time in the app. The app is combining your personal preferences and the use of the best available charging moments on the real time energy market, saving money and together increasing the share of renewable energy. Jedlix controls the charging process at compatible charging stations and makes sure the car is fully charged at the desired time and the EV driver gets a financial incentive too. Jedlix has recently developed a unique new feature for Tesla drivers. As of January 2017 these users can also smart charge at their home charge point using the connected car. Jedlix can use the Tesla platform for data exchange after users 'opt-in' through their My Tesla account. This shows that the market is constantly looking for new ways to address the "demand side flexibility", also when charging at home.

When making an investment to address the "demand side flexibility" from electric vehicles when charging at home, interoperability plays an important role to avoid "vendor lock-in" and to get an open and future-proof solution with equipment that is able to communicate with each other. The "EV related protocol study" confirms that many combinations of protocols are possible but no combination of protocols is considered as a "silver bullet" for all current and future situations.

However, some main conclusions drawn from the study are that:

- the next step for roaming protocols seems to be the addition / extension of smart charging functionality.
- a choice is to be made whether point-to-point protocols or a clearing house type of communication is to be pursued, or perhaps both.
- an important smart charging aspect of 15118 is the retrieval of the state of charge. In some cases, this information can also be retrieved via OEM platforms but only through specific, non-standardized interfaces. For the short term a next step in the protocols related to smart charging, could be the addition of connections to different OEM platforms for getting this state of charge using an open standard.

When looking at the current state of the protocols under consideration, it is recommended to put more work in the smart charging aspects of the existing roaming protocols and to take a next step in roaming platforms (e.g. connecting, merging). In order to accelerate the adoption of smart charging, the state of charge and time of departure are crucial pieces of information. For getting the state of charge it is recommended to focus on open protocols to include OEMs in the EV domain. In the longer term, the ISO/IEC 15118 protocol seems to be an alternative for this, this protocol however does not seem to be implemented in the short term. The first EV's with ISO/IEC 15118 basic functionality ("plug & charge") are expected in mid-2018.

When the time of departure is needed, communication with the EV user might be necessary, either directly or via the EV (ISO/IEC 15118). A new protocol could be of use here, but this choice is left to the commercial parties in the EV market. If a protocol is desirable, an "open" protocol should be preferred to avoid lack of adoption due to interoperability issues. When purely looking at protocols, communicating grid limits or dynamic prices is already possible. However, current legislation in most countries is not yet prepared for dynamic pricing or setting grid limits from a power system operator.

It is recommended that this legislation is changed (perhaps even equalized) to make it possible to utilize the flexibility EVs have to offer to the energy transition.

4.3. CONCLUSIONS

Based on the information collected on EVs, which was presented in chapters 1-4, and which encompasses 1) scope and standards, 2) market analysis, 3) user analysis of profiles, and 4) technical analysis of EV chargers, it can be concluded that the EV chargers have high potential for provision of demand response. Therefore, they will be further considered in the update of tasks 5 and 6 of the Preliminary study (Definition of base cases and design options), where the value of EV charger flexibility will be determined in the context of reference years 2020 and 2030.

Although there are many studies, research efforts, pilots, and sometimes even commercial products that focus on the technical and economical capability of EV chargers to provide demand response, the publicly available data is often limited and far from representative. Therefore, additional assumptions and simplifications were taken where necessary in the further considerations of the follow up study. Wherever possible, the sources and assumptions presented in this chapter were utilized.

CHAPTER 5 DEFINITION OF BASE CASES

The purpose of this chapter is to presents results of the following two goals of the second phase of the study:

a) the inclusion of the EEA countries (Norway, Iceland, Liechtenstein) and Switzerland into the assessment, and of
b) holistic evaluation of the impacts of energy smart appliances including EVs in the EU28 area extended with Norway, Iceland, Liechtenstein and Switzerland.

The inclusion of the EEA countries can be split into several subtasks:

1. Evaluation of the flexibility potential of energy smart appliances in Norway, Iceland, Liechtenstein and Switzerland.
2. Data collection and approximation:
    a. collecting and processing data from different sources
    b. building up the assumptions for missing information
    c. data synthesis for the missing data
3. An extension of the methodology to model generation types, which are more represented in the EEA countries and Switzerland, in more detail, such as
    a. geothermal fired power plants
    b. pumped hydro storage
    c. hydro power plants.

The results of the first subtask, evaluation of the flexibility potential of energy smart appliances in Norway, Iceland, Liechtenstein and Switzerland, are described in section 2.3. The second two points are described in this section.

In order to quantify the economic and environmental benefits of energy smart appliances from an energy system perspective, the following key performance indicators (KPIs) are considered relevant:

1. KPI1: Economic value in terms of total energy system costs. This KPI quantifies the avoided costs related to the more efficient use of the energy system following the achieved flexibility.
2. KPI2: Total amount of CO_2 emissions over the considered period. This KPI quantifies part of the environmental benefits of decreased utilization of the less efficient and more CO_2 emitting peak power plants in the system.
3. KPI3: Energy efficiency of the utilized generation mix over the considered period. For the purposes of this report, the efficiency is defined as the quotient of the output energy (produced electrical energy) and the input energy (the total primary energy) used to fire the different types of power plants. This KPI more specifically reflects the increased share of Renewable Energy Sources (RES) integrated in the generation mix, and decrease in utilization of low efficient, often peaking, generating units. Energy efficiency of the utilized generation mix as defined here is related to the primary energy savings in the electricity production. It is not related to e.g. decrease in total consumption (load shedding).
4. KPI4: Primary energy savings [TWh] due to utilisation of energy smart appliances. This KPI is closely related to KPI3, where the efficiency of the total generation mix is expressed as quotient of output and input energy. This key performance index is useful as it gives a guideline of maximum additional energy consumption of energy smart appliances for interoperability and connectivity energy consumption.

A generic optimisation model, which was developed for the purpose of the original study, is now extended to incorporate the EEA countries and Switzerland, and to incorporate the flexibility from EV charging. To quantify the KPIs, the model is run over a time horizon of one year for each of the three chosen benchmark years: 2014, 2020, and 2030.

5.1. ASSESSMENT MODEL DESCRIPTION

A generic optimisation model developed for the purposes of the original study to assess the value of flexibility from the energy smart appliances is extended to include the additional countries in the model, and to include flexibility of electric vehicles and hydro pumped storage. The task 5 report of the original study explains the model in more detail. In this section, the adaptations of the model are briefly explained.

The developed model is an extension of the unit commitment (UC) model described in [1]. The model is utilized to determine the optimal schedule and costs of a given set of power plants over the considered time period, for the specified input data, as presented in Figure 20. Optimality is defined in terms of minimizing the total costs over the considered time period.

The total costs are defined as the sum of fuels costs, variable operational and maintenance costs, ramping costs, start-up and shut-down costs for generator units, CO_2 emission costs, variable RES (VRES) curtailment costs, and costs of loss of load.

The model takes into account the technical constraints of each type of generation technology, transmission system constraints, and also the energy balance constraints.

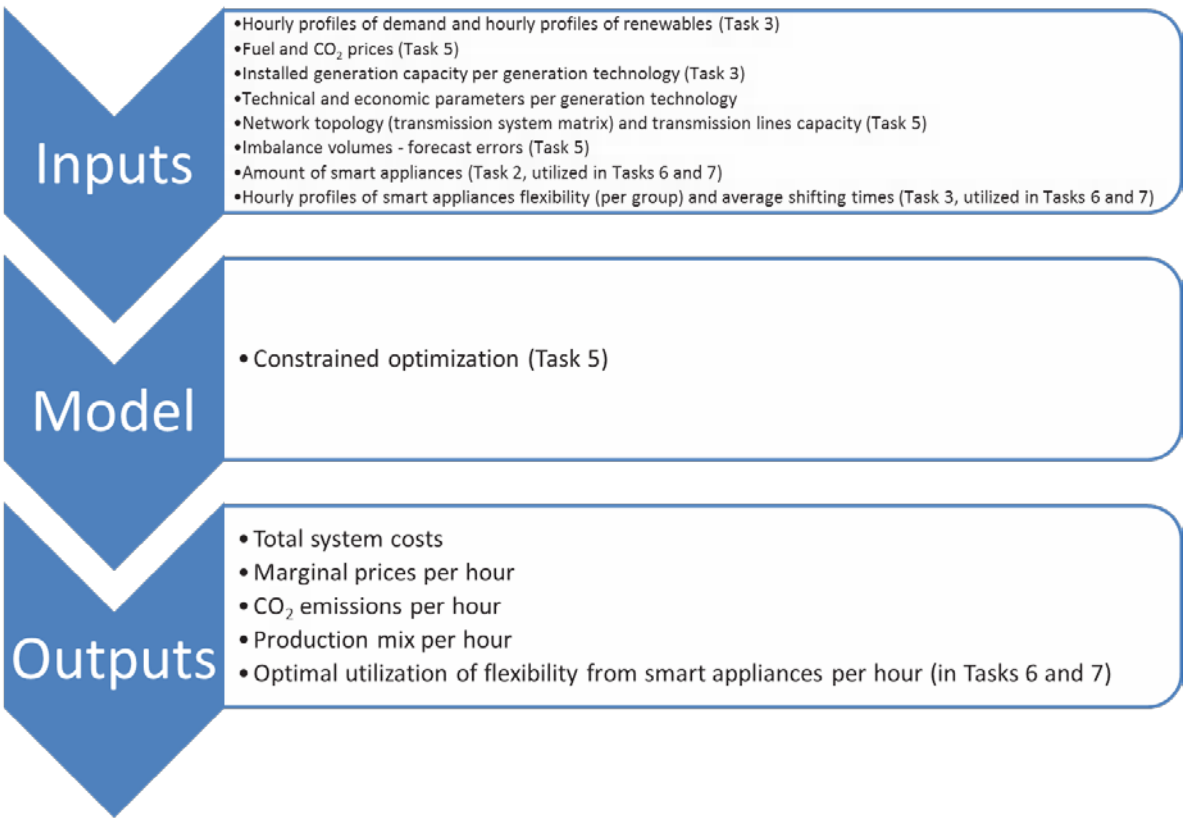


Figure 20 Overview of inputs and outputs of the utilized model.

The model is optimized, and as a result, relevant indicators are obtained for assessment of benefits of energy smart appliances flexibility, such as: the total system costs, marginal electricity prices per hour, CO_2 emissions per hour, and utilized production mix to serve demand (per hour). In Task 6, where the model is extended to include the flexibility from energy smart appliances, the optimal utilization of flexibility from energy smart appliances per hour is also one of the outcomes of the optimization (only in Task 6).
The utilized indicators are defined in the next section.

