e-HIGHWAY 2050

Modular Development Plan of the Pan-European Transmission System 2050

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WP 3	**Setting the boundary conditions for 2020-2050 grid planning**		
D3.1	**Technology assessment from 2030 to 2050**		

Annex to D3.1 – Selection and characterization of the most impacting demand-side technologies at the 2050 time horizon

Revision	Organisation	Date
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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

Document information

General purpose

This document is an annex of deliverable **D3.1** focusing on the technology assessment (technical and economic performances) of generation, storage, transmission and demand-side technologies. It deals with the approach followed within WP3 to select and characterize the most impacting demand-side technologies for the electric load in EU27 at the 2050 time horizon.

The present document is complemented by:

- an attached document (Excel file) providing the rationale for selection of the critical end uses and technologies according to the methodology described in the next sections,
- three annexes of deliverable D3.1 constituting the technology assessment reports for three retained technologies: Heat Pumps and LED technologies for lighting for the residential and commercial sectors, as well as Electric Vehicles for the transport sector.

Change log

Revision	Date	Changes description	Authors
V1.0	05/07/13	Creation of the document and associated Excel file. Two annexes included: Technology Assessment Reports on Heat Pumps and Electric Vehicles	Technofi
V2.0	26/08/13	Update according to comments from RTE, KUL. Addition of a third report on LED and lighting. Version sent for review by Quality Pool members (RTE, RSE, KUL)	Technofi
V3.0	20/09/13 - 10/10/13	Update according to comments by Quality Pool (RSE, KUL, RTE).	Technofi
V3.1	08/11/13	Integration of ENSIEL comments	Technofi
V4.0	06/12/13	Updated version for review by the project	Technofi
V5.0	29/08/14	Final version integrated to D3.1	Technofi

Glossary

The entries in the glossary are presented in a self-explanatory order, i.e. in the order of appearance in the present document.

Demand-side technology

Any technology consuming electricity.

Demand-side enabling technologies

Technologies needed to monitor and control the demand-side technologies. In Milestone Ms 1.1, a list of such enabling technologies has been proposed (electricity meters, concentrators, communication channels and protocols, etc.). They open the way to load management features by a remote operator or a local automatic control.

Sectors

The four sectors considered for electricity consumption are Residential, Commercial, Industry, Transport. NB: The commercial sector is sometimes called Services.

Electricity end-use

Electricity is consumed in a variety of uses by technologies/appliances/device/processes. Electricity end-uses represent a segmentation of these uses by final consumers in the residential, commercial, industry, transport sectors. The segmentation in each of the four sectors is given by Table 2.1.

"Technology mix" of an end-use segment

In a given end-use segment, the typical technology/appliances/device consuming electricity is called the typical average "technology mix": it should be understood as a theoretical "average" system addressing the considered electricity end-use.

Criticality

By criticality, it is meant any major modification of the demand main characteristics at different time and space scales (daily load curve, yearly consumption, etc.) resulting from the use of electricity, following an evolution of a demand-side technology or of a typical use. Such criticality might result either from a significant evolution of a given end use (decrease or expansion of the end use), or from the evolution or emergence of a specific technology meeting this end use (evolution of performances or new technology). Therefore, the criticality could be of two kinds:

- A criticality related to energy: the overall electricity demand at the 2050 time horizon is significantly different (positive or negative) in comparison to the current situation. It is measured as a variation in electricity consumed in EU27 (in TWh over a year). The criticality related to energy is assessed based on the Volume effect and the Energy efficiency effect.
- A criticality related to the load profile (power): the typical load profile of an end-use is significantly modified through the massive deployment of a breakthrough technology, a strong evolution of the energy efficiency or consumption per technology, or a load management

implementation. It is measured by a qualitative assessment of the impact of a technology in terms of typical daily load profile. The criticality related to the load profile is evaluated based on the volume effect combined to the typical end-use profile (base or peak load) and the Load controllability potential.

Consequently, criticality is measured by the three indicators defined below ("volume effect", "energy efficiency improvement effect", "load controllability potential").

Volume effect

Indicator measuring the criticality of an end-use. In the residential sector, the "volume effect" is the number of units of typical technologies/appliances/devices required to meet a given end-use (in EU27 in 2050). It is thus defined by a dimensionless number characterizing the energy consumption of the considered electricity end-use segment (in EU27 in 2050) assuming a typical average "technology mix". This definition is generalized to the commercial and industry sector.

Efficiency improvement effect

Indicator measuring the criticality of an end-use. It is characterized by the evolutions of a level of electricity consumed per unit over the period 2012 to 2050, where unit is a typical average technology mix meeting a considered end-use.

Load controllability potential

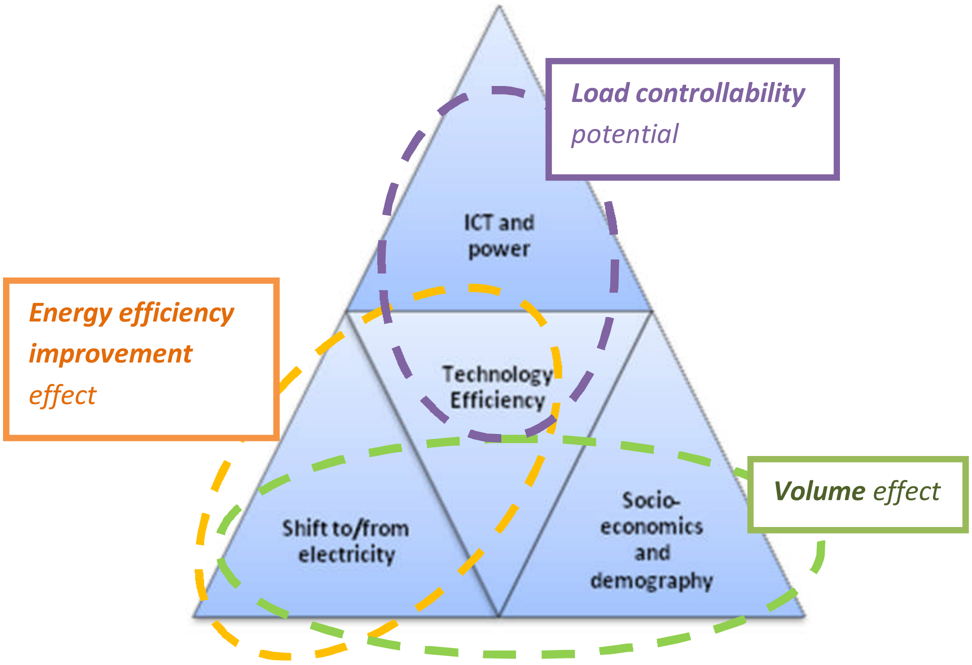
Indicator measuring the criticality of an end-use. It measures the ability of a remote operator to control part of the load of a given end-use.

Drivers

Drivers impacting the electric demand at 2050 have been organized into four categories:

- "technology efficiency": the improvement of the electricity consumption due to incremental innovation or a breakthrough technology,
- "socio-economics and demography": any evolution of the end-user electricity needs in nature or in volume,
- "shift to/from electricity": any change in electrification or to new uses (or shift from industry to services),
- "ICT and power": the expected convergence of the ICT world and the power system will overall increase the ability to control the electric load.

The four categories of drivers are closely related to the three indicators impacting the criticality of an end-use (cf. Figure next page).



Contextualisation

By contextualization, it is meant the ability to adjust the values of variables (for instance costs or efficiency for example) of a set of technologies at the 2050 time-horizon according to a given e-Highway2050 scenario.

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1 Introduction

1.1 Purpose

This document aims at describing the demand-side technologies retained for the e-Highway2050 project and to be included in the main output of WP3, namely a technology database.

The key underlying assumption is about the way to approach the electricity demand curve at the 2050 time horizon in terms of structural modifications including both energy (annual consumption) and power (daily load profile):

- a theoretical reference electricity load curve is assumed at 2030 with regard to the best knowledge gathered from short to mid-term projections (typically the current electricity demand and projections up to 2030),
- this 2030 reference is structurally modified by a series of effects which are sought for at the level of individual end-uses (per sector),
- the above identified effects at 2030 are assumed to still be valid for the 2050 time horizon, based on each of the five scenarios considered by the e-Highway2050 project. This “contextualization” process is described in the chapter 6.

Electricity consumption is analyzed by sector and by end-use. Technology options are multiple for each end use. The three main goals of this report are:

- to identify a set of demand-side technologies according to criteria related to their impact onto the transmission system once massively deployed in Europe,
- to describe such a selection process and the resulting list of demand-side technologies as well as the rationale of selection,
- to characterize each of these demand-side technologies according to a set of variables including possible uncertainties at the 2050 time horizon (cf. annexes).

1.2 Content

The present report is organized in two parts.

- <u>A main document</u> focusing on the rationale and criteria for selecting the demand-side technologies.
    - o Chapter 2 recalls the outputs of Ms1.1 for demand.
    - o Chapter 3 describes the criteria and methodology of selection of the most impacting demand-side technologies with regard to the transmission grid.
    - o Chapter 4 synthesizes the results of the selection process.
    - o Chapter 5 focuses on the structure of the technology database and on the generic process for collecting, building, cross-checking and validating the data.
    - o Chapter 6 focuses on the management of uncertainties related to the technology evolutions by 2050, and more specifically on the tuning of data according to the five scenarios elaborated in WP2 (contextualization).
    - o An attached document (Excel file) provides the rationale for selection of the critical end uses and technologies according to the methodology described in the next sections.

- Annexes organized per selected technology. For each selected demand-side technology a separate document details:
    - the specific assumptions for collecting, building, cross-checking and validating the data (TAR, i.e. Technology Assessment Report),
    - the data (technology datasheet).

2 Technological scope of demand-side technologies

This Chapter is a synthesis of the outputs of WP1/task 1.2 (formalized in the document named Milestone Ms1.1).