5.2. DEFINITION AND COMPUTATION OF KPIS

The definition and computation of the three key performance indices (KPIs) remains the same, namely:

1. KPI1: Economic value – total system costs [€/MWh].
2. KPI2: Total amount of CO_2 emissions over the considered period [Mt].
3. KPI3: Energy efficiency of the utilized generation mix over the considered period (defined as produced electrical energy divided by the total primary energy utilized to produce the electrical energy) [%].

In addition, primary energy savings that were expresses in the report as well in TWh is defined as an additional KPI:

4. KPI4: Primary energy savings [TWh].

For the calculation of the KPI, for hydro, geothermal, wind and solar power plants, the energy efficiency factor of 100% is utilized, although this is not the real efficiency factor for these types of power plants. This is justified by absence of primary energy that was utilized to fire the hydro, wind and solar power plants. In line with the definition of efficiency used for the purposes of this report, and because hydro, solar and wind power plants are not fired in the same way as for instance thermal power plants, their efficiency is set to 100%.

5.3. ASSESSMENT DATA

5.3.1. TRANSMISSION NETWORK

The transmission network within EU28 and EEA area is modelled by means of the net transfer capacity (NTC) matrix. NTC values can be adapted seasonally, and are in general computed ex-ante at several important moments before real-time: year-ahead, month-ahead, and day-ahead. We utilized month-ahead data wherever possible, and where not possible, year-ahead computed NTC values were utilized. All the data, for all EU-28 and EEA countries, can be downloaded from the ENTSO-E transparency portal[10], under the tab “Transmission”. High voltage DC (HVDC) interconnector capacity was also taken into account.
For 2020 and 2030, the network capacity in the model is extended according to expectations presented in the ENTSO-E Ten-Year Network Development Plan (TYNDP) from 2014[11].
Iceland is modelled as an isolated system, as it is not connected to any of the other considered countries. This is done for all the scenarios. Although there are some plans for building an

[10] ENTSO-E transparency portal is at transparency.entsoe.eu
[11] All the documents related to the ENTSO-E Ten-Year Network Development Plan can be found here https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx

interconnector between Iceland and the UK (Project IceLink[12]), the project is not confirmed at the moment of conducting the study, so it will not be considered.

5.3.2. FUEL AND CO_2 COSTS

The utilized fuel and CO_2 prices adapted according to PRIMES 2016 reference scenario. The exact price values are given in Table 21 and Table 22. The values are updated compared to the original eco-design preparatory study. Important element to review is the potential inclusion of financial subsidies for technologies such as biomass as this will influence the marginal cost of these power plants.

Table 21: CO_2 prices per reference year

	2015 (2014)	2020	2030
Carbon price ETS sectors (€'13/ t of CO_2)	7,5	15,0	33,5

Table 22: Fuel prices per fuel type and reference year

PRIMES 2016 utilized prices converted to €'16/MWh			
	2015 (2014)	2020	2030
Diesel oil			
Power generation	60,69	72,21	82,89
Fuel oil			
Power generation	32,93	46,80	56,99
Natural gas			
Power generation	21,65	24,03	26,62
Solids			
Hard coal – PG	10,36	12,38	16,00
lignite – PG	7,72	8,07	8,15
Biomass			
Power generation	26,76	29,56	31,85

5.3.3. LOAD SHEDDING AND VRES CURTAILMENT COSTS

The assumptions on load shedding and VRES curtailment costs are kept the same as in the previous preparatory study.
More precisely, the load shedding costs are defined as the multiplication of the total shed load by the value of the lost load. The price for lost load is chosen to be 20,000 €/MWh, which corresponds to

[12] See e.g. http://www2.nationalgrid.com/About-us/European-business-development/Interconnectors/Iceland

the estimated value of lost load for Austria[13] for combined residential and non-residential load for the duration of 1 hour in summer at 10 am.
In the model, VRES curtailment is allowed, however VRES curtailment is not free. There are also costs related to the curtailment of VRES. These costs are set to be 2,900 €/MWh, so that they are lower compared to the load shedding costs.

5.3.4. DEMAND PROFILES AND INSTALLED CAPACITY

Installed capacity in EU28

The assumptions on the installed electricity generation capacity within the EU-28 area are improved compared to the original study, and adapted according to the values computed in the PRIMES 2016 reference scenario for years 2020 and 2030. For 2014, the data from ENTSO-E transparency platform was used.

Lichtenstein imports 90% of its electricity consumption[14]. Remaining 10% is produced locally. Moreover, Lichtenstein has no own transmission system operator, instead, due to the high transmission capacity and geo-political circumstances, Swiss TSO Swissgrid is the TSO for both Switzerland and Liechtenstein. Therefore, Lichtenstein is not modelled separately, but as a part of Switzerland, i.e. Swiss control area. The Swiss control area also includes the production park of Lichtenstein.

For 2020 and 2030 for the EEA countries, the data from scenarios presented in the ENTSO-E adequacy reports is utilized. In particular, EU2020 scenario and Vision 1 scenario are utilized.
For Iceland there are no scenarios available for generation mix in 2020 or 2030. Therefore, an assumption is made that generation capacity will be equal to the installed capacity in 2014.

Installed base of pumped hydro storage (PHS)

The pumped hydro storage capacity is taken from the ENTSO-E database for 2014. The power pumping and turbining capacity of pumped hydro storage plants is taken from [72], p 183 – 200.

For 2020 and 2030, for EU-28 the same capacity will be assumed unless there are indications that it will change, in particular for the countries with a lot of PHS geological potential[15].
In 2014, there was 1344 MW installed PHS capacity in Norway. Although it is hard to predict future price volatilities, there seems to be no reason to assume that the installed PHS capacity will increase significantly in 2020 and 2030, so the same numbers will be used in all the years.
For Switzerland, there is expected growth in installed base of PHS. The new expected projects are listed as follows:

- 2015: additional 240 MW of PHs capacity (extension of Pumped Storage FMHL[16]
- 2016-17: additional 1000 MW (new power plant Linth-Limmern)[17]
- 2018-19: additional 900 MW (new power plant Nant de Drance[18]
- 2020: additional 150MW Grimsel 1E[19]

[13] Austria is chosen in [10] as a representative European country.
[14] According to the OFFICE OF STATISTICS PRINCIPALITY OF LIECHTENSTEIN: Liechtenstein in Figures 2015, available online at http://www.llv.li/files/as/fl-in-zahlen-englisch-internet.pdf
[15] See JRC study for assessment of geological potential for hydro plants, https://ec.europa.eu/jrc/sites/jrcsh/files/jrc_20130503_assessment_european_phs_potential.pdf
[16] Source http://www.fmhl.ch/PgStd1.asp?m=210
[17] Source http://www.axpo.com/axpo/fi/en/group/portfolio/assets/limmern.html
[18] Source http://www.nant-de-drance.ch/accueil/
[19] Source http://www.grimselstrom.ch/ausbauvorhaben/kraftwerk-grimsel-1-e/

This capacity will be added for Switzerland for 2020 and 2030.

Growth in demand

Demand growth on annual basis will be used to synthetize the demand profiles for 2020 and 2030 scenarios. For the EU28, the newest numbers from the PRIMES, as presented in Table 23, are used.

Table 23: Annual % Change in the EU-28 in the electricity consumption. Source: Primes 2016 reference scenario

Annual % Change in the EU-28	'00-'10	'10-'20	'20-'30	'30-'40	'40-'50
Electricity consumption	1,0	0,1	0,4	0,6	0,8

The same demand growth numbers are used for Switzerland, Lichtenstein, and Iceland as well. For Switzerland and Lichtenstein, there are also findings reported by Swiss Energy Perspectives 2050[20] from which some demand growth numbers can be deduced. Although not identical, these numbers are comparable to the PRIMES numbers. For Norway, projection from the baseline scenario calculated by NVE is used. The projected gross consumption of electricity in Norway is given in Table 24. From the table, it can be calculated that the annual demand growth in Norway is 1,06% in the period 2015-2020, and 0,35% in the period 2020-2030. These numbers are used for demand growth in Norway.

Table 24: Projected gross consumption of electricity in Norway. Baseline scenario. Source: NVE-report 55-2016 and Meld. St. 25 (2015 – 2016).

Electricity consumption [TWh]	2015	2020	2030
Industry	44,3	46	48
Petroleum sector	7,1	9	8,5
Households	36,6	37,5	37
Services	22,8	23	23
Transportation	0,9	1,5	4,5
Other electricity consumption	8,3	9,5	10
Total	120	126,5	131

5.3.5. WIND AND SOLAR HOURLY PROFILES

In the previous study, not all the wind profiles for 2014 were found online, so for a number of countries, the hourly time series were estimated from the published profiles by rescaling the realised profiles of a comparable country, based on the difference in realised monthly production. In this second phase of the study, we use the wind load factors coming from the Setis database, so no rescaling as done in the original study is necessary.

For Switzerland, the solar profiles are downloaded for 2014 from the ENTSO-E transparency database. For Norway and Iceland, there was not significant solar installed capacity in 2014, so these are not modelled.

[20] Source: http://www.bfe.admin.ch/themen/00526/00527/06431/index.html?lang=en&dossier_id=06420

For 2020 and 2030, the same methodology of upscaling the 2014 solar hourly profiles is used as in the previous study.

5.3.6. FORECAST ERROR HOURLY PROFILES

The methodology to synthetize forecast errors remained the same as in the original study.

5.3.7. TECHNICAL PARAMETERS

Due to the properties of the generation portfolio of the EEA countries and Switzerland, it is necessary to model some generation technologies in more detail compared to the previous study. The generation technologies in question are the geothermal power plants, hydropower plants and pumped storage.

→ **Geothermal power plants**

Geothermal power plants are to a large extent working on a similar principle to a steam turbine. Therefore, geothermal power plants are modelled as dispatchable generation, and not by means of time series, like for instance wind and solar power production is modelled.

The differentiation in different types of geothermal power plants, such as Organic Rankine Cycle (ORC), Flash, Dry Steam or Binary Geothermal Plants will not be considered, as similar differentiation is also not modelled for fossil fuel fired power plants.

Operational data (variable, fixed costs, ramping constraints, CO_2 emissions/produced MW, minimum time down, minimum time up, and yearly availability factor) is extrapolated from literature[21] wherever possible, and wherever the data was missing, parameters for a steam turbine are used.

In the majority of literature[22], also some CO2 emission rates are reported in relation to geothermal energy. This is also taken into account, as summarized in Table 25.

[21] For instance, a white paper by EPRI on Geothermal Energy (https://www.google.be/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwij-PL274DTAhUMbhQKHch1AdwQFggmMAA&url=http%3A%2F%2Fwww.epri.com%2Fabstracts%2FPages%2FProductAbstract.aspx%3FProductId%3D000000000001020783&usg=AFQjCNGaddeW3Zb6TUAadiCv-rG_wFbYtQ), reports by Geothermal Energy Association (https://www.google.be/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwipvoG38IDTAhXCnBoKHZdtAFwQFgghMAA&url=https%3A%2F%2Fgeo-energy.org%2Freports%2F2015%2FFirm%2520and%2520Flexible%2520Power%2520Services%2520from%2520Geothermal.pdf&usg=AFQjCNHbdR16dw9rM3fH0vfy8FSGillDhA&bvm=bv.151325232,d.d24), and scientific literature on geothermal power: Bertani - Geothermal Power Generation in the World 2010-2014 Update Report, 2014, available at https://www.google.be/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjpn4nf8IDTAhWDtBQKHSM5DD4QFgghMAA&url=https%3A%2F%2Fpangea.stanford.edu%2FERE%2Fdb%2FWGC%2Fpapers%2FWGC%2F2015%2F01001.pdf&usg=AFQjCNGUBo5WbfqxZi_aRSA8dWL-aO8krg&bvm=bv.151325232,d.d24 or Halldór Ármannsson, Thráinn Fridriksson, Bjarni Reyr Kristjánsson, CO2 emissions from geothermal power plants and natural geothermal activity in Iceland, Geothermics, Volume 34, Issue 3, June 2005, Pages 286-296, ISSN 0375-6505, http://dx.doi.org/10.1016/j.geothermics.2004.11.005. Available at http://www.sciencedirect.com/science/article/pii/S0375650504000744

[22] See Table 4 in Halldór Ármannsson, Thráinn Fridriksson, Bjarni Reyr Kristjánsson, CO2 emissions from geothermal power plants and natural geothermal activity in Iceland, Geothermics, Volume 34, Issue 3, June 2005, Pages 286-296, ISSN 0375-6505, http://dx.doi.org/10.1016/j.geothermics.2004.11.005. Available at http://www.sciencedirect.com/science/article/pii/S0375650504000744

Table 25: CO_2 emission factors for different generation technologies

Category	CO_2 emission [t_{CO2}/MWh_{prim}]
Coal fired	0,34
Gas fired	0,21
Oil fired	0,27
Geothermal	0,00015

→ **Hydropower plants**

There are different types of hydro power plants with very different behaviour from the system operation perspective. The different types are: run-of-river hydro, conventional hydro with water reservoir, or pumped hydro storage power plant.
Run-of-river hydro power plants are modelled in the same way as intermittent generation such as wind and solar, i.e, by means of historical time series. Note that some run-of-river will in the end be dispatchable in cases where the river ends up in a bigger river with storage capacity). This was checked by inspection of the time series downloaded from the ENTSO-E transparency database. The same time series will be used for 2020 and 2030 as well.

Conventional hydro with water reservoir are modelled as dispatchable generation, i.e., same as before. The available capacity and availability factor are adapted accordingly, as run of river plants are now forming a separate group of power plants.

Pumped storage power plants are modelled as energy storage, i.e. similar to the home batteries. Their operation is limited by their efficiency, installed capacity, and maximal instantaneous consumption and production of electricity.

The main source of data to be used for capacity and time series of hydro fired power plants is ENTSO-E transparency website (Installed Capacity per Production Type).

5.4. Flexibility

The amount of residential energy smart appliances in EEA was extrapolated from the EU-28 and number of households in respective countries, and presented in sections 2.2.4 and 2.3.

Additionally, to obtain flexibility profiles for commercial refrigeration and HVAC, climatological areas were assumed, similarly as in the original study.

5.5. Summary of assumptions

In summary, the assumptions made are listed as follows:

1. All the input data for benchmark year 2014 are based on 2014 realized data.
2. The influence of the transmission system is modelled by means of the net transfer capacity (NTC) matrix. Transmission constraints within each country are not considered.
3. The generation units are clustered per generation type, e.g., nuclear, hydro, coal fired power plants, etc. For each generation type, there is one cluster. There is one equivalent unit for each generation type for each EU28 country.

4. Hydro generators are assumed to be dispatchable, with the accordingly adapted yearly availability factor, which is set to approximately 0.4 for EU-28, and to 0,75 in Norway, and 0,9 in Iceland. These factors are obtained by calculation of historical yearly availability factors in each country.
5. Undispatchable renewable generation, such as wind and solar power production, is represented in the model by the hourly generation profiles. Load factors of wind and solar power production are assumed to remain the same in 2020 and 2030 as it was in 2014.
6. The marginal price of wind power and solar power is chosen to be 0. The efficiency of these units is set to 100%, as there is no input fuel directly utilized for these types of generation technologies. Similarly, the marginal price of hydro and geothermal power is set to be 0.
7. Fuel prices are based on the realised fuel prices in 2014 and the assumptions for 2020 and 2030 as published by the PRIMES 2016 scenario. No subsidies are considered for any fuel type.
8. For future scenarios, growth of demand is assumed to be consistent with the PRIMES 2016 scenario, and with NVE assumptions for Norway. Generation installed capacity and mix is assumed to grow as predicted by PRIMES scenarios, and national scenarios for Norway and Switzerland, as specified above.
9. Forecast errors are assumed to be normally distributed, and proportional to peak load, and installed intermittent RES capacity (installed wind and solar capacity).
10. In the lack of better references, forecast quality is assumed not to improve in the future, i.e., statistical properties of demand, load and wind forecast errors will remain the same in 2020 and 2030 as they are in 2015.
11. No generation unit is equipped with the carbon capture and storage (CCS) technology. No CO_2 emitted as a consequence of electricity production is captured and stored.

5.6. Day-ahead use case

In this section, the KPIs are presented for the benchmark case, i.e. for the case with no activation of energy smart appliances flexibility. In this section, the statistics for EU-28 region is presented. In the appendix, the overall statistics for the EU-28 extended by Norway, Switzerland, Iceland and Lichtenstein are provided.

This section presents results for the day-ahead benchmark use case for the chosen benchmark years 2014, 2020 and 2030. Firstly, the outcome of the model in the form of a realized generation mix is presented in Table 26. The ratio of the electricity produced by the intermittent RES will increase over the years, whereas the share of gas and coal fired power plants will decrease. Also the import from mostly Norway and Switzerland will increase, due to the increased transmission capacity and large hydro capacity in these countries.

The outcome of the model corresponds closely to the data as measured in reality for share of total generation per type, nevertheless there are some discrepancies. For nuclear, the model outcome is 26,35% against 27,9% realized in 2014, for hydro generation, model outcome was 15,15% against 13,1% realized. Share of other intermittent RES generation shows good resemblance of the model outcome to the realized data as well: for wind the model outcome is 8,93% against realized 7,9%, and for solar the model outcome is 3,3% against 3% realized share of total electricity generation. Furthermore, if the total sum is considered for the fossil fuels fired power plants, very good overlap can be observed: gas and coal fired power plants produced 40,7% of total electricity in the year, whereas according to the model computation, it was 35,3%.
There is a minor mismatch in fuel fired generation (gas, oil, coal fired) if these technologies are considered individually. The mismatch in model-obtained and realized share of gas fired units and coal fired units is mostly due to the interchangeability of these technologies: both can be used as

peaking units. Some of the mismatch can also be contributed to the limitations of the model, such as limiting the transmission network to the cross-border connections, the fact that hydro power plants are modelled to be completely dispatchable. Lastly, the mismatch can be contributed to the choice of fuel prices and their variability over the year, which was not taken into account.

Table 26: Total realized generation mix for EU28 area per benchmark case, for 2014, 2020 and 2030.

Generation type (EU-28)	2014	2020	2030
Nuclear [%]	26,35	24,90	23,04
Hydro [%]	15,15	15,36	14,96
Biomass [%]	6,98	0,08	0,10
Coal [%]	30,90	28,74	20,69
Gas [%]	4,30	6,17	14,12
Oil [%]	0,14	0,25	0,02
Wind [%]	8,93	14,40	14,38
Geothermal [%]	0,22	0,26	0,25
Solar PV [%]	3,39	4,68	6,25
Import from EEA and CH [%]	3,64	5,16	6,19

The KPIs per benchmark year for day-ahead use case are presented in Table 27. Although these values are interesting on their own, their main purpose within the scope of the study is to serve as benchmark for the cases with utilized flexibility from energy smart appliances. Therefore, they are more elaborately discussed in chapter 6 along with the KPIs from the use cases presented therein.

In the day-ahead use case, an increase in total costs for electricity production, i.e. KPI1, is observable over the years. All the costs are given in $€_{2014}$ value. The highest costs are expected in 2030, due to the increase in total electricity demand, and due to the increase of CO_2 emission price.

The development of the efficiency of the utilized generation mix (KPI3) over the benchmark years shows the slight increase in efficiency, from 50% in 2014 to 64% in 2030. Main reasons for this are firstly, the increased VRES installed capacity, and secondly, the switch from electricity production by coal-fired power plants to the gas-fired power plants, which are more efficient than the coal-fired ones: 50% compared to 45%.

Table 27: KPIs for the day-ahead use case for each of the benchmark years in the EU-28 area

Day ahead case	KPI1 (total system costs) [M€]	KPI2 (CO_2 emissions) [Mt]	KPI3 (efficiency of the utilized generation mix) [%]	KPI4 (primary energy consumption) [TWh]
2014	61.984	748	57,8	3.581
2020	71.289	746	62,2	3.147
2030	94.663	672	63,8	3.089

The decreasing trend over the years can be observed for the CO_2 emissions and primary energy consumption. This trend goes hand in hand with increased VRES installed capacity.

There was no load shedding in any of the benchmark scenarios. The VRES curtailment was minor, and is presented in Table 28.

Table 28 VRES curtailment in the EU-28 area in the reference case

VRES curtailment (EU-28)	2014	2020	2030
TWh	0,06	1,21	1,12

5.7. Conclusions

This Task introduced the model and data utilized for the purposes of this study. Moreover, it sets the ground for the evaluation of the potential impacts from energy smart appliances, which is continued in Task 6. Therein, the results of the cases with energy smart appliances will be put in perspective with these benchmark results.

CHAPTER 6 DESIGN OPTIONS

The Task 6 report of this second phase of the study on Lot 33 Preparatory Study mainly focuses on the assessment of the economic and environmental benefits the use of flexibility from energy smart appliances and electric vehicles. In this Task 6 report it is investigated how potential (future) flexibility provided by energy smart appliances and electric vehicles can support the power system and an attempt is made to quantify the value of the economic and environmental benefits potentially provided by the flexibility of energy smart appliances and electric vehicles to the energy system. The focus is on the impacts for the day-ahead use case, however, additional use cases exist where the flexibility of energy smart appliances would have significant value.
The benefits of flexibility from energy smart appliances are evaluated according to the four key performance indicators (KPIs) already defined in Task 5: CO_2 emission savings[23], impact on the utilized generation mix in terms of efficiency (which indirectly shows primary energy savings and additional Renewable Energy Sources (RES) which can be integrated in the system), which is expressed as percentage, and as primary energy savings, and impact on the total energy system costs and marginal energy prices. The resulting KPIs are compared with the KPIs calculated in Task 5 for the base case. Where the base-case scenario served as a reference situation which did not take into account flexibility, in this Task 6 report the KPIs are calculated for a situation in which a certain share of energy smart appliances and electric vehicles, each with their flexibility profile, could provide flexibility to the system in the future.