2.1 Scope of electricity demand-side technologies

With respect to segmentation of the whole technology area covered by the project, demand-side technologies are included in the Consumption technology area which includes also decentralised storage[1].

Any technology consuming electricity (today or in the future up to the 2050 time horizon) has been defined as a **technology option**. These options are bound by a set of constraints restraining their potential for implementation. The resulting technology perimeter is set by these boundary conditions on a set of electricity demand-side technologies which has been screened in task T1.2. This was performed by a bottom-up analysis of the main sectors: residential, commercial, industry and transport.

The bottom-up analysis carried out consisted in a review of the unitary uses of electricity by the "larger consumption groups" and allowed identifying consumption technologies which, once massively deployed, might have a significant impact on the load curve. These electricity consuming devices/processes can be organized in two groups:

- existing electricity consuming devices and processes;
- new uses resulting from technologies not yet mature or fully deployed which might have a major impact on the power system. These uses could be for instance the result of a substitution effect (e.g. heat pumps in buildings) or "real" new uses (e.g. electro-mobility).

A draft list of the electricity consumption technology options organized by segment is proposed below in Table 2.1 They represent the boundary conditions for consumption technology options, in other words the technological scope which will be considered as the input for the selection process described in Chapter 3.

A second useful concept was also defined in task T1.2. The effective deployment of a technology over an about 40-year time span is clearly subject to major **uncertainties**. Each of the considered demand-side technology could be characterized by a set of variables influencing its development and the evolution of its costs/performances over time. Again boundary conditions for these uncertainties have been considered to set limits to these uncertainties. Hence, they take the form of extreme values (both quantitative: min/max and qualitative: high/low) for each of the variables considered, including costs, efficiencies and other performances.

2.2 Electricity consumption technology options per end use

2.2.1 List of technologies per end-use sector considered in the analysis

All appliances and processes have to be considered since impacting the load curves in terms of energy consumed and shape of the load. A draft list is provided in the table next page which has been built with the support of experts on electricity demand in Europe. It lists the technological innovations that are likely to emerge in the next 30-40 years. No assumption is made at that level on the degree of likelihood or on their potential of deployment.

[1] Not presented in this report.

Table 2.1. Electricity consuming appliances/processes considered in this report.

Sectors		Sub-sectors/ technologies	Sub-technologies (non-exhaustive)	Main technological innovations up to 2050
RESIDENTIAL	D1	White goods	washing machines, dishwashers, dryers, washer-dryers, refrigerators, freezers	- smart appliances in Home Area Network (HAN), - radio-frequency identification (RFID), - remote control capabilities for demand response programmes or consumption optimisation - higher efficiency: European standards
	D2	Cooking appliances	ovens	- smart appliances in HAN, - RFID, - higher efficiency : European standards, etc.
	D3	Lighting	halogen lamp, LED, OLED, bulb lamp	- smart lighting (presence, etc.) - sensors, lighting controls
	D4	Water heating	solar heating, geothermal energy, heat pumps, biomass boiler	- better performing heating systems with renewables, - smart thermostats water heaters
	D5	Electronic appliances	TV, computer, Cable TV receiver, stereo recorder, telephone	- multiservice device: home energy management system, sensor plug and socket, alarm
	D6	Space heating	Heat pumps, insulation, electric heaters	- more effective insulation, - efficiency of heat pumps, - remote control capabilities for demand response programmes or consumption optimisation - micro-cogeneration
	D7	Space cooling	Heat pumps, insulation	- more effective insulation, - remote control capabilities for demand response programmes or consumption optimisation - higher efficiency, - smart thermostats
COMMERCIAL	D8	Office equipment		
	D9	Cooling and ventilation in tertiary buildings		-efficient HVAC
	D10	Commercial lighting		- sensors, - remote control capabilities for demand-response programme and consumption patterns
	D11	Outdoor lighting	LED, electronic ballasts, PLC	- intelligent outdoor lighting (steering on presence, weather, etc.), - adaptive light to brightness, wireless protocols
	D12	Commercial refrigeration	refrigerators	-remote control capabilities for demand-response programme and consumption optimisation
	D13	Heating in tertiary buildings	heat pumps	heating controls

	D14	Data management	cloud, data sharing	- infrastructure optimisation, - higher efficiency, - digital signature
INDUSTRIAL	D15	Steel	Recovery of Basic Oxygen Furnace (BOF) gas, BOF gas sensible heat recovery	- reduce the need for raw materials and encourage reuse of existing products
	D16	Paper and Pulp	Pumps, material processing, material handling, refrigeration, compressed air, boiler, motor system, combined heat and power	improvement in pulp and paper making process
	D17	Aluminium	Process heating/burners, compressed air systems, electric motor systems, pumping systems	enhanced aluminium making process
	D18	Zinc		
	D19	Cement	Dry process, clinker production (wet and dry)	
	D20	Chemical industry	Speed drives, refrigeration, compressed air, relighting, steam flow boiler	
	D21	Food processing	Steam system, motor and pump system, refrigeration system, compressed air system	improvement in food making process
	D22	Agriculture	Irrigation	
TRANSPORT	D23	Electric vehicles and plug-in vehicles	battery, KERS, AC (Type 2, Type 3), , DC fast charging (CHAdeMO) charging, inductive charging	- better performing and long-lasting batteries, - faster charging, - smart charging infrastructure, - remote interaction with SCADA systems, - integration with DER - new standard for fast chargings
	D24	Freight	Regenerative breaks	
	D25	Buses	Batteries; Distributed inductive recharge or in-road inductive recharge	A mix of several alternative fuels needed to replace fossil fuels
	D26	Electrified railways	Power converters, storage systems, regenerative braking, automation systems	- energy saving, - increased transportation capacity, - voltage stability, - increase in power quality, - integration with renewable energies

2.2.2 Demand-side enabling technologies

In addition to these appliances/device/ processes consuming electricity, one shall also consider the so-called demand-side enabling technologies. They are indeed needed to monitor and control the demand-side technologies. Milestone Ms1.1 has proposed a breakdown of such enabling technologies.

Table 2.2. Demand-side enabling technologies (not considered in this report).

		Technologies	Sub-technologies	Comments
Demand-side Enabling Technologies	D27	technologies using electricity meters (inside customers places)	Smart Metering, HAN, smart thermostats, security devices, automated load control devices, in-home displays, informative billings, consumption report, web portal, mobile application, local intelligence/automation	
	D28	technologies used by the concentrator	Communication channels, IT infrastructure, Protocol	the concentrator gathers all the data from the different smart meters
	D29	technologies used by the aggregator	Communication channels, IT infrastructure, Protocol	The aggregator sends messages / orders to the smart meters
	D30 D31	technologies used by the DSO (resp. TSO)	Communication channels, IT infrastructure, Protocol	

We assume that the dedicated ICT infrastructure upon which they rely will be developed at the 2050 time horizon, which in turn will have different impacts on the future load curve:

- In terms of induced electric consumption: the induced electricity consumption by such enabling technologies will remain marginal
- In terms of electric consumptions of the controlled devices (processes in industry and services; appliances in residential ; electro-mobility, etc.): the impact will clearly depend upon :
  - the future deployment of the demand response
  - the technical features of the controllable devices
  - the characteristics of the power system as a whole (market signals, inertia of building for heating/cooling, social acceptance, regulation, etc.).

This second list of enabling technologies is thus only considered in terms of load controllability potential which is assessed for each end-use consumption segment (see section 3.5.3).

One should also observe that the resulting demand-side management strategies which are expected to be implemented by a remote operator within the next decades will rely on two main components, e.g. energy efficiency and load management[2]. The table below describe typical control strategies:

Table 2.3 Demand-side enabling technologies not considered in this report

Demand-side management strategies	**Effect / Rationale**	***Examples of control strategies***
Energy efficiency	Effect: reduction of overall consumption Rationale: the technological improvement of processes and devices.	Eco-efficiency labels of white goods
Peak shaving	Effect: reduction of electricity consumption during peak hours Rationale: - substituting appliances used at peak hours (i.e. convectors) by other equipment or technologies (passive peak shaving) - remote control at large scale of devices	Remote control at large scale of heat pumps in building
Load shifting	Effect: transfer of electricity consumption from peak hours to non-peak periods Rationale: Time shifting of a given load (positive or negative) without any critical impact to the end-consumer.	Postponing the use of electric water heaters before/ after peak hours.
Electricity Storage management	Effect: spread a peak consumption to non-peak periods Rationale: This effect is a combination of the two previous strategies applied to the charging of electric batteries. It is obtained by "diluting" the consumption process over non-peak periods	Slow charging (overnight) instead of quick charging (at 7pm) of electric vehicle
	Effect: retrieve stored electricity from electric batteries Rationale: The stored electricity during non-peak hours is used when needed. Electric battery is used as a generator.	Vehicle to Grid or battery to grid

[2] Based on the description proposed by deliverable D2.1 of the project, "Structuring of uncertainties, options and boundary conditions for the implementation of EHS", 2013, section on demand side management, page 44

3 Criteria for selecting the demand-side technologies

3.1 Forecasting the electricity consumption at 2050

Forecasting the electricity consumption at a long-term time horizon (2050), i.e. beyond the conventional extrapolation forecasts is a tricky exercise. Among the possible methods to build robust assumptions based on the existing consumption levels or short-term forecasts, one could consider an analysis of some drivers which might modify the electricity consumption. For instance, it is clear that not only the number of consumers matters for the residential end-use but also more subtle sociological[3] and economic drivers[4].

Performing such an analysis leads naturally to cluster these drivers in four intertwined families. The drivers can be related to:

- the decrease of the consumption of electricity for the same service: "technology efficiency"
- the end-user needs which could evolve in nature or in volume: "socio-economics and demography",
- the change in electrification or to new uses: "shift to/from electricity",
- the increased ability to control the load resulting from a convergence from the ICT world and power system : "ICT and power".