The value of the benefits provided by the flexibility of energy smart appliances to the system is extracted from the computed KPIs in Tasks 5 and 6. It is expressed in environmental and economic terms. The obtained value is the highest value that can be obtained, as the perfect foresight is assumed, all the flexibility is utilized in a holistic aggregated way to benefit the system, and no strategic behaviour of any actors, or control imperfections, such as communication delay, suboptimal controller tuning, etc. exist.

6.1. EXTENSION OF THE ASSESSMENT MODEL BY EVS

The EVs were modelled as a combination of electricity storage and load shifting, i.e., similar to the other appliances. As the EVs are primarily used for commuting from one place to another, it is important to ensure that they can keep on fulfilling this primary purpose. Hence, to make sure it is possible to conduct the desired trips by EV, the charging profile is assumed to be allowed to shift for a limited number of hours. It is assumed that during night, charging of the EVs can be postponed for maximally 8 hours, whereas during the day, it can be shifted maximally for 5 hours. Similarly, as only grid-to-vehicle case is considered, the discharging profile of EVs is only defined by the energy use of the EV, and cannot be influenced in any other way.

Due to the relatively few data on driving profiles for each of the EU-28 and EEA countries, and the complexity of scaling such data to a national level, to model the charging pattern, the study team utilized the charging profiles as synthetized by NVE, for each of the modelled countries. Such profiles are shown in Figure 13 and Figure 14 for Norway.

[23] In this project, CO_2 emission is considered and not CO_2-equivalent emission.

6.2. ASSESSMENT DATA FOR THE MODEL EXTENSIONS (EEA COUNTRIES AND EVS)

In this section, an overview of the additionally used data related to the developed flexibility model of energy smart appliances is given.

6.2.1. NUMBER OF SMART ENABLED APPLIANCES IN EEA COUNTRIES

The utilized model is the zonal model. Therefore, among others, the model utilizes as inputs the following hourly profiles:

- hourly profiles of total demand,
- hourly profiles of wind and solar power production, and
- hourly profiles of flexibility (per energy smart appliances group)

for each modelled country. To calculate the total amount of available flexibility for each category of energy smart appliances, the numbers of smart enabled appliances in each country for 2014, 2020 and 2030 are needed.

The number of smart enabled appliances is calculated by multiplying the share (%) of smart enabled appliances, as described in Task 2, with the total number of energy smart appliances per considered energy smart appliance group. The share of smart enabled appliances and the corresponding number of smart enabled appliances in the EU28 area for each of the benchmark years are presented in Table 29.

Table 29 Share (%) and amount (#) of energy smart appliances per benchmark year in the EU28 area

		2014		2020		2030	
Group	Energy smart appliance	#	%	#	%	#	%
Periodical appliances	Dishwashers	0	0	2.300.720	2	11.884.240	8
	Washing machines	0	0	2.008.050	1	8.189.760	4
	Tumble dryers, no heat pump	0	0	718.010	2	622.224	16
	Tumble dryers, heat pump based	0	0	718.010	2	11.822.256	16
Energy storing appliances	Refrigerators and freezers (residential)	0	0	154.00.000	5	63.520.000	20
	Electric storage water heaters (continuously heating storage)	0	0	2.500.000	5	9.100.000	20
	Electric storage water heaters	0	0	950.000	5	3.440.000	20

	(night storage)						
	Tertiary cooling - compressor[24]	0	0	11.501.466	10	70.101.114	50
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	1.053.000	5	3.790.800	18	11.408.963	54
	HVAC cooling, with thermal storage	567.000	5	2.041.200	18	6.143.288	54
	HVAC heating, no storage	104.000	5	374.400	18	1.126.811	54
	HVAC heating, with thermal storage	56.000	5	201.600	18	606.744	54
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	78.000	5	280.800	18	845.109	54
	HVAC cooling, with thermal storage	42.000	5	151.200	18	455.059	54
	HVAC heating, no storage	106.167	5	382.200	18	1.150.287	54
	HVAC heating, with thermal storage	57.167	5	205.800	18	619.385	54
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0	0	6.696.000	3	46.985.342	21
	Electric radiators, with inertia	0	0	555.000	3	3.894.394	21
	Boilers	0	0	30.000	3	210.508	21
Energy storage appliances	Electric vehicles	0	0	2.780.306	50	18.090.086	75

The average maximal shifting period per energy smart appliance group was discussed in detail in the original study, and for the purposes of overview and completeness, in Table 30, the maximal shifting period per energy smart appliance group is presented.

Table 30 Maximal average shifting time [h] for each group of the considered smart appliances

Group	Energy smart appliance	Maximal average shifting time [h]
Periodical appliances	**Dishwashers**	**3**
	Washing machines	**3**
	Tumble dryers, no heat pump	**3**
	Tumble dryers, heat pump based	**3**
Energy storing appliances	**Refrigerators and freezers (residential)**	**0,17**
	Electric storage water heaters (continuously heating storage)	**0,17**
	Electric storage water heaters (night	**0,17**

[24] For tertiary cooling processes (compressor and defrost), instead of number of appliances, total nominal square meters, obtained as explained in Task 3 report, are given.

	storage)	
	Tertiary cooling - compressor[1]	0,25
	Tertiary cooling - defrost	1,5
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,17
	HVAC cooling, with thermal storage	6
	HVAC heating, no storage	0,17
	HVAC heating, with thermal storage	6
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	0,17
	HVAC cooling, with thermal storage	6
	HVAC heating, no storage	0,17
	HVAC heating, with thermal storage	6
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0,17
	Electric radiators, with inertia	0,17
	Boilers	0,17
Energy storage appliances	Electric vehicles	8 (during night), 5 (during day)

6.2.2. NUMBER OF RESIDENTIAL STORAGE APPLIANCES (HOME BATTERIES)

For residential storage appliances, under which we understand home batteries for the purposes of this study, the significant number of home batteries is assumed to be present only in Germany, for the reasons presented in the reports of the original study. An overview of the assumed battery sized and numbers can be found in the documents of the original study and is repeated here for completeness.

Table 31 Installed numbers, energy and power capacity[25] of home batteries (only for Germany), source: B. Normark et al, "How can batteries support the EU electricity network?", technical report, 2014

Year	Charging rate [MWh/h]	Energy capacity [MWh]	Efficiency η [%]	Number
2014	37,95	73,6	85	11500
2020	264	512	85	80000
2030	676,5	1312	85	205000

6.2.3. FLEXIBILITY PROFILE

In Task 3 of the original study, the relevant parameters to determine the aggregated flexibility potential of energy smart appliances are described. These profiles are utilized in this Task, and not repeated in the text of this report. The flexibility profiles for EV charging are presented in Task 3 of this report (Section 2.2.4).

[25] Energy and power capacity is deduced from battery numbers based on specifications of Tesla Powerwall, see https://www.tesla.com/powerwall

6.2.4. ASSUMPTIONS

In this section, an overview of assumptions related to the flexibility of energy smart appliances is presented. Note that the assumptions below are both based on reflections made in earlier Tasks and additional assumptions made in Task 6.

12. The optimisation model used is the model as explained in Task 5. It determines the value of flexibility for each individual EU28 country, taking into account that:
    a. Import and export between countries is possible, but it is constrained by the capacity of the transmission lines.
    b. There are different time zones between countries.

13. The flexibility of energy smart appliances is modelled as two conceptually different groups:
    a. load shifting, for all the appliance groups besides batteries;
    b. storage: home batteries

14. The price to activate flexibility from energy smart appliances is set at zero in the model, to allow determining the maximum potential and evaluate the maximal benefits of energy smart appliances. Benefits computed in such a way do not take into account costs or additional losses in appliances[26], and can be seen as gross benefits. The computed benefits are later evaluated against costs further in this report. The computed benefits should be interpreted as an upper bound for the flexibility payments in the value chain for activation of this flexibility. In this sense, this model's assumption of a zero price for flexibility activation is not equivalent to the assumption that there is no price to activate flexibility from energy smart appliances in the overall analysis.

15. For a certain category of energy smart appliances, in case the flexibility has the same characteristics (same shifting period), the energy smart appliances are considered of equal value for the energy system. This means that for example, no real distinction can be made in the model optimization between washing machines and dish washers, as they have the same average shifting time (see also Table 30). Further in this report, it will be explained that although benefits could be considered similar for certain appliances, differences in costs could still result in a preference for one type of appliance to provide flexibility.

16. The total amount of flexibility of periodical and energy storing appliances is based on the assumption that on average, there is one appliance per household, meaning that in order to calculate the entire base of smart enabled periodical and energy storing appliances, it is sufficient to multiply the % of smart enabled appliances (data provided in Task 2) with the number of households for a certain country. This methodology was only used for periodical appliances and energy storing appliances.

17. Flexibility coming from industrial demand response is not taken into account in the model. This means that the value of flexibility to be awarded to energy smart appliances and EVs is slightly overestimated, as a part of the need for flexibility could (and will) be covered by industrial demand response instead of energy smart appliances and EVs. Today, it is unclear for which flexibility provider it will be most profitable to offer flexibility (industrial demand response, EVs, energy smart appliances). It will depend on both, the costs to enable this flexibility (including infrastructure, communication technology,…), the use case (day-ahead

[26] Additional losses are considered only for home batteries, by taking into account the efficiency of the batteries.

optimization of portfolio, balancing,…), and the characteristics of the flexibility (reaction time, availability,…).

18. For home batteries, it is assumed that only in Germany, this market will develop in the scope 2020 and 2030, due to the fact that today, in no other countries, the investment of home batteries is subsidized[27].

6.2.5. COMPUTATION OF KPIS

The economic and environmental benefits of energy smart appliances from an energy system perspective are quantified by means of the following key performance indicators (KPIs), as defined for the base case in Task 5.

Same as in Task 5, for each of the three chosen benchmark years: 2014, 2020, and 2030, the model is run over a time horizon of one year. The KPIs represent the yearly values: KPI1 are the yearly electrical energy production costs, KPI2 are the yearly CO_2 emission quantities from the generation mix utilized to produce electricity, and KPI3 is the efficiency of the utilized generation mix throughout the whole year, which is defined as the quotient of the produced electrical energy and the total primary energy utilized to produce the electrical energy.

6.3. DAY-AHEAD USE CASE

In this section, the results for the business as usual (BAU) scenario, and the 100% scenario are compared to the reference scenario for the day-ahead use case presented in chapter 5. The two scenarios, business as usual (BAU) scenario, and the 100% scenario, differ from each other in assumptions on the energy smart appliances that act in a flexible way. For the BAU scenario, the assumed amounts of flexible energy smart appliances were given in Table 19. For the 100% scenario, it is assumed that all the appliances are energy smart appliances.

In Table 32, KPIs for the day-ahead use case with flexibility for BAU and 100% scenario are presented. The same trends over the benchmark years that were observed in the base case can be seen here:

- there is an increase in total costs over the years, which is largely due to the increased fuel and in particular increased CO_2 emission costs
- there is a decrease in CO_2 emissions over the years and primary energy consumption, which is largely due to the increased installed capacity of RES
- there is an increase in generation mix efficiency, which is due to the increased installed capacity of RES.

Table 32: KPIs for the day-ahead use case for each of the benchmark years, EU-28 area

Day ahead use case	KPI1 (total system costs) [M€]		KPI2 (CO2 emissions) [Mt]		KPI3 (efficiency of the utilized generation mix) [%]		KPI4 (primary energy consumption) [TWh]	
Scenario	BAU	100%	BAU	100%	BAU	100%	BAU	100%
2014	61.961	60.997	748	740	57,8	58,3	3.580	3.546

[27] http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf

2020	69.838	68.831	732	725	62,4	63,1	3.086	3.055
2030	94.181	80.231	640	582	64,1	66,3	3.085	2.628

The effects of flexibility from energy smart appliances on decrease of VRES curtailment are quantified in Table 33. Therein, it can be observed that the flexibility in the system help reduce the VRES curtailment up to 50%.

Table 33: Load shedding and VRES curtailment for EU28 area per benchmark case, for 2014, 2020 and 2030.

	2014 base	2020 base	2030 base	2014 BAU	2020 BAU	2030 BAU	2014 100%	2020 100%	2030 100%
Load shedding [%]	0	0	0	0	0	0	0	0	0
VRES curtailment [TWh]	0,06	1,21	1,12	0,03	0,59	0,54	0,02	0,054	0,52

In Table 34, differences in KPIs, ΔKPIs, as a consequence of utilization of flexibility from energy smart appliances for the day-ahead use case and each of the benchmark years, and both scenarios, are presented.
The general trend that can be observed in the results is that the more flexibility there is, the better economic and environmental indicators become, which was to be expected. Note that ΔKPI2 is given in kt of CO_2 emissions, whereas KPI2 was expressed in Mt of CO_2 emissions.

Table 34: Differences in KPIs as a consequence of utilization of flexibility from energy smart appliances for the day-ahead use case and each of the benchmark years in the EU-28 area

Day ahead use case	ΔKPI1 (savings in total system costs) [M€]		ΔKPI2 (savings in CO_2 emissions) [kt]		ΔKPI3 (primary energy savings) [%]		ΔKPI4 (primary energy savings) [TWh]	
Scenario	BAU	100%	BAU	100%	BAU	100%	BAU	100%
2014	23	987	182	8.412	0,0	0,5	1	35
2020	1.451	2.458	13.667	20.481	0,1	0,9	60	91
2030	482	14.433	32.136	89.513	0,3	2,5	4	461

To put the savings in total system costs further in perspective, Table 35 gives the savings as percentage of the total system costs for the electricity production, for each of the scenarios. In the table, also the share of flexible demand in the total demand (in terms of energy and not peak power) is given for reference of the amount of flexibility. Over the years, not only the absolute value of savings increases, but also the savings computed as percentage of the total system costs tend to increase, with the largest amounts for the 2030 scenario, when there is the most flexibility, and when also the fuel and CO_2 emission prices are the highest.

Table 35: Savings in total costs due to utilization of flexibility from energy smart appliances, and share of flexible demand in the total system demand in the EU-28 area

	Savings as % of the total costs		Share of flexible demand in the total demand (energy-wise)	
scenario	BAU	100%	BAU	100%
2014	0,04%	2%	0,2%	17,0%
2020	2%	3%	1,4%	17,3%
2030	2%	15%	6,1%	20,1%

Average marginal electricity prices [€/MWh] for the day-ahead use case, base, BAU, and 100% scenario in the EU-28 area: differences due to utilization of flexibility from energy smart capable appliances are given in Table 36. In general, electricity prices are expected to increase significantly by 2030, and reach almost 75 €/MWh in the base case. The increase is primarily driven by the increase in CO_2 costs. Nevertheless, the table below shows that the use of flexibility from smart appliances in 2030 could lead to an average decrease of marginal electricity prices of around 2,2% in the BAU case, and 16% in the 100% case.

Table 36: Average marginal electricity prices [€/MWh] for the day-ahead use case, base, BAU, and 100% scenario in the EU-28 area: differences due to utilization of flexibility from energy smart capable appliances

	100% scenario	BAU scenario	Base case
2014	44,81 €/MWh	44,92 €/MWh	44,93 €/MWh
2020	56,64 €/MWh	56,75 €/MWh	58,02 €/MWh
2030	61,79 €/MWh	73,67 €/MWh	73,74 €/MWh

The KPIs as presented above are defined on the system level, and as such, quantify the operation of the system as a whole using the flexibility of all the energy smart appliances together. Therefore, KPIs cannot straightforwardly, without introducing additional assumptions, be determined separately per energy smart appliances category or even per individual smart appliance. In other words, there is no simple way to completely accurately distinct in resulting benefits from flexibility among appliance groups. Nevertheless, on the basis of this schedule, additional information from Tasks 1-3, and the optimal schedule of different appliances, an approximation of the value of benefits per enabled energy smart appliance per year from the computed total system benefits is extracted and presented in Table 37.

Table 37: Value of benefits due to flexibility of energy smart appliance per enabled appliance per year (given in [€/year/appliance] or [€/year/m^2] for tertiary cooling]) for BAU and 100% case in the EU-28 area

		2014		2020		2030	
Group	Energy smart capable appliance	BAU	100 %	BAU	100 %	BA U	100 %
Periodical appliances	Dishwashers	0	1,3	5,2	1,3	3,6	1,0
	Washing machines	0	0,7	2,9	0,7	2,0	0,5
	Tumble dryers, no heat pump	0	1,4	5,6	1,4	3,7	0,9
	Tumble dryers, heat pump based	0	1,2	4,5	1,1	3,0	0,8
Energy storing appliances	Refrigerators and freezers (residential)	0	0,2	0,6	0,2	0,4	0,1
	Electric storage water heaters	0	0,9	2,4	0,9	2,4	0,7

	(continuously heating storage)						
	Electric storage water heaters (night storage)	0	1,4	15,2	1,4	8,4	1,0
	Tertiary cooling - compressor[28] and defrost	0	0,6	0,2	0,6	0,8	0,5
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	1,7	0,2	1,4	0,3	0,8	0,3
	HVAC cooling, with thermal storage	14,6	1,5	11,3	1,8	5,4	2,0
	HVAC heating, no storage	22,1	2,8	14,2	2,2	8,3	1,3
	HVAC heating, with thermal storage	156,7	16,4	106,3	13,6	45,9	5,6
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	12,3	1,9	11,6	1,4	5,9	0,9
	HVAC cooling, with thermal storage	198,4	19,4	149,0	11,6	47,8	7,4
	HVAC heating, no storage	3,2	0,5	2,5	0,4	1,5	0,3
	HVAC heating, with thermal storage	29,0	3,3	20,2	2,3	9,7	1,2
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0	0,2	1,4	0,2	0,8	0,1
	Electric radiators, with inertia	0	0,4	2,2	0,4	1,3	0,2
	Boilers	0	1,8	10,9	1,8	6,6	1,0
Residential energy storage systems	Home batteries	0	14,8	35,5	14,5	26,2	6,6
	Residential electric vehicles	0	8,9	34,7	6,8	17,1	3,9

For a household equipped with the following energy smart appliances, i.e., the following sources of flexibility: all periodical appliances, refrigerators and freezers, and a heating/cooling installation based on heat pump technology without the thermal storage, the expected yearly benefits are between 20 and 35 €/year in the BAU scenario. For a household that on top of it has an EV, solar panels, and a home battery, the expected yearly benefits are between 20 and 105 €/year in the BAU scenario. The benefit per year is an average for the EU-28 area, and will vary between the countries depending on their energy mix, other available flexibility sources, and the interconnection strength. Some household flexibility sources, i.e., some energy smart appliances, will be more valuable for other use cases (e.g. refrigerators and freezers might obtain a higher value on the reserve and imbalance use case than for the day-ahead use case). This will also impact the total value of energy smart appliances for a household.

The herein presented theoretical monetary benefits are smaller compared to those calculated in the original preliminary study on smart appliances. There are two main factors that explain this change. Firstly, the CO2 emission prices are assumed to be as given by PRIMES 2016 scenario in the amended calculations, and are significantly lower than in the original calculations. Secondly, in the previous calculations, no pumped hydro storage was modelled in the system. Pumped hydro storage plants are very flexible, and although their efficiency losses are larger than efficiency losses of the appliances in scope, their capacity is larger. Because of presence of more flexibility in the system, the total flexibility value per unit dropped.

The conclusions drawn before are still valid: the HVAC appliances and energy storage systems (both, home batteries and residential electric vehicles) have the largest value to the end consumer.

6.4. Other use cases

The benefits of the flexibility from smart appliances are evaluated for the day-ahead case and presented above. Nevertheless, these are not the only possible system use cases for the flexibility provision. In addition to the day-ahead use case, there are other use cases where the flexibility of could also have significant value such as imbalance use case, or grid support use case.

The individual values per appliance for the other use cases vary, but are in the same order of magnitude as for the day-ahead use case. The value of appliances that have shifting periods shorter than 1 hour (such as refrigerators) is larger for the imbalance use case and some reserve products than for the other cases. This is explained by the time resolution of some reserve products, which can be as short as 30 seconds, and as long as several hours, and the imbalance prices, which is 15 minutes, against time resolution of day-ahead markets (1 hour). Nevertheless, the average value per appliance will not deviate a lot from one use case to another. This statement is further supported by the fact that the values awarded today for flexibility in the reserve market (R3DP) in Belgium (imbalance use case) are in the same order as the values reported in Table 37 (day-ahead use case).