For instance better insulation of buildings belongs to the first category, while the massive deployment of heat pumps or the emergence of electro-mobility are two drivers of the third category.

This first analysis allows to draft a framework of systematic analysis of the drivers impacting the electric demand at 2050.

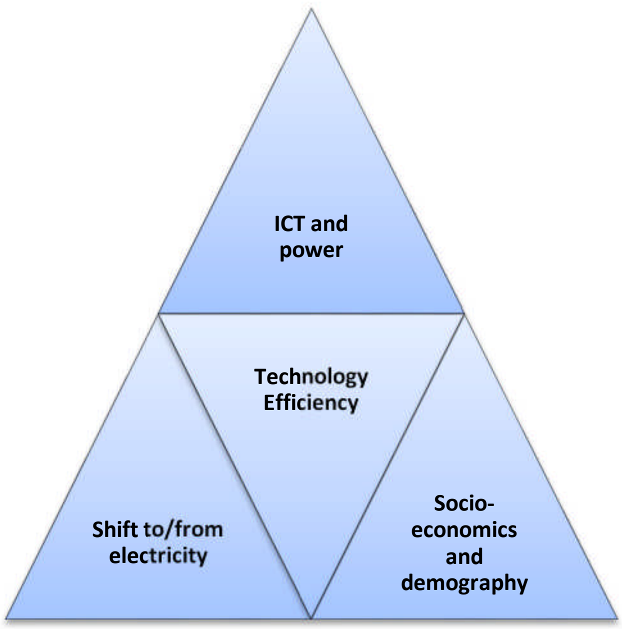


Figure 3.1: Framework of the drivers impacting the electric demand

[3] Such as ageing population, change of lifestyle, size of dwellings, structure of the family
[4] Price of electricity, of energy, etc.

This general framework will be used to develop a specific method to identify a selection of the "most impacting" technologies in a sense defined below.

3.2 The proposed challenge: identifying relevant technologies

Consumption is detailed by sector and by end-use. Technology options are multiple for each end-use. Our main challenge is the following:

How to identify the end-uses (by sector) for which the evolutions over a 40-year time period will structurally modify the load curve at the European level?

The technology analysis performed in WP3 aims to identify the criticalities induced by the future demand-side technology changes which might impact the transmission system at 2050. The selection of the relevant technologies is based on the following driving principle:

Innovations expected up to 2050 having the most important effect in terms of criticality will be retained.

The proposed approach has been designed in two successive steps:

- the first step focuses on the "selection of end uses": it is based on the assessment of their criticality (either a criticality related to energy or to power as defined below),
- the second step will focus on the selection process "from end-uses to technologies": for each of the retained end-uses, technologies which are the driving factor of the criticality are identified. For instance, the massive deployment of a breakthrough technology as LED for the lighting end-use will drastically impact the consumption of this end-use.

Such an approach allows to describe in-depth a limited number of technologies, which might have a major impact in terms of electricity demand at the 2050 time horizon. It has however some limitations. It is assumed that some major uncertainties remain in the deployment of technologies at that time horizon (and in the estimated related electricity consumption). For instance, analyzing what could be the demand in electronic appliances for the residential sector at that time horizon might be very tricky. In such cases, it was preferred to avoid formulating statements without any strong scientific foundation.

3.3 Criticality: the criterion to estimate the impact on the electricity demand at 2050 (step1)

By criticality it is meant any major modification of the demand main characteristics at different time and space scales (daily load curve, yearly consumption, etc.) resulting from the use of electricity, following an evolution of a demand-side technology or of a typical use. Such criticality might result either from a significant evolution of a given end use (decrease or expansion of the end use), or from the evolution or emergence of a specific technology meeting this end use (evolution of performances).

Therefore, the criticality could be of two kinds:

- A criticality related to energy: the overall electricity demand at the 2050 time horizon is significantly different (positive or negative) in comparison to the current situation. It is measured as a variation in electricity consumed in EU27 (in TWh over a year);
- A criticality related to the load profile (power): the typical load profile of an end-use is significantly modified through the massive deployment of a breakthrough technology, a strong evolution of the energy efficiency or consumption per unit, or a load management

implementation. It is measured by a qualitative assessment of the impact of a technology in terms of a typical daily load profile.

An approach to estimate these two criticality criteria is proposed in the next section.

3.4 Assessing the criticality (step 1)

The traditional bottom-up approach to model the electricity demand at the 2050 time horizon consists in adding end-uses per sector and to make specific assumptions for each use (and technology, appliance, process).

In the present approach, for each end-use (per sector), the criticality assessment is performed based on the following indicators that are preliminarily estimated:

- Volume effect: a dimensionless number of typical consumption units[5] for a given end use.
- Efficiency improvement effect: based on the analysis of the recent trends in energy consumption a regular progress in terms of energy efficiency can be anticipated. In addition, other effects might hamper/speed-up such effect. It is measured by a change in the typical energy consumed by unit.
- Load controllability potential: it measures the ability of a remote operator to control part of the load of a given end use.

Based on these indicators, the criticality related to energy is first assessed based on the "volume effect" and the "energy efficiency improvement effect".

Then the criticality related to power (load profile) is evaluated based on the "volume effect" combined to the typical end-use profile (base or peak) and on the "load controllability potential".

Table 3.1 The factors impacting the criticality for each end use

Assessment of the criticality of an end-use	
Criticality in energy • Volume effect • Energy efficiency improvement effect	**Criticality in power** • Volume effect (combined to typical end use profile: base or peak) • Load controllability potential

Next table is illustrative of the assessment performed for each end use. See the Excel file for more details.

Table 3.2 Template used to estimate the factors impacting the criticality for each end use

	Volume effect		Energy efficiency improvement effect	Load controllability potential
Consumption end use (and related technologies)	today	Trends at 2050	Trends at 2050	Potential at 2050
	X TWh or % of load in a given sector	+++ (example)	-- (example)	"Low" (example)

[5] Or technology/processes for the commercial or industrial sector

In the next section, the process to estimate each of the three factors impacting the criticality of a consumption end use is detailed.

3.5 Characterization of the three effects per end-use (step 1)

A single scale has been used to estimate the volume effect and the efficiency effect.

3.5.1 The "volume effect"

In the residential sector, the "volume effect" is the number of units of typical technology/appliances/device required to meet a given end use (in EU27+ in 2050). It is thus defined by a dimensionless number characterizing the energy consumption of the considered electricity end-use segment (in EU27+ in 2050) assuming a typical average "technology mix"[6].

It is observed that the "volume effect" is impacted by the drivers identified above as "socio-economics and demography" and "shift to/from electricity" which will allow to define a metric.

For the residential sector, three components can thus be identified in the "volume effect":

i. Evolution of the population in Europe. It is assumed that the trend up to 2050 is a steady increase (reference scenario of population growth in Europe – "natural growth");

ii. Equipment rate of the technology/appliance needed to provide such end use. For instance, in 2009, 75% of households in Europe were equipped with microwaves and this rate is expected to further increase. This rate also includes the electrification of an end-use (e.g. shift from gas to electrified heating);

iii. Duration of operation: number of hours of operation / standby appliances.

When considering the commercial (resp. industry) sector, the above definition can be extended. Components ii[7], iii are still valid while the first one is adjusted:

i. Evolution of the commercial activity (resp. industrial production) resulting from the GDP evolution and the shifting trend from industry to services.

The trends in volume effect over the 2012-2050 period are evaluated in a four-level scale as detailed in the table below.

Table 3.3. Trends of the "volume effect" for a given end use

Volume effect trends 2012-2050 for a given end use		
Mark for rate of increase	Legend	Main driver for modification
+++	Exponential increase of the equipment rate (multiplying factor more than X2 over 40-year)	New uses /electrification of an end use (with massive deployment)
++	Significant increase of the equipment rate (double digit – 30% to 90% over 40-year)	New uses /electrification of an end use
+	Stable equipment rate combined with the "natural" growth (either of population/commercial activity/industrial production8)	"Natural growth"

[6] The typical technology/appliances/device is called in the following sections the typical average "technology mix": it should be understood as a theoretical "average" system addressing the considered electricity end use.

[7] As an example, it is observed that the trend on motorisation in industrial processes contributes to the component (ii) (increase of equipment rate).

[8] For industry the "natural" evolution might be a decrease and the appropriate mark should have been = (or even -). In order to keep homogeneity among the scale for all the sectors, we kept the + mark.

-	Significant decrease of duration of operation	Socio-economics

The following observations have to be made regarding the above definition of the 4-degree scale. If we wanted to be precise from the methodological point of view, we would need a more complicated table composing the three factors of the "Volume effect", and then their aggregation, but this would create more complexity than added value. Therefore we have made the following assumptions:

- the "equipment rate" is expected to be the more impacting component of the "Volume effect",
- the neutral point is set to "+" assuming that the evolution of the population (case of Residential sector) in this table is assumed to be "natural growth",
- the "duration of operations" component might decrease the volume effect (see mark – in the last line of the table-) or at least compete with the "equipment rate" (if the latter increases).

For each end-use segment, we have assessed in a qualitative way the impact to the "volume effect" of electricity demand. Then an aggregated resulting mark in terms of volume effect is proposed taking into account possible competing components.

3.5.2 The "energy efficiency improvement effect"

The "energy efficiency improvement effect" is characterized by the evolutions of a level of electricity consumed per unit over the period 2012 to 2050, where unit is a typical average technology mix meeting a considered end-use.

It is observed that the "energy efficiency improvement effect" is impacted by the drivers identified above as "technology efficiency" and "shift to/from electricity" which will allow to define a metric.

Three components can thus be identified[9]:

- Energy efficiency improvement for the technology mix meeting the considered end use (where the end use assumed to remain constant - as opposed to expanded, see below): it is defined by the decrease in electricity demand of a given technology/appliance/device to meet a given functional performance (end use);
- Expansion of the individual technology end use (for a particular end-user): for instance larger TV or more powerful processors lead to an increase of the unitary energy consumption;
- Change in the typical average technology mix: for instance more nomadic applications instead of desktop IT applications will reduce drastically the unitary energy consumption.