6.5. Conclusions

Energy smart appliances can provide flexibility to the electricity system in a number of system use cases by shifting operation and as a result, adapting the consumption. This leads to a reduced cost and CO_2 emission compared to a situation without appliances' flexibility, due to the fact that additional generation by conventional power plants could be avoided as a consequence of a smart shift in load. In addition, the use of smart appliances also leads to a reduction in curtailment of VRES in case there is too much intermittent energy production compared to the demand, and increase in primary energy savings for electricity generation.

The quantification of these system benefits is detailed in previous sections of this chapter. Please note that the benefits are determined for flexibility at the level of a specific smart appliances flexibility group. In the optimisation, the assumption is made that the marginal price of flexibility is zero, to allow a maximal use of flexibility. This means that the analysis is a representation of the maximum potential that flexibility might have in the current and future energy system.

CHAPTER 7 POLICY OPTIONS

Policy recommendations for EV chargers are described in the reworked version of the task 7 report of the original Preparatory study on Smart Appliances, and are not repeated here.

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CHAPTER 8 ANNEX 1 RESULTS FOR THE EXTENDED AREA (EU-28 AND NORWAY, SWITZERLAND, ICELAND AND LICHTENSTEIN)

In this section, the results presented for the EU28 area in the report are extended by the results for the interconnection of Norway, Switzerland, Iceland and Lichtenstein with the EU-28.
The observations and conclusions drawn for the EU28 area hold equally for the extended area (EU28 connected to Norway, Switzerland, and Lichtenstein, and Iceland separately). For this reason, they are not repeated here. For better readability, in the caption of each table it is written to which table for the EU28 numbers it corresponds.

Table 38: Total realized generation mix for EU28+EEA+CH area per benchmark case, for 2014, 2020 and 2030, corresponds to Table 26.

Generation type (EU-28)	2014	2020	2030
Total dispatchable [%]	87,90	81,25	79,67
Nuclear [%]	25,67	24,28	22,29
Hydro [%]	22,13	23,39	23,79
Biomass [%]	6,61	0,08	0,10
Coal [%]	29,27	27,34	19,80
Gas [%]	4,09	5,93	13,67
Oil [%]	0,13	0,24	0,02
Total Wind [%]	8,52	13,81	13,88
Geothermal [%]	0,36	0,46	0,44
Solar PV [%]	3,21	4,48	6,01
Total renewable: [%]	12,10	18,74	20,33

Table 39: KPIs for the day-ahead use case for each of the benchmark years for the EU28+EEA+CH area, corresponds to Table 27

Day ahead case	KPI1 (total system costs) [M€]	KPI2 (CO_2 emissions) [Mt]	KPI3 (efficiency of the utilized generation mix) [%]	KPI4 (primary energy consumption) [TWh]
2014	64.489	749	61	3.605
2020	74.128	747	66	3.169
2030	97.800	674	67	3.107

There was no VRES curtailment in the EEA countries and Switzerland, so the VRES curtailment numbers for EU28+EEA+CH area are the same as for EU28 area.

Table 40 VRES curtailment in the EU28+EEA+CH area in the reference case, corresponds to Table 28

VRES curtailment (EU28+EEA+CH)	2014	2020	2030
TWh	0,06	1,21	1,12

Table 41: KPIs for the day-ahead use case for each of the benchmark years for the EU28+EEA+CH area, corresponds to Table 32

Day ahead use case	KPI1 (total system costs) [M€]		KPI2 (CO2 emissions) [Mt]		KPI3 (efficiency of the utilized generation mix) [%]		KPI4 (primary energy consumption) [TWh]	
scenario	BAU	100%	BAU	100%	BAU	100%	BAU	100%
2014	64.464	63.479	748	740	61,0	61,4	3.604	3.569
2020	72.616	71.573	733	726	65,6	66,2	3.108	3.076
2030	97.226	82.779	641	583	67,5	69,3	3.100	2.639

Table 42: Differences in KPIs as a consequence of utilization of flexibility from energy smart appliances for the day-ahead use case and each of the benchmark years in the EU-28+EEA+CH area, corresponds to Table 34

Day ahead use case	ΔKPI1 (savings in total system costs) [M€]		ΔKPI2 (savings in CO_2 emissions) [kt]		ΔKPI3 (primary energy savings) [%]		ΔKPI4 (primary energy savings) [TWh]	
scenario	BAU	100%	BAU	100%	BAU	100%	BAU	100%
2014	25	1.010	195	8.548	0,0	0,5	1	36
2020	1.512	2.555	13.713	20.726	0,1	0,7	61	93
2030	573	15.021	32.572	90.598	0,2	2,0	7	467

Table 43: Savings in total costs due to utilization of flexibility from energy smart appliances, and share of flexible demand in the total system demand in the EU-28+EEA+CH area , corresponds to Table 35

	Savings as % of the total costs		Share of flexible demand in the total demand (energy-wise)	
scenario	BAU	100%	BAU	100%
2014	0,04%	2%	0,2%	16,7%
2020	2%	3%	1,4%	17,1%
2030	1%	15%	6,2%	20,0%

Table 44: Average marginal electricity prices [€/MWh] for the day-ahead use case, base, BAU, and 100% scenario in the EU-28+EEA+CH area: differences due to utilization of flexibility from energy smart capable appliances, corresponds to Table 36

	100% scenario	BAU scenario	Base case
2014	42,84	42,98	42,99
2020	54,56	54,65	55,88
2030	59,42	70,97	71,01

Table 45: Value of benefits due to flexibility of energy smart enabled per enabled appliance per year (given in [€/year/appliance] or [€/year/m^2] for tertiary cooling]) for BAU and 100% case in the EU-28+EEA+CH area, corresponds to Table 37

		2014		2020		2030	
Group	**Energy smart capable appliance**	**BAU**	**100 %**	**BAU**	**100 %**	**BAU**	**100 %**
Periodical appliances	Dishwashers	0	1,3	5,2	1,3	3,6	1,0
	Washing machines	0	0,7	3,0	0,7	2,0	0,5
	Tumble dryers, no heat pump	0	1,4	5,6	1,4	3,7	0,9
	Tumble dryers, heat pump based	0	1,2	4,5	1,1	3,0	0,8
Energy storing appliances	Refrigerators and freezers (residential)	0	0,2	0,6	0,2	0,4	0,1
	Electric storage water heaters (continuously heating storage)	0	0,9	2,4	0,9	2,4	0,7
	Electric storage water heaters (night storage)	0	1,4	15,1	1,4	8,3	1,0
	Tertiary cooling - compressor[29] and defrost	0	0,6	0,2	0,6	0,8	0,5
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,1	0,2	0,2	0,3	0,4	0,3
	HVAC cooling, with thermal storage	0,7	1,5	1,9	1,8	2,8	1,9
	HVAC heating, no storage	0,6	1,7	1,4	1,3	2,3	0,7
	HVAC heating, with thermal storage	4,6	10,3	10,4	8,1	13,3	3,2
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	0,6	2,0	2,1	1,5	3,2	1,0
	HVAC cooling, with thermal storage	9,9	20,0	27,9	13,0	27,2	8,6
	HVAC heating, no storage	0,2	0,5	0,5	0,4	0,8	0,3
	HVAC heating, with thermal storage	1,6	3,6	3,8	2,5	5,5	1,2
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0	0,2	1,3	0,2	0,8	0,1
	Electric radiators, with inertia	0	0,3	2,0	0,3	1,2	0,2
	Boilers	0	1,7	10,1	1,7	6,1	1,0

Residential energy storage systems	Home batteries	0	14,8	35,5	14,5	26,2	6,6
	Residential electric vehicles	0	9,0	36,3	7,2	18,3	4,2

CHAPTER 9 ANNEX 2: STANDARDIZATION AND INITIATIVES

This section describes the progress made in standardization related to energy smart appliances since the completion of the preparatory study. As some of the industrial initiatives in smart home and IoT can have a substantial impact on the interaction of the user with energy smart appliances, trends in this domain are also listed.

9.1. SAREF AND SAREF4EE

To address the issue of the multiple overlapping and competing standards within the smart home - between the energy smart appliances and the home/building energy management system- the European Commission/DG CONNECT orded a study on “Available Semantics Assets for the Interoperability of Smart Appliances: Mapping into a Common Ontology as a M2M Application Layer Semantics" (see also section 1.5.2 in Preparatory study on Smart Appliances Task 1).

The study resulted in the creation of a reference ontology of consensus called SAREF (Smart Appliances REFerence ontology) covering the needs of appliances related to energy efficiency, and expandable to future intelligence requirements. Subsequently SAREF was mapped on the ETSI M2M Architecture. The European Telecommunications Standard Institute (ETSI) participated actively in the process of SAREF creation and accepted to cover the communication aspect and provide the necessary standardization process support.

SAREF is conceived as a shared model of consensus that facilitates the matching of existing semantic assets in the energy smart appliances domain, reducing the effort of translating from one asset to another, since SAREF requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets (see Figure 21).

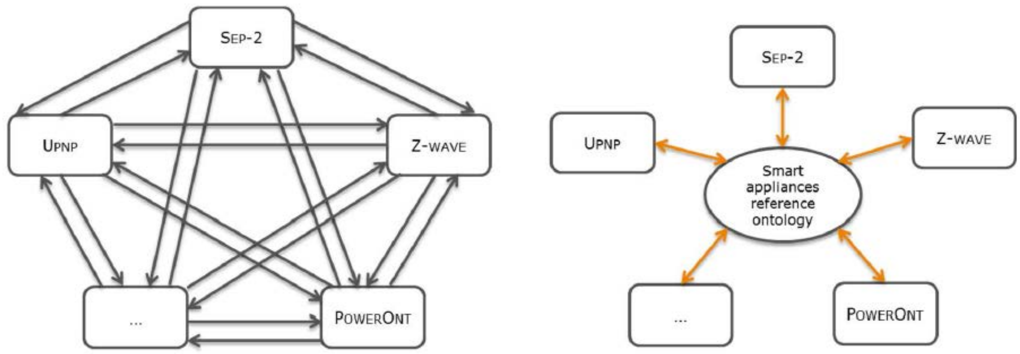

Figure 21 The role of SAREF in the mapping among different assets [54]

Different semantic assets share some recurring, core concepts, but they often use different terminologies and adopt different data models to represent these concepts. Using SAREF, different assets can keep using their own terminology and data models, but still can relate to each other through their common semantics. In other words, SAREF enables semantic interoperability in the energy smart appliances domain through its shared, core concepts.

The energy smart appliances industry is the main user of SAREF and is very pragmatic. This has been taken into account when defining SAREF. For instance, although the use of upper ontologies is a best practice in ontology engineering SAREF currently does not contain explicit references to upper ontologies, because the energy smart appliances industry is not acquainted with high-level upper ontologies [55].

Table 28 lists the ETSI SAREF and oneM2M base ontology related standards. ETSI released the second version of the SAREF standard (ETSI TS 103 264) in March 2017. The SAREF standardisation work was also included in second release of the OneM2M initiative. SAREF standardisation work contributed largely to the work and concepts of semantics and creation of its own oneM2M Base Ontology. The ETSI standard TS 103 267 (Smart Appliances; Communication Framework) complements the SAREF ontology standard with the standard for the means to communicate and share information. It mandates the use of oneM2M as interworking and communication framework for Energy smart Appliances, to ensure the ability for energy smart appliances to communicate in a common way, either directly or via interworking with specific local protocol.

SAREF is the core model to connect energy smart appliances from all domains (environment, building, energy, health, transport,…). As different domains have different information needs, extensions of SAREF will be defined to tune the standard for a domain. An example of such an extension is SAREF4EE. EEBus and Energy@home extended SAREF with mainly energy related use cases and named the extended version SAREF4EE [56]. SAREF4EE is described in ETSI TS 103 410-1 V1.1.1.

Table 46 ETSI SAREF and oneM2M base ontology related standards

Standard	Release date
ETSI TS 103 264 V2.1.1: "SmartM2M; Smart Appliances; Reference Ontology and oneM2M Mapping".	03-2017
ETSI TR 103 411 V1.1.1: "SmartM2M; Smart Appliances; SAREF Extension Investigation".	02-2017
ETSI TS 103 410-1 V1.1.1: "SmartM2M; Smart Appliances Extension to SAREF; Part 1: Energy Domain".	01-2017
ETSI TS 103 410-2 V1.1.1: "SmartM2M; Smart Appliances Extension to SAREF; Part 2: Environment Domain".	01-2017
ETSI TS 103 410-3 V1.1.1: "SmartM2M; Smart Appliances Extension to SAREF; Part 3: Building Domain".	01-2017
ETSI TR 118 517 V2.0.0: "oneM2M; Home Domain Abstract Information Model"	09-2016
ETSI TS 118 112 V2.0.0: "oneM2M; Base Ontology"	09-2016
ETSI TS 103 267 V1.1.1: " SmartM2M; Smart Appliances; Communication Framework"	12-2015

Analogy to understand the concept of SAREF, SPINE and communication technologies like Wi-Fi, Ethernet, etc. SAREF can be considered as the means to define an idea. For instance a chair has 4 legs. SPINE is the language you use to exchange your idea with another person. You have to use the same language (English, Dutch) and representation of the idea(so compliant with SAREF) , otherwise the other person will not get the idea. And to be able to exchange the information the involved persons have to use the same communication technology, for instance speech or written text; thus Ethernet , Wi-Fi or any other communication technology in the energy smart appliance world.

9.2. The Amsterdam initiative

Three European energy smart / smart home-initiatives AGORA, Energy@Home and EEBus established an international cooperation (in this document called the Amsterdam initiative) to define a common data model and language, called SPINE, for the Smart Home.
SPINE stands for Smart Premises Interoperable Neutral-message Exchange and defines a neutral layer which helps connecting different technologies to build a smart home system. SPINE defines the messages and procedures on application level (ISO-OSI layer 7) and is independent from the used transport protocol.
SPINE covers use cases concerning every kind of control and monitoring of energy smart appliances, with a focus on the sectors of energy smart , smart home & building, connected devices and E-Mobility.
SPINE can be considered a technical realization of the SAREF/SAREF4EE ontology

The initiative is currently focusing on three domains: white goods, HVAC and eMobility.

- The work related to the whitegoods domain has been progressed the most and resulted in the SPINE specifications [57] and the draft/planned standards listed in Table 47, prepared by the WG 7 (Smart Household Appliances) of Technical Committee CENELEC TC 59X (Performance of household and similar electrical appliances).
- In the HVAC domain, an expert workgroup has been established to extend/improve the SPINE specification related to HVAC devices and functionality. The HVAC industry is involved in this workgroup.
- In the eMobility domain the focus is on EV charging at the customer premises. A recently established workgroup is working together with the Open Charge Alliance (http://www.openchargealliance.org/) on the interface between the CEM and EV supply equipment (EVSE).

Table 47: prEN-50631-x standardisation

Standard	Status
prEN-50631-1: Household appliances network and grid connectivity - General Requirements, Generic Data Modeling and Neutral Messages . ***Part 1 defines general requirements, generic data modeling and generic neutral messages without relation to any specific communiction technologoy or any product specific layout.***	Draft standard
prEN-50631-2-x: Household appliances network and grid connectivity - Product Specific Requirements and Specifications ***Part 2 lists and specifies product specific requirements and implementation guidance based on the generic data model and generic neutral messages.***	planned
prEN-50631-3: Household appliances network and grid connectivity – General Test-Requirements & Specifications ***Part 3 defines Test-Requirements and Test-Specifications.***	planned
prEN-50631-4-x: Household appliances network and grid connectivity –	planned

Technology Specific Implementation and Test Requirements
Part 4 defines the mapping of neutral messages to examples of typical communication protocols like ZigBee, KNX, OIC, SHIP, Echonet light, Thread and so forth. These communication protocols are neither mandatory nor to be seen as complete spectrum of communication protocols.

Practically, there are three options to deploy SPINE (see also Figure 22):

A. **The straightforward scenario.** Any technology that supports the bi-directional exchange of arbitrary data can be used more or less directly. For instance the SmartHome IP (SHIP) protocol defined by the EEBus initiative or the Thread protocol.
B. **The protocol & data model mapping scenario.** When using other communications technologies a mapping is needed. Within this mapping, the data points (resources) are mapped as well as the protocol definitions. The capabilities of existing technologies are very diverse, so each SPINE-to-technology mapping is different and possibly not all SPINE functions are supported.
C. **The collaboration scenario.** In this scenario the SPINE resources (data model) are embedded in/next to the resources of an existing protocol. For instance OCF (see 9.6) provides the possibility to add additional data resources next to the OCF resources.

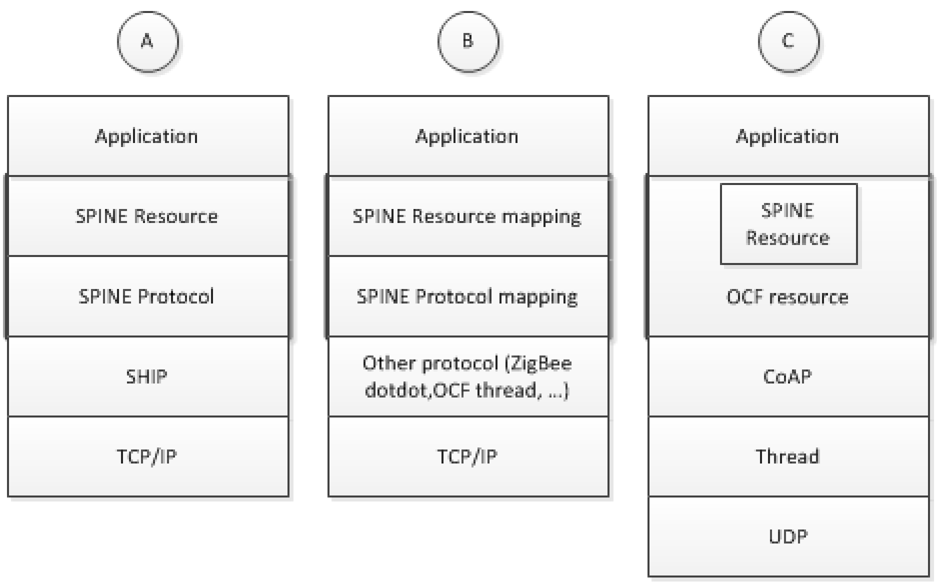

Figure 22 SPINE scenarios: communication stack integration

Scenario A is the ideal scenario: the devices are using the same protocol stack. All SPINE functionality is guaranteed. However, it is unlikely that this will become the reality as appliance and CEM manufacturers have well-founded preferences and interests.
Scenario B is feasible, but has some disadvantages:

- Because SPINE is mapped to an existing technology, not all SPINE functions and capabilities may be supported by this existing technology.
- Maintenance may be difficult as for each (new) version of the 'mapped to' technology and of SPINE a corresponding mapping layer has to be developed and deployed.

Scenario C is almost as good as scenario A. If in the example given above the OCF alliance changes or extends the OCF resources or the underlying protocol, this will have no impact on the SPINE resources (data model). However, agreements between technology providers and the EEBus

initiative are necessarily, and not all technology providers might be in favour of collaboration with EEBus/SPINE.
These scenarios can also be mixed. A CEM could use scenario A to communicate with one energy smart appliance and scenario B or C to exchange information with another energy smart appliance. The consortium is negotiating with alliances like OCF and ZigBee to facilitate scenario C.

Safety and security requirements are not part of the prEN-50631-x series and have been set in IEC/EN 60335-x [58].

9.3. Study on ensuring interoperability for enabling Demand Side flexibility

This is a follow-up study of the SAREF study ordered by DG CONNECT. The study started recently. The purpose of this study is to provide a solution for the problem of the multitude of non-aligned (or in some cases non-existing) standards on a semantic level on the different interfaces between the components of the end-to-end Demand-side flexibility (DSF) flow. The expected end result is that from a semantic interoperability and standardisation point of view the market for demand-side flexibility will become fully functional and the most common and important use cases will be made technically possible.

The study will:

- Identify representative use cases for DSF and provide an overview of the most commonly used data elements in relation to the most common use cases for DSF;
- Provide an analysis of the state of standardisation of data formats for DSF in the Standards Developing Organisations, and identify gaps and the necessary alignments regarding the existing standard data formats and ontology definition;
- Define a solution for the alignment of standard data formats and ontology definitions taking into account the existing SAREF technical specification and bring the results to the Standards Developing Organisations according to a predefined roadmap for standardisation.

9.4. IEC TS 62950

IEC TS 62950 ED1 "Household and similar electrical appliances - Specifying smart capabilities of appliances and devices - General aspects" (see TASK 1 section 1.5.3) is intended to develop the common architecture which applies widely to different use cases and appliance types, and the principles of measuring smart performance within the context of the common architecture.
The standard is in the Draft Technical Specification (DTS) stage and is expected to be published in September 2017. *The draft could not be obtained.*

9.5. ZigBee DOTDOT :||

Early 2017 the Zigbee Alliance has unveiled what they are calling a "universal language" for IoT, ZigBee dotdot [59]. The dotdot language can be seen as an extension of the ZigBee Cluster Library (ZCL) specification used to issue commands across ZigBee 3.0's interoperable application layer. In addition, dotdot has been made compatible with other networks to allow for communication across disparate transports. Therefore, ZigBee-based devices will be able to communicate with IP-based devices residing on a different transport network.