[9] It is observed that electrification (e.g. heat pumps) of an end-use might have in parallel an impact in terms of *volume effect* (through the increase of the equipment rate) but also in terms of *energy efficiency improvement* (expansion of the individual end use). This will be shown in figure 4.3: the driver "Shift to/from electricity" is linked to both effects (green and orange colors).

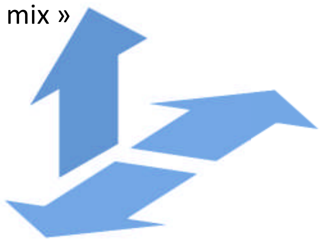


Figure 3.2 The three components of the energy efficiency improvement effect

These three components when combined result in a synthetic mark characteristic of the resulting trends in the energy efficiency improvement effect over the 2012-2050 period. A four-level scale is proposed to support this assessment as detailed in the table below.

Table 3.4. Trends of the "energy efficiency improvement effect" for a given end use.

Energy efficiency improvements trends 2012-2050 for a given end use		
Mark for rate of increase	**Legend**	**Main driver for modification**
_ _ _	Exponential increase of energy efficiency improvement (multiplying factor more than X2 over 40-year) and leading to an inverse effect in terms of consumed electrical energy. The" energy efficiency" component wins over the "expanded individual end use" component	Technology breakthrough (implying a change in the technology mix)
_ _	Significant increase of energy efficiency improvement (double digit – 40% to 80% over 40-year) and leading consequently to a significant decrease in the electrical energy consumed for that end use. The" energy efficiency" component wins over the "expanded individual end use" component	Technology improvement (implying possibly a change in the technology mix)
_	**Slight increase of energy efficiency (in line with the "natural" increase of energy efficiency for a given technology) and leading to a slight decrease in the consumed electrical energy consumed for that end use.** **The "energy efficiency" component wins over the "expanded end use" component**	**"Natural learning curve of technology"**
+	The "expanded individual end use" component wins over the "energy efficiency" component. It leads to a significant increase in the electricity consumed (in energy)	Expanded individual end use

3.5.3 The "load controllability potential"

It is estimated according to the nature of the end-use (and of the new controlling features offered by new technologies and more specifically by the expected convergence of the ICT and the power system worlds).

It is observed that the “load controllability potential” is impacted by the drivers identified above as “ICT and power” and “technology efficiency”.

The resulting metric is a three-grade scale with a mark that can be either “no”, “marginal” or “high”. When possible a typical fraction of load controllability is proposed (see next page).

Table 3.5. Load controllability potential for a given end use.

"Load controllabiity potential": estimation at 2050 for a given end use		
Mark	**Legend**	**Main drivers**
High	There is a high potential for implementing a load shifting/curtailing the load by a remote operator. The corresponding value created by the demand response programme could be shared by the end user and the grid operator or totally kept by the grid operator.	ICT and power ; "technology efficiency"
Marginal	The considered end-use allow some flexibility to delay/advance/curtail the load without any major impact to the end-user.	ICT and power ; "technology efficiency"
No	For the considered end-use there is no potential for controlling the load	N/A

3.5.4 Linking the drivers impacting the electric demand at 2050 and the three indicators allowing to assess the criticality of a segment

In Section 3.1, a framework in the form of four main drivers impacting the changes of the electric demand in comparison to the current one has been introduced. In Sections 3.2 to 3.5, the criticality of an end-use has been assessed thanks to three indicators: the "volume effect", the "energy efficiency improvement effect", the "load controllability potential".

The approach initiated in Section 3.1 would have been relevant for forecasting the electric demand at a remote time horizon. This was not done since not being our main objective.

The methodology developed and detailed in section 3.2 to 3.5 has allowed to "identify critical end-use segments for which the evolutions over a 40-year time period will structurally modify the load curve at the European level" as stated in the challenge formulated in section 3.2. This paves the way for section 3.6 dealing with the selection of technologies in critical end-use segments (step 2).

It should be pointed out that both approaches (four drivers; three indicators) are consistent as shown in the figure hereafter. Each of the three indicators is impacted by two categories of drivers.

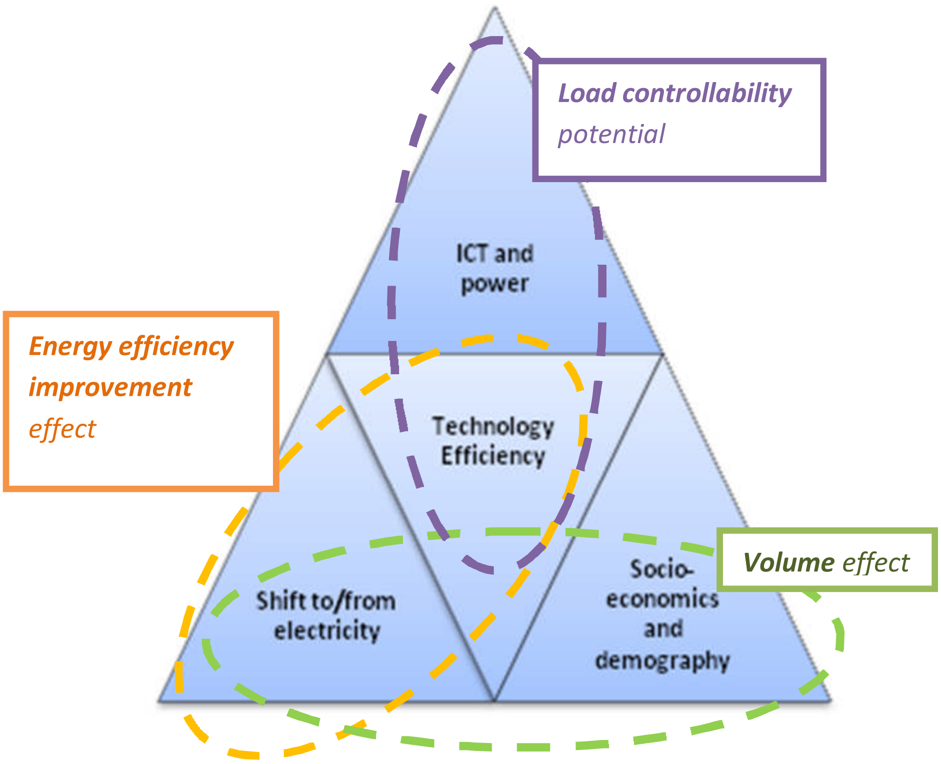


Figure 3.3. Linking the 3 indicators on criticality of an end-use and the 4 drivers impacting the demand.

3.6 From end-uses to technologies (step 2)

Once the most critical end-uses have been identified according to the criticality criteria, the second step aims at the selection of the technologies which are the driving factor of the criticality. Three types of technology modifications have been detailed in the right column of Table 3.4, namely “technology breakthrough”, “technology improvement” or “natural learning curve of technology”.

They are representative of the degree of technological change:

- the natural evolution of the technology: the technology is unchanged and evolves according to the conventional principle of learning curve (upon which it is expected that technology costs are decreasing according to a power law function of the accumulated produced units),
- the technology improvement: the technology change results from an effort of R&D which increases the performance/cost ratio;
- the technology breakthrough where a new technology offer drastically modifies the market equilibrium. As a result, there is a step change in terms of performance/cost ratio.

A critical end-use segment identified in step 1 might include a set of technologies/appliances/device which was considered so far as a number of average units (the so-called “average technology mix”). To go further, it is requested to distinguish among this mix, what will be the most critical technologies in terms of load modification for the considered end-use.

It is clear that natural evolutions of already mature technologies will not change the structure of the load. The only cases which will require further investigations are:

- the change of the technology process (either due to a technology substitution or to the electrification i.e. substitution of the primary vector of energy[10]): a typical example is heat pump systems substituted to fossil-fuel based space/water heating systems, and adding or merging new functionalities (heating/cooling);
- the emergence of a breakthrough technology: for instance the LED replacing incandescent lamps.

To proceed with step 2, it is thus proposed to retain only these two types of structural changes of the electricity load for the considered end-use segment.

[10] E.g. transfer from gas to electricity

4 A selection of relevant technologies to be further characterized

4.1 First step: selection of end uses

As already mentioned, consumption is detailed by sector and by usage, the starting point being the Table 2.1 and data on the electricity consumption for each sector.

The main sources which have been used to provide an estimation of the electricity consumption of each segment and its trend are:

- JRC report
- The role of electricity, Eurelectric
- EUROSTAT database [11]

Additional sources (see references) have been used to complement some gaps or to cross-check some data.

In particular, the Data Base on Energy Saving Potentials (http://www.eepotential.eu/esd.php) was used to cross-check some results. However the scope of such tool was focused on the estimation of energy savings per end-use segments[12] rather than on the estimation of electric consumption. Exploiting such facility allows to cross-check the indications on the electricity consumption trends per sector at the 2030 time horizon provided by the primary sources.

The assessments per end-use have been based on such trends, having in mind that extrapolation at the 2050 time horizon remains difficult. However, such inputs are often sufficient to estimate the criticality of a given end-use segment.

Table 4.1: Total electricity consumption in industry in EU27

	Year Unit	2009	2010	2011
TOTAL Electricity	**TWh**	**2698**	**2822**	**2768**
Households electricity consumption	TWh	818	841	803
Service and public administration electricity consumption	TWh	793	829	805
Agriculture electricity consumption	TWh	50	48	48
TRANSPORT electricity	TWh	66	68	68
INDUSTRY electricity (excluding energy sector)	TWh	964	1027	1032

It is observed that the peak corresponding to the year 2010 is mainly due to the thermo-sensibility effect of equipment in the residential and commercial sectors and resulting of severe climatic conditions.
These elements provide an order of magnitude of electricity use per sector.

[11] http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database

[12] and per scenarios representing up to four scenarios with respect to the diffusion of technologies at 2012 and 2030 (two extreme and two intermediate). The two extreme scenarios are the so-called "autonomous" scenario and the "technical" scenario.
The autonomous scenario considers that technology diffusion is only driven in an autonomous way. It corresponds to what we have called "natural" evolution of the technology in previous section.
The technical scenario considers a full technology diffusion of best available technologies to the maximum possible (i.e. to their technical limits).

4.1.1 Residential

The seven classes of end uses D1 to D7 described in Table 2.1 are analyzed with regard to their volume and energy efficiency effect as well as their load controllability potential. Then the resulting criticalities in terms of energy / load profile are considered for the final selection of end-uses.

The candidate end-uses are:

- D1: White goods
- D2: Cooking appliances
- D3: Lighting
- D4: Water heating
- D5: Electronic appliances (category renamed)
- D6+D7: space heating and cooling.

Table 4.5 displays the selected end-uses for the residential sector. Explanations can be found in the attached Excel file.

Table 4.2: Step 1 selection of critical end uses for the residential sector

Step 1: Selection of end uses (RESIDENTIAL)		
End use	Rationale for selecting/discarding the end use	End use selected (step 1): Y/N
D1 – White goods	Limited impact on demand	N
D2 – Cooking appliances	Marginal impact	N
D3 - Lighting	Breakthrough technology	Y
D4 – Water heating	New shape for load profile	Y
D5 – Electronic appliances	Impact on peak load and global volume (high increase of equipment rate)	Y
D6+D7 space heating and cooling	New shape for load profile	Y

4.1.2 Commercial

The seven classes of end-uses D8 to D14 described in the Table 2.1 are analyzed with regard to their volume and energy efficiency effect as well as their load controllability potential. Then the resulting criticalities in terms of energy / load profile are considered for the final selection of end-uses.

The candidate end-uses are:

- D8: Office equipment
- D9: Cooling and ventilation in tertiary buildings
- D10: Commercial lighting
- D11: Outdoor lighting
- D12: Commercial refrigeration
- D13: Heating in tertiary buildings
- D14: Data management.

Table 4.6 (next page) displays the selected end-uses for the commercial sector. Explanations can be found in the attached Excel file.

Table 4.3: Step 1 selection of critical end uses for the commercial sector.

Step 1: Selection of end uses (COMMERCIAL)		
End use	**Rationale for selecting/discarding the end use**	**End use selected (step 1): Y/N**
D8- Office equipment	Significant impact on energy while limited in power (base)	Y
D9- Cooling and ventilation in tertiary buildings	Significant impact on energy Modification of the load profile expected (day/night effect ; seasonal effect ; controllability)	Y
D10- Commercial lighting	Significant impact on energy. Breakthrough technology expected (LED). Modification of the load profile expected (controllability)	Y
D11- Outdoor lighting	Limited impact on energy. Breakthrough technology expected (LED). Modification of the load profile expected (controllability)	Y
D12 – Commercial refrigeration	Impact on energy and on power will remain limited (base13)	N
D13 - Heating in tertiary buildings	Significant impact on energy and new shape for load profile	Y
D14 - Data management	Impact on energy is limited. No controllability (base load).	N

The Eurostat figure for EU27 in 2011 for electricity consumption in the commercial sector is 805 TWh. See the attached Excel file for the analysis carried out per commercial segment.

4.1.3 Transport

The four classes of end uses D23 to D26 described in Table 2.1 are analyzed with regard to their volume and energy efficiency effect as well as their load controllability potential. Then the resulting criticalities in terms of energy / load profile is considered for the final selection of end uses.

The candidate end-uses are:

- D23: Electromobility (vehicles)[14]
- D24: Freight
- D25: Buses
- D26: Electrified railways.

Table 4.4: Step 1 selection of critical end uses for the transport sector.

Step 1: Selection of end uses (TRANSPORT)		
End use	**Rationale for selecting/discarding the end use**	**End use selected (step 1): Y/N**
D23 - Electromobility (vehicles)	Significant impact in terms of energy and even more in power: the constraints on the grid will be very high	Y

[13] Due to safety and health concerns related to food, a large use of flexibility in freezing is rather unlikely.
[14] End-use renamed.

	especially in case of fast charge and non-controllable charge. (controllability) Uncertainty on the speed of deployment.	
D24 – Freight	Impact will remain limited: some transfer from road to rail might remain limited (despite development of intermodal transport)	N
D25 - Buses	Impact will remain limited despite the progressive electrification and the advent of new technologies such as inductive charging system	N
D26 – Electrified railways	Impact will remain limited despite the number of km*passengers which is expect to grow. In addition load controllability potential is very low. Most fast train technologies are already well optimized, thus the energy efficiency improvement effect is expected to be low.	N

The Eurostat figure for EU27 in 2011 for electricity consumption in the Transport sector is 68 TWh (railways, tramways).
See the attached Excel file for the analysis carried out for each transport segment.

4.1.4 Industry

The eight classes of end-uses D15 to D22 described in Table 2.1 include a variety of different technologies and processes for which a detailed analysis is beyond the scope of the current work. When considering the whole industrial sector, the following observations could be made with regard to the criticalities related to energy and load profile:

- Volume effect: two opposite factors are competing, viz.
    - a negative one: a transfer from industry to services is a trend which might be continued in the next decades resulting in a decrease of the industrial sector in Europe,
    - a positive one: the assumption of a steady growth in Europe will mechanically lead to a growth of the industry in volume.
- Energy efficiency effect: energy savings in industry have been thoroughly addressed during the last decade especially in sectors like chemical or steel production and possible opportunities for further progress might be limited. However some opportunities remain to be investigated (electric arc furnace for steel production) or process improvement for instance.
- Controllability effect: a level of 10% to 30% of load in industry could be shifted depending on the different industrial segments (see the 9 GW of flexibility potential in industry and commerce estimated in Germany: see attached Excel file, spreadsheet “Industry”).

All in all, the volume, energy efficiency improvement effects[15] as well the load controllability potential[16] have been estimated though literature review and based on Ms1.1 findings. A parallel

[15] The potential in terms of energy efficiency are thoroughly explored and captured in industry, much more than in the residential area.

[16] Flexibility in industry might have several dimensions and depends on the type of industry and of the process considered (continuous/batch). For a given industry the flexibility potential decreases according to the duration of its interruption. It should also be noted that the flexibility which could be created by expanding the capacity of some processes and using them in a variable mode rather than on constant option has not been considered in this analysis.

task in WP3 has been launched to fine tune the data collection in industrial segments (expected results early 2014).

- The criticality on energy is considered significant since the overall electricity demand in industry is expected to grow. The EURELECTRIC report *Role of electricity, projections at 2030,* based on a bottom up approach foresees 1705 TWh/a for industry (1071 TWh/a in 2006 according to the EC -2006)[17].
- The criticality on the load profile depends on the flexibility potential and has to be analyzed on a particular industry segment.

All industry segments have thus been retained from step 1 filtering (except textile sector). See the attached Excel file for the performed analysis per industry segment.

4.2 Second step: from end-uses to technologies

4.2.1 Residential

From the four selected end-uses in the residential sector, a set of three technologies is selected for further analysis as described in the table hereafter.

Table 4.5: Step 2 selection of technologies from the critical end uses for the residential sector.

Step 2: From end uses to technologies (RESIDENTIAL)		
Selected end use	**Rationale for selecting/discarding technologies**	**Technologies selected**
D3 - Lighting	LED as breakthrough technologies (CFL transitory product towards LED)	LED
D4 – Water heating	Deployment of water heating heat pumps to be considered	Heat Pumps
D5 – Electronic appliances	The diversity of technologies and options at that time horizon leads to challenges beyond the scope of the e-Highway2050 project	None
D6+D7 space heating and cooling	Massive deployment of heat pump technology for residential sector in Europe due to an increased energy efficiency combined to a transfer from gas to electricity will significantly modify the load profile	Heat Pumps

4.2.2 Commercial

From the four selected end-uses in the commercial sector, the two technologies selected for further analysis are LED and Heat Pumps.

Table 4.6: Step 2 selection of technologies from the critical end uses for the commercial sector

Step 2: From end uses to technologies (COMMERCIAL)		
Selected end use	**Rationale for selecting/discarding technologies**	**Technologies selected**
D10- Commercial lighting	LED as breakthrough technologies (CFL transitory product towards LED)	LED
D11- Outdoor lighting		

[17] The Eurostat figure for electricity consumption in industry in EU27 (2011) is 1032 TWh (industry excluding energy sector).

<table>
<tr><td>D9- Cooling and ventilation in tertiary buildings</td><td rowspan="2">Massive deployment of heat pump technology for commercial sector in Europe due to an increased energy efficiency combined to a transfer from gas to electricity will significantly modify the load profile</td><td rowspan="2">Heat Pumps</td></tr>
<tr><td>D13 - Heating in tertiary buildings</td></tr>
</table>

4.2.3 Transport

Only the electro-mobility segment was considered fitting the criticality criterion: two technologies are selected (battery electrical vehicles and plug-in hybrid vehicles).

Table 4.7: Step 2 selection of technologies from the critical end uses for the transport sector.

Step 2: From end uses to technologies (TRANSPORT)		
Selected end use	**Rationale for selecting/discarding technologies**	**Technologies selected**
D23 – Electro-mobility (vehicles)	Both Electrical and plug-in vehicles have to be considered.	Battery electric vehicles and plug-in vehicles

4.2.4 Industry

Due to the multiplicity of processes for each industrial segment, the selection of critical technologies impacting the load profile at 2050 is beyond the scope of the current work.

5 The technology characterization database

5.1 Purpose

WP3 technology database aims at two complementary and overlapping objectives:

- Providing other Work Packages of the project with valuable information on cost and performances of power system technologies, e.g. with estimation for the next decades, of a level of uncertainty and the underlying assumptions;
- Providing stakeholders beyond the project with structured information on cost and performances of technologies after the end of the project.

5.2 Architecture

The database is organized per technology and sub-technology when relevant. For each technology, a set of variables is documented on the costs, performances and other characteristics. The variables are organized according to a set of data types.

- **Technology performance characteristics**
  - The variables included in this data type mainly focus on power and efficiency levels
- **Technology readiness and maturity**
  - The variables included here focus on the innovations sources of major cost/performance improvement in the future, and the evaluation of their respective maturity.
- **Possible implementation constraints**
  - This data type includes variables typical of the possible barriers to the deployment of a technology.
- **Costs**
- **Environmental impact and public acceptance**
- **Market and supply chain issues**
  - This data type includes estimates on market penetrations.
- **Dynamic performance of technology**
  - This data type includes variables on load profile and flexibility.

The data organization within a given data type is detailed when required in the annex datasheet and reports dedicated to each technology.

- M31a_report_electricvehicles_Technofi_20131206
- M31a_data_electricvehicles_Technofi_20131206
- M31a_report_Heat Pumps_Technofi_20131206
- M31a_data_HeatPumps_Technofi_20131206
- M31a_report_ LED and lighting _20131206
- M31a_data_LED and lighting_Technofi_20131206

5.3 Data collection and validation process

5.3.1 Data collection

Data has been collected from available literature and expert interviews, with a selection criteria based on the authority of the source. All data sources are listed in the annex reports.

5.3.2 Data validation

The data validation is performed in three steps:

- **Step (i): analysis of data discrepancies**

Large discrepancies exist between different sources on a same variable: they are mainly related to different assumptions on technology penetrations on the long term (specific deployment scenarios). These discrepancies are analyzed in the annex reports, and the assumptions used when required for calculation are detailed as well.

As much as possible, ranges of values are kept for each variable: the extent of ranges reflects both the variety of perspectives from the different sources, and the margin of uncertainty assessed by each source on a given variable.

- **Step (ii): adjustment of value ranges**

Based on the analysis of data discrepancies regarding performances, and when required, costs and market penetrations, recommendations are made to adjust the value ranges.

- **Step (iii): review of adjusted value ranges**

The adjusted value ranges recommended in step (ii) are reviewed in collaboration with EURELECTRIC, RTE demand experts as well as the representatives of WP3 quality pool. This final validation step will be performed in summer 2013.

6 Management of uncertainties

As already mentioned, providing technology data over a nearly 40-year time period can be subject to major uncertainties. Extreme values (both quantitative: min/max and qualitative: high/low) for each of the variables (costs, efficiencies and other performances) and the associated ranges are given to forecast such possible evolutions of costs/performances over time.

In a parallel task of the e-Highway2050 project (WP1), a scenario building approach has been defined to characterize five scenarios covering the 2020-2050 time period and taking into account technological, financial/economic, environmental and socio-political issues.

A key question for the downstream simulations to be performed in WP2 is the following:

How to adjust the typical ranges of technology data according to the five selected scenarios?

Consequently, an approach is proposed for the needs of WP2. This approach is called **data contextualization** and aims to allocate, for a given technology, typical values to key variables descriptive of this technology, at the 2050 time horizon, and this for each of the five considered WP1 scenarios.

To that purpose, first methodological elements have been developed on the generation side. EURELECTRIC has indeed proposed an approach to allocate, for a given technology, typical cost and performance values to each of the five considered WP1 scenarios. This approach has been applied on WP1 data on boundary conditions for generation and storage technologies. This methodology can easily be extended to data contextualization for transmission and demand technologies.

For example, for demand, for each of the critical identified technologies, it appears that the main driver for contextualization is the penetration rate of the technology (cumulated number of units at a given time). It is indeed assumed that the cost and performance trends of the technologies by 2050 are directly correlated to its level of deployment.

In the following the methodology applied to EVs (electric vehicles) is presented (see more details in the specific annex on electric vehicles). Figure 6.4 (next page) summarizes the successive steps to build such adjusted values:

1. A given scenario is a combination of :
    a. a “future” characterized by a set of quantified “uncertainties” and
    b. a “strategy” characterized by a set of quantified “options”.

    The future deployment of EVs by 2050, i.e. its penetration level, is impacted by some of these uncertainties and options. A selection of uncertainties and options is therefore made according to their potential impact on future EV deployment: uncertainties and options are assessed in terms of their potential support or barrier to EV deployment. Only uncertainties and options with a significant impact (i.e. incentive/barrier to penetration) are retained.
2. Depending on the considered future and strategy, each uncertainty or option has a specific value. The potential impact related to this value on EVs deployment is assessed for the selected uncertainties and options. This assessment is qualitative.
3. By aggregating these individual assessments of each selected uncertainty and option, an overall qualitative assessment is made, which reflects the impact of the given scenario on the deployment level of EVs, on a three degree scale (Low, Medium, High).
4. In parallel, a subset of key technology variables describing EVs is selected. The selection focuses on penetration level (number of units by 2050), performances (efficiency) and costs (battery and vehicle).

5. From the value ranges attached to the selected EV key technology variables are extracted the minimum, average, and maximum values, which will then be allocated to the market penetration assessment scale (Low, Medium, High –see point 3).
6. By combining the scenario assessments made at step 3 and the EV value tables built at step 5, specific values are allocated to the subset of EV variables (key technology variables) according to each given scenario.

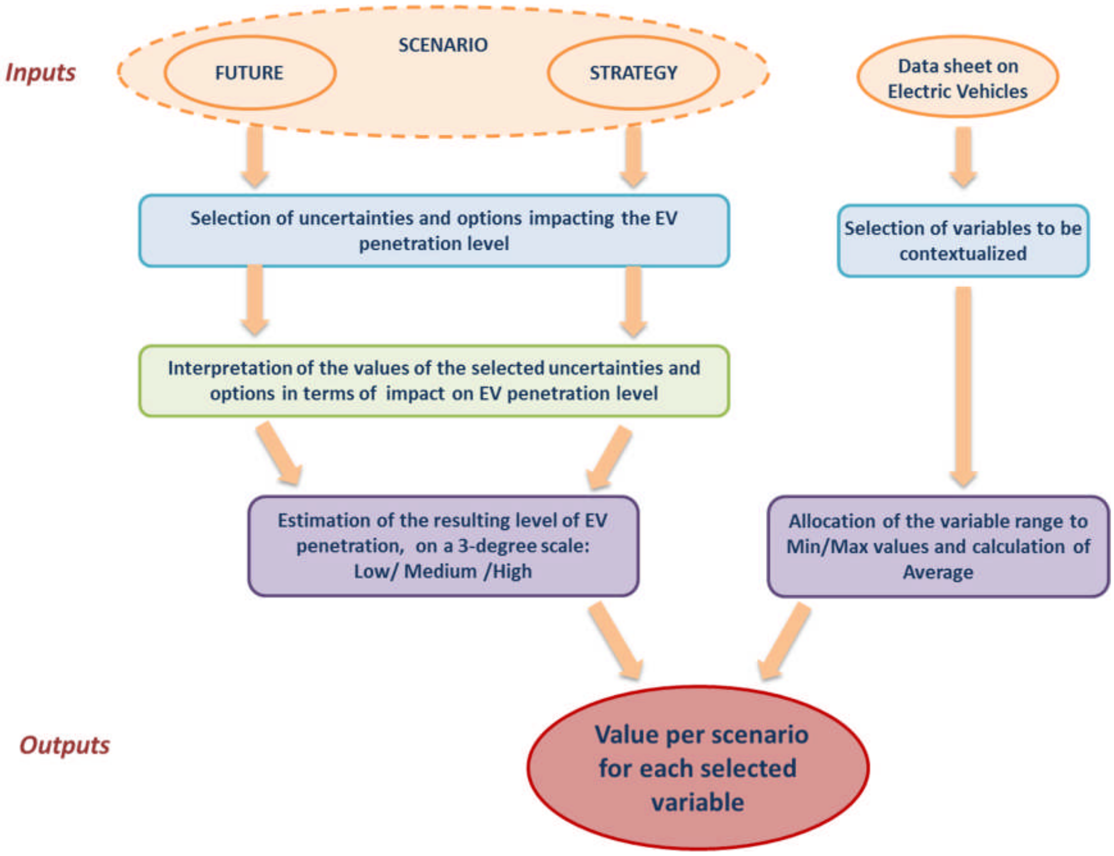


Figure 6.4: Contextualisation process (generic steps applied to electric vehicle for illustration purposes)

7 Sources

The selection of end-uses (step 1) and technologies (step 2) is based upon a database built from different sources. The database includes quantitative and qualitative elements collected and validated according to complementary modes: expert interviews, literature study, dedicated modeling.

Generic sources have been included here. The specific references for the selected technologies (after step 1 and 2) are mentioned in the attached annexes.

Table 7.1. Main generic literature sources for demand-side technologies.

Name	Brief description
EURELECTRIC's Role of Electricity, "Residential and tertiary electricity demand"	This report covers an analysis of electricity consumption in the residential and tertiary sectors, looking at the role of key end-uses and technologies, excluding lighting. The report synthesizes previous studies and includes the electricity consumption per main use for 2005 as well as an estimation of their evolution over the period 2005 to 2030. For some end uses, estimations until 2050 are proposed.
Energy efficiency status report 2012, Joint Research Centre Scientific and policy report, Electricity consumption and Efficiency trends in the EU27	This report gives per end-use (residential and tertiary sectors) the electricity consumption for 2009 for EU-27. It gives some data on the market (number of appliances, market share per energy efficiency label, average unit consumption, best technology consumption, etc.).
Energy Efficiency potential EU database	Database gathering the results of a study on energy efficiency potential for Europe up to 2030 (all sectors). It includes in particular data on energy savings potential. See database http://www.eepotential.eu/esd.php and the related report: http://ec.europa.eu/energy/efficiency/studies/doc/2009_03_15_esd_efficiency_potentials_short_report.pdf
REMODECE project	Intelligent Energy Europe project, Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe. See in particular the following paper : A. Almeida, P. Fonseca, "Residential monitoring to Decrease Energy use and Carbon Emissions in Europe", European Council for an Energy Efficient Economy, ECEEE 2007 Summer Study, La Colle sur Loup, Côte d´Azur, France, 4-9 June 2007 http://remodece.isr.uc.pt/
Energy Efficiency Trends in the Industrial Sector in the EU, Lessons learned from the ODYSSEE MURE project	This report gives the electricity consumption per branch of the industry for 2009
ADDRESS FP7 Project	ADDRESS event: active demand, a reality in electric systems, 23 May 2013 Rome. Slides:http://www.addressfp7.org/index.html?topic=ws2013/workshop2013_agenda
EU energy trends to 2030	EC publication (DG ENER, 2010), the "Energy Trends 2030" presents scenarios in particular on energy efficiency up to 2030. Update of the previous trend scenarios, such as the - European energy and transport - Trends to 2030 published in 2003 and its 2005 and 2007 updates

Transport and TEN-T publications	http://ec.europa.eu/transport/themes/infrastructure/studies/doc/2010_high_speed_rail_en.pdf http://www.vialibre-ffe.com/PDF/errac%20metro%20y%20fcligero%2004.pdf http://www.internationaltransportforum.org/Pub/pdf/10FP04.pdf

8 Methodological annex

Estimation of the electricity demand at a mid-term time horizon: complementarity of the approaches followed in WP3 and WP2

The purpose of this annex is to present the complementarities and the links between the two approaches followed in WP3 and WP2 with respect to the estimation of demand at a mid-term[18] *time horizon*[19] *:*
After a description of the rationale of each methodology used in WP3 and WP2 to characterize electricity demand in Europe until 2050, the complementarity and differences of the two approaches are discussed.

In the following:

- **bottom-up** should be understood as the compilation of unitary load curves (per end-use segment) into an aggregated electric demand curve for a given geographical area and a given time horizon (e.g. EU27, 2050).
- **top-down** refers to any modification of the global load curve that applies to all countries according to the same macro-economic and political assumptions for the future. Technological features (and thus their impact on the resulting end-use) are not captured by such approach.

8.1 The WP2 and WP3 approaches regarding demand related technologies

8.1.1 Methodology developed and implemented by Technofi in WP3 to address the impact of demand related technologies on electricity demand in Europe at 2050

WP3's methodological scope is to select impacting demand related technologies in order to assess their costs and technical performances trajectories at the 2050 time horizon[20]. It follows a bottom-up approach based on a systematic analysis of the criticality of end-use segments in each sector (residential, commercial, industry, transport), while WP2 quantification of scenarios mainly follows a top-down approach[21].

Such bottom-up selection methodology has been validated and discussed with experts (TSOs) and WP3 quality pool.

The main purpose of the WP3 methodology being the identification of key technologies that are likely to significantly modify the electricity end-use (in energy and in power) at 2050, this

[18] Mid-term time horizon refer to 2050.
[19] Source: webconference of September 25th, 2013 and bilateral discussions
[20] The costs and performances trajectories refer to data for specific "unit" technologies (e.g. electric vehicles)
[21] Except for the quantification of the impact of new uses (step 2 of the methodology).

methodology does not aim at estimating electricity consumption volumes at 2050. It is also not designed to provide an 'algorithm' which gives figures for demand at the top-down aggregated levels of WP2 (macro-area, country, cluster).

The selection of the technologies that are the most impacting ones for the electricity demand at 2050 is performed with a specific metric including three indicators that are the ”volume effect”, the ”energy efficiency improvement effect” and the ”load controllability potential”.

These three indicators are closely related to four drivers which are expected to impact the electricity demand in 2050: Socio economics and demography; Shift to / from electricity; Technology efficiency ;ICT and Power (see glossary in the main document).

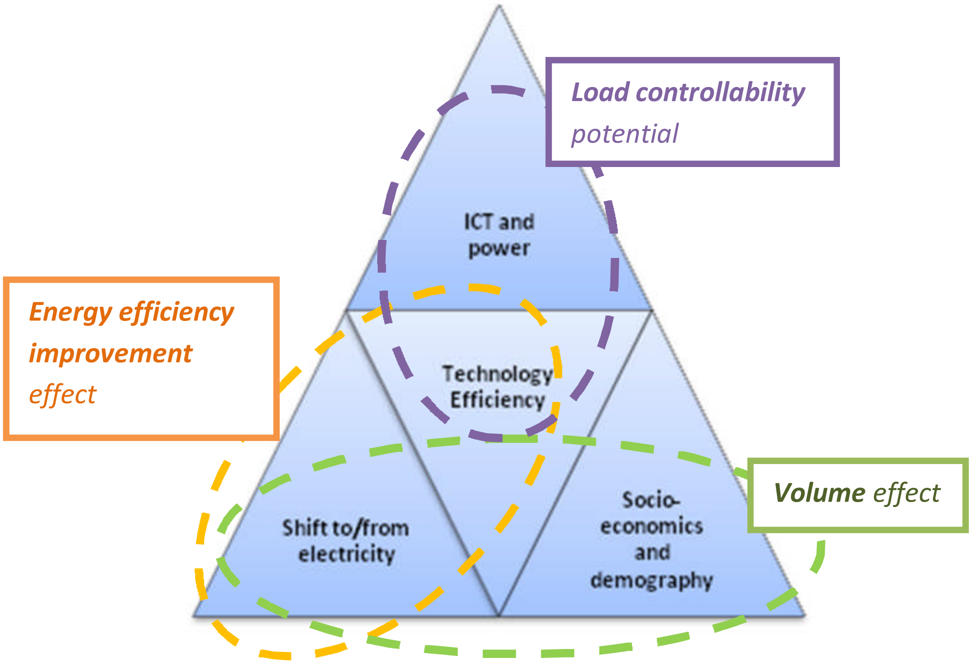


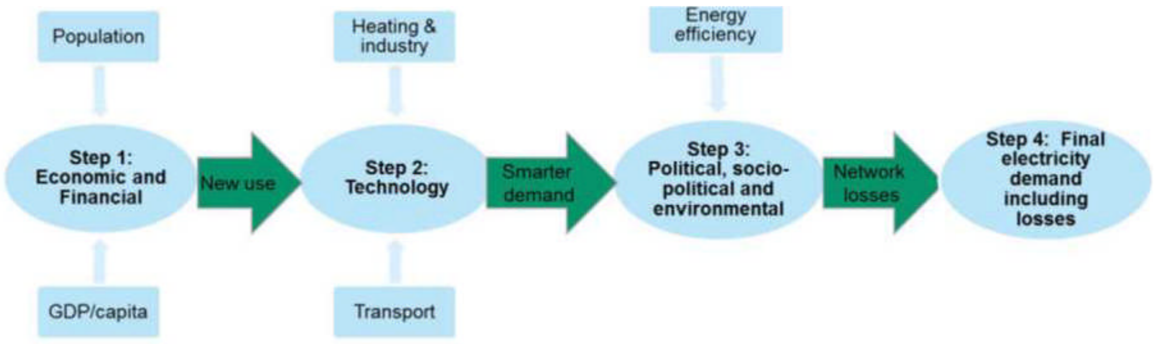
Figure 8.5: Framework of the drivers impacting the electric demand and relation to the three indicators

As a result, the methodology has allowed to select three impacting technologies : electric vehicles, heat pumps and LED technologies (lighting). Data have been provided for each technology ; the aggregation of these unit data at a given spatial scale (geographical area) is out of scope of WP3. For example, data provided by WP3 for electric vehicles include technical characteristics and costs of one typical BEV (and PHEV) combined to tentative projections of market penetration at 2020/30/40/50. Such “envelopes” of likely evolutions result from available studies considered and mapped into the e-Highway2050 scenarios.

8.1.2 Methodology developed and implemented by POYRY to appraise electricity demand per country at 2050

A top-down methodology is used and deployed by POYRY for WP2 in order to quantify the level of electricity consumption at 2050 per scenario and per country.

The figure below summarises the three-step process used in WP2 to produce the country-level projections for final annual electricity demand including network losses in 2050 (indicated as step 4 in the figure).



Source: Pöyry Management Consulting

Figure 8.6: Three-step process to produce the electricity demand per country (source WP2)

The first three steps reflect the scenario criteria used in e-Highway2050 D1.2 to group options [22], uncertainties[23] and assumptions (fixed across all scenarios):

- Economic and financial;
- Technology; and
- Political, socio-political and environmental.

For each of these three steps, demand data are quantified depending on the considered scenario using:

- The verbal description of each scenario and the corresponding values of uncertainties and options
- The ten parameters used in the scenario filtering process (developed in WP1.2).

Table 8.1 : Overview of the quantification steps for each of the five e-Highway2050 scenarios

	Scenario number	x-5	x-7	x-10	x-13	x-16
	Scenario name	Large scale RES & no	100% RES"	Big & Market	Big Nuc and CCS	Small and Local"
Calculation step and Criteria	**Demand parameter**					
Step 1: Economic and Financial	**Population (demographic changes)**	Growth	Growth	Growth	Growth	Migration only
	GDP increase	Medium	Medium	Medium	Medium	Low
Step 2: Technology	**New use**	High	High	High	High	Low
Step 3: Political, socio-political and environmental	**Energy efficiency**	Low	High	Medium	Low	High

Source: Extract from Table 8.5 in eHighway2050 Deliverable D1.2 [2]

The final step in the process set out in Figure 1 adds network losses to final electricity demand. As these losses primarily consist of losses on the lower voltage distribution networks, they will not be

[22] Used to define strategies according to the project terminology
[23] Used to define futures according to the project terminology

captured by the topography analysis in WP2.3. Therefore, a fixed estimate for the loss rate has been used.

8.2 Complementarity and links between the two approaches

Data and assumptions provided by WP3 and their relation with the data / assumptions used by POYRY for the quantification of annual demand at EU and country level have been discussed during dedicated web conferences. The main characteristics of each of the two demand-related methodologies are described in the following table.

Table 8.2 : Key characteristics of WP3 and WP2 approaches on the estimation of the electricity demand at 2050

	Electricity demand in WP2	**Electricity demand in WP3**
General purpose of the methodology	Estimate final electricity demand24 per country at 2050 for each of the five considered e-Highway2050 scenarios.	Identify impacting technologies and provide cost and performances data trajectories until 2050 time horizon
Key assumptions	Three-step approach including: 1. "economic and financial" analysis 2. "technology" analysis 3. and "political, sociopolitical and environmental" analysis. Each step implements modifications to the electricity demand level per country and scenario. These modifications are the result of the following factors: - Step 1: GDP and population - Step 2: "New use" - Step 3: "energy efficiency".	Systematic analysis of end-use segments to identify in two stages the ones for which technologies could have a major impact in electricity consumption by 2050 (in energy and in power). Four driving forces have been identified which are assessed by three indicators. - Socio economics and demography - Shift to / from electricity - Technology efficiency - ICT and Power. The indicators used to identify the criticality of a segment are: - Volume effect - Energy Efficiency improvement effect - Load controllability potential.
Resulting implementation of methodology	Projections of final electricity demand per country and per scenario.	Three technologies selected (Electric vehicles, LED, Heat Pumps).

[24] Including network losses

	New uses considered for step 2: “electrification of heating” and” electrification of transport”.	Three dedicated technology assessment reports. Data are contextualized per scenario.
Quality assessment of the approach	WP2 internal validation	WP3 Quality Pool experts TSO experts on demand Industry experts.

More specifically, the WP2 three-step approach could be also formally linked to the four drivers as described in the table below.

Table 8.3 : Correspondence table of WP3 and WP2 approaches on electricity demand

Factors used in WP3 **Steps in WP2**	**Socio economics and demography**	**Shift to / from electricity**	**Technology efficiency**	**ICT and Power**
Step1 (WP2) "Economic and Financial"	X			
Step2 (WP2) "New uses & Technology"		X	X	X
Step3 (WP2) "EE Political, socio-political and environmental"	X	X	X	X

The two methodologies bring their own value to their specific purposes:

- WP2 methodology provides a systematic transformation of global electricity demand level for a given European country by a series of successive steps

- WP3 adopts a end-use based methodology shedding light on the most impacting technologies on the global electricity demand by capturing specific end-use and technology related features

- Both methodologies are closely interconnected. WP3 provides to WP2 (step 2) data on market penetration and performances of impacting technologies (EVs, lighting and Heat Pumps). For more details see separate documents
    - report_electric vehicles_Technofi
    - data_electric vehicles_Technofi
    - report_heat pumps_Technofi
    - data_heat pumps_Technofi

- report_ LED and lighting_Technofi
- data_LED and lighting_Technofi

8.3 Differences observed between the two approaches and interpretation

8.3.1 Penetration levels for "new uses" technologies

Electricity demand at 2050 for two of the technologies identified as critical at the 2050 time horizon e.g. Electric Vehicles and Heat Pumps was estimated according to the two approaches developed by WP2 and WP3.

It is observed that some differences appeared in the levels of estimated electricity demand in 2050 for "new uses" such as electrical vehicles and heat pumps. A further analysis identified that the estimation of the key contributing factors (penetration levels and performances of the technology) is based on different interpretations of the five scenarios selected in the e-Highway2050 project.

In particular, the differences in penetration levels between WP2 and WP3 are due to the fact that:

- WP2 uses two different, yet dependent, datasets:
  - the descriptions of uncertainties and options with their corresponding metrics,
  - the 10 parameters [25] chosen to better appraise and quantify the different scenarios.
- WP3 uses only the first dataset.

As explained in the report *The selection of energy scenarios for e-Highway2050 project*, the ten parameters are a re-analysis of the raw data (the set of corresponding uncertainties and options). This reanalysis was performed in order to better sort the scenarios and select the most extreme ones. However, the level allocated to the parameter "new uses" is not always consistent with the verbal description or with the uncertainty (the raw data, in our case u8), which can lead to an over-or under-estimation of the penetration level.

The above diagnosis of the methodological bias is illustrated in terms of impact on the electricity demand at 2050 for the two considered "new uses" technologies.

8.3.2 Impact on electricity demand estimation at 2050 for Electric Vehicles

The differences between the results obtained by WP2 and by WP3 are mostly related to the discrepancies in the penetration levels.

The figures for consumption and number of km travelled per year estimated by WP2 and WP3 are more or less consistent across the scenarios (when the energy efficiency (EE) factor[26] is taken into

[25] See report *The selection of energy scenarios for e-Highway2050 project*,

[26] Energy Efficiency factor applied in Step 3 of WP2 methodology

account in Step 2). However the same conversion efficiency is used for both PHEVs and BEVs[27], even though hybrids use their electrical drive only part of the time, unlike BEVs.

These discrepancies and their impact are presented in the table below.

[27] PHEV=Plug-In Hybrid Electric Vehicles ; BEV = Battery Electric Vehicles

2050		Scenario X5 Large scale RES & no emissions	Scenario X7 100% RES	Scenario X10 Big & Market	Scenario X13 Large fossil fuel with CCS & Nuc	Scenario X16 Small and local
Total number of vehicles (all type of energy) considered in WP3	**million**	**350**	**350**	**350**	**350**	**300**
WP2 data	*million*	*313*	*313*	*313*	*313*	*287*
BEV - level of penetration – WP3		**Medium to high**	**High**	**Low**	**Low**	**High**
BEV - level of penetration – WP2		***Medium***	***Medium***	***Low***	***Low***	***Low***
Number of BEVs WP3	**million**	**130**	**157**	**52**	**52**	**157**
Share of fleet WP3	**%**	**37%**	**45%**	**15%**	**15%**	**52%**
WP2 data	*%*	***20%***	***20%***	***15%***	***15%***	***10%***
Battery cost	€/kWh	165	140	250	250	140
Retail price of BEV	€	16 300	15 000	20 250	20 250	15 000
Driving range of BEV	km	550	650	250	250	650
Consumption WP3	**kWh/km**	**0.12**	**0.1**	**0.2**	**0.2**	**0.1**
(WP2 without EE[28])	*kWh/km*	*(0.2)*	*(0.2)*	*(0.2)*	*(0.2)*	*(0.2)*
WP2 with EE	*kWh/km*	*0.13*	*0.11*	*0.12*	*0.13*	*0.11*
Nb of km driven by a BEV WP3	km	10 000	10 000	10 000	10 000	9 000
WP2	*km*	*12 880*	*12 880*	*12 880*	*12 880*	*12 880*
Total Nb of km driven by BEVs in WP3	million km	1 300 000	1 570 000	520 000	520 000	1 413 000
Corresponding energy demand – WP3	GWh	156 000	157 000	104 000	104 000	141 300
(WP2 without EE)	*GWh*	*(161 258)*	*(161 258)*	*(120 943)*	*(120 943)*	*(73 931)*
WP2 with EE		*107 877*	*88 099*	*73 125*	*80 908*	*40 390*
PHEVs - level of penetration – WP3		**Medium to high**	**Medium**	**Low**	**Low**	**Low**
BEV - level of penetration – WP2		***Very high***	***Very high***	***High***	***High***	***Medium to high***
Number of PHEVs WP3	**million**	**120**	**92.5**	**65**	**65**	**65**
Share of fleet WP3	**%**	**34%**	**26%**	**19%**	**19%**	**22%**

[28] Energy Efficiency factor applied in Step 3 of WP2 methodology

WP2 data	%	*70%*	*70%*	*55%*	*55%*	*40%*
Retail price of PHEV	€	29 000	29 500	29 750	29 750	29 750
Driving range of PHEV	km	1200	1200	1200	1200	1 200
Consumption (electric drive) WP3	**kWh/km**	**0.2**	**0.2**	**0.25**	**0.25**	**0.2**
Share of use of electric drive	**%**	**50%**	**50%**	**50%**	**50%**	**50%**
Equivalent consumption WP3	**kWh/km**	**0.1**	**0.1**	**0.125**	**0.125**	**0.1**
(WP2 without EE)	*kWh/km*	*(0.2)*	*(0.2)*	*(0.2)*	*(0.2)*	*(0.2)*
WP2 with EE	*kWh/km*	*0.13*	*0.11*	*0.12*	*0.13*	*0.11*
Nb of km driven by a PHEV WP3	km	12 000	12 000	12 000	12 000	10 000
WP2	*km*	*12 880*	*12 880*	*12 880*	*12 880*	*12 880*
Total Nb of km driven by PHEVs in WP3	million km	1 440 000	1 110 000	780 000	780 000	650 000
Corresponding energy demand – WP3	GWh	144 000	111 000	97 500	97 500	65 000
(WP2 without EE)	*GWh*	*(564 402)*	*(564 402)*	*(443 458)*	*(443 458)*	*(295 725)*
WP2 with EE	*GWh*	*377 569*	*308 345*	*268 125*	*296 661*	*161 561*
Total demand WP3	**TWh**	**300**	**268**	**202**	**202**	**206**
(Total demand WP2 - without EE)	*TWh*	*(749)*	*(749)*	*(564)*	*(564)*	*(370)*
Total demand WP2 - with EE	***TWh***	***501***	***409***	***341***	***377***	***202***
Total demand for EVs-Difference (%)between WP3 and WP2 with EE		-67%	-53%	-69%	-87%	2%

The biggest difference in the estimation of demand is found in scenario X13 and is mostly due to the choice of levels of penetration for PHEVs.

In general (i.e. across all scenarios), the penetration levels for PHEVs retained by WP2 are indeed far higher than those estimated by WP3. However WP3 estimates are based on available literature and reports (eight different sources in total) and are therefore