The core of the dotdot language is the ZigBee interoperability layer, but without the protocol. A layer comprises a protocol, interface, and service (the action that the layer performs). The dotdot language is agnostic to underlying networks and protocol message structure, so it defines only the interface and the action. Hence, it is an interaction model, defining the behavior and interaction between devices. For each qualified network, a dotdot specification will standardize or recommend protocols to complete the application layer.

Dotdot may have a head start as the ZigBee ecosystem is already well established and the dotdot language will be compatible with existing ZigBee devices. These ZigBee devices can be brought into the dotdot world through translator and gateway bridges.

The zigbee alliance will be announcing more details about dotdot, including specifications, certification, and logo program, as 2017 progresses.

9.6. Open Connectivity Foundation (OCF)

In 2016 the Open Interconnect Consortium (see Task 1 Annex 2) merged with the AllSeen Alliance (see Task 1 Annex 2). The merged entity is called the Open Connectivity Foundation (OCF)[60] and is now made up of more than 300 companies, with members spanning from companies such as Cisco, Intel, Microsoft, Samsung, LG, Sony and Qualcomm to industrial concerns like Electrolux and GE.
The Open Connectivity Foundation has been founded with the goal of defining the connectivity requirements and ensuring interoperability of the devices that make up the IoT. The OCF efforts include specification, certification and branding in order to efficiently achieve the goal of interoperability of devices, networks, and applications. The OCF set of specifications defines a common communication framework based on industry standard technologies to connect and intelligently manage the flow of information among devices, regardless of form factor, operating system or service provider.

IotTivity is the open source framework implementation of the specified software stack allowing application developers and device manufacturers to deliver interoperable products across various platforms. Moreover, OCF is also seeking interoperability at the data model level by providing an online tool, the oneIoTa Data Model Tool, to encourage the design of interoperable device data models for the IoT. The web-based oneIoTa tool enables users to create simple models for any IoT device, compatible with the OCF RESTful architecture. The automated process of the site enables crowd-sourcing of data models and will allow for the rapid development of new IoT devices.

9.7. The IoT schema.org initiative

Another example of an open community process collecting vocabularies is schema.org [61]. Schema.org is a collaborative, community activity with a mission to create, maintain, and promote schemas for structured data on the Internet, on web pages, in email messages, and beyond. schema.org vocabularies cover entities, relationships between entities and actions, and can easily be extended through a well-documented extension model. Many applications already use these vocabularies to power rich, extensible experiences.

In 2016 Google has started an initiative IoT schema.org [62] focussing on vocabularies for IoT. Energy efficiency and DSF are regarded as one of the use cases where IoT schema.org could contribute. TNO as developer of SAREF for the European Commission and member of ETSI is involved in this initiative.

9.8. IETF

The IETF already has a decade of history specifying and documenting key IoT standards and guidance. Other organizations and consortia working on IoT have for instance adopted the Internet protocol (IP) stack as the basis of their solutions. The document "Internet of Things: Standards and Guidance from the IETF" [63]provides an overview of the IETF work related to IoT.

In addition to the work on standards the IETF Thing-to-Thing Research Group (T2TRG) [64]is working in close collaboration with the W3C's Web of Things group, on longer term research issues to turn a true "Internet of Things" into reality, an Internet where things can communicate among themselves and with the wider Internet. Current work is centered around RESTful design / hypermedia-driven applications and security, but also data models, formats and semantics are part of the research. The workshop "IoT Semantic Interoperability Workshop 2016" [65] focused on semantic interoperability and provided a list of some excellent overview papers.

Related to the discussion on architecture in Task 3, the standard IETF RFC 7452 "Architectural Considerations in Smart Object Networking" [66] illustrates four communication patterns utilized in the IoT in the smart object environment:

- Device-to-Device Communication Pattern:

This pattern is not relevant in the context of this study.

- Device-to-Cloud Communication Pattern

In this pattern communication from and with the IoT device relays via back-end server of a application service provider. Often the application service provider is also the manufacturer or vendor of the IoT device. In that case, the entire communication happens internal to the provider and no need for interoperability arises at the IoT device interface.
To prevent silos the application provider should allow third-party device vendors to connect to their server infrastructure as well, but then the need for interoperability arises again.
Another frequent concern from end users in this scenario is that a change in the business model (or for instance bankruptcy) of the IoT device/ application service provider might make the service or even the hardware become unusable.

- Device-to-Gateway Communication Pattern

This communication pattern is convenient when special application-layer functionality has to be provided or interoperability is needed with legacy, non-IP-based devices. The gateway can bridge between different technologies and may perform other networking and security functionality. Often, these gateways are provided by the same vendor that offers the IoT product, because of the use of proprietary protocols, to lower the dependency on other vendors or to avoid potential interoperability problems. It is expected that in the future, more generic gateways will be deployed to lower cost and infrastructure complexity for end consumers. Such generic gateways are more likely to exist if IoT device designs make use of generic Internet protocols and not require application-layer gateways that translate one application-layer protocol to another one. The use of application-layer gateways will, in general, lead to a more fragile deployment.

- Back-End Data Sharing Pattern

The device-to-cloud pattern often leads to silos. IoT devices upload data only to a single application service provider. However, users often demand the ability to export and to analyze data in combination with data from other sources. Hence, the desire for granting access to the uploaded sensor data to third parties arises. Typically a RESTful API design in combination with a federated authentication and authorization technology is used. However, the entire protocol stack (including the information/data model and RESTful Web APIs) is often not standardized.

9.9. AIOTI

The Alliance for Internet of Things Innovation (AIOTI) [67] was initiated by the European Commission in 2015, with the aim to strengthen the dialogue and interaction among Internet of Things (IoT) players in Europe, and to contribute to the creation of a dynamic European IoT ecosystem to speed up the take up of IoT. Other objectives of the Alliance include: fostering experimentation, replication, and deployment of IoT and supporting convergence and interoperability of IoT standards; gathering evidence on market obstacles for IoT deployment; and mapping and bridging global, EU, and member states' IoT innovation activities.
The AIOTI website contains several reports related to IoT, IoT architecture and standards. The white paper “Semantic Interoperability for the Web of Things” [68] explains the concept of semantic interoperability. It expresses also the need for a shared roadmap and commitment to work together across standards organizations, consortia, alliances, and open source projects.

9.10. “My Energy Data” report

The European Smart Grids Task Force Expert Group 1 Standards and Interoperability released in November 2016 the “My Energy Data” report [69]. With smart meters being deployed across Europe and the number of installed IoT devices rising, the amount of data that will be available about energy consumption will raise tremendously. To fully reap the potential benefits for the energy market and consumers in general, it must be ensured that **a trusted mechanism is in place for consumers to access and manage their data.**

‘My Energy Data’ is the term adopted in this report as a generic description of services to offer customers the possibility of:

- **downloading** their energy consumption information,
- **granting access to third parties to that information** to enable service providers to offer analytical and other services to customers.

The report:

- provides an overview of some of the existing initiatives in Europe on data access and data management in the field of energy distribution, and of the industry led Green Button initiative launched in 2011in the US,
- identifies obstacles for controlled data access and data management,
- explores at EU level the potential for and scope of a possible industrial initiative on a common format for energy data interchange.

Early 2017 a Memorandum of Understanding should be drafted and proposed for signature by a core group of industries interested in the initiative, with the possibility for other interested parties to join at a later stage of the process. In the meantime, however, the Enel Group announced [70] that it is the first European utility to join the Green Button Alliance. Enel will make “Green Button Download My Data” and “Green Button Connect My Data” available to selected customers in Italy via Enel's Energy Management System.

9.11. Interoperability of the H1/H2 interfaces Report

The purpose of this report [71] is to set out more precisely the process by which member states may ensure interoperability required for the provision of energy services to consumers and to enable DSF. This report focuses on the interfaces the metering infrastructure and on the provision of profiles for the following interfaces:

- H1: the interface between the smart meter and a simple external display device (where applicable) via one-way communication.
- H2: the interface used for smart grid communications exchanging information between the advanced metering infrastructure (AMI) and DSF applications. H2 connects the smart metering gateway (LNAP) and the energy management gateway. H2 enables two-way communication for home automation end.

Smart Grid Co-ordination Group recognised that simply selecting communication standards is not sufficient to guarantee interoperability. The report therefore encouraged the use of additional or companion specifications, here referred to as Basic Application Profiles (BAPs). A BAP is a document that describes how standards or technical specifications are applied to support the requirements of a particular (national) infrastructure. Profiling fixes the way standards/specifications are used: it determines the part of the standard used and how options are used in order to achieve interoperability between products of several manufacturers in the most economical way.
In addition the report considers Basic Application Interoperability test Profiles (BAIOPs), which are used to check that the individual technical requirements of the selected profile are met. Interoperability testing is an important aspect. It confirms that implementations are compliant with the standards/specifications (conformance testing) and exchange information according to the predefined use cases (interoperability testing) and has the goal of ensuring interoperability with other infrastructure components. Testing processes therefore have to be specified to enable a check that the individual technical requirements of the selected profile are met.

9.12. CONCLUSION

To resolve the interoperability problem, a lot of organizations and consortia that develop standards are moving the focus from communication interoperability to information/semantics interoperability. At the application layer, interoperability is not yet mature. The work on data formats (in the form of information models and data models) has not seen the same level of consistency throughout various standardization groups. Examples of standardization efforts in the IoT and energy smart appliance area include the Cluster Library developed by the Zigbee Alliance, the OMA LWM2M, or SPINE by EEBus. One common problem is the lack of an encoding-independent standardization of the information, the so-called information model. Another problem is the strong relationship with the underlying communication architecture, such as a RESTful design. SAREF, supported by DG CONNECT and ETSI, is a potential candidate to become the information model in the energy smart appliance area. The extension SAREF4EE adds the necessary resources and functions to the model to enable energy related use cases, like DSF.
Realizing semantic interoperability at scale will require collaboration and coordination across standards organizations, consortia, alliances, and open source projects. The need for a shared roadmap and commitment to work together seems evident.

Until mid-2016, it seemed like every month a new “IoT standards organization” was popping up with the promise of application-layer interoperability for connected devices. However, developments over the last six months of 2016 have started to reverse that fragmentation. AllSeen has now merged with the OIC alliance to form the Open Connectivity Foundation (OCF). And others are beginning to fade into irrelevance. Furthermore, complementary organizations are collaborating more on application layers that will enable devices compatible with their respective technologies to interoperate. One such example is the ZigBee dotdot language. Another example is EEBus SPINE: besides the mapping scenario option the EEBus initiative is also seeking collaboration with other alliances to have the SPINE data model/resources incorporated in other application protocols.

Most alliances are not only defining the specifications, but are also certifying compliance to these specifications. In Germany then again, a certification programme “Smart Home + Building“ has been set up by DKE/VDE to test interoperability of systems in the smart home area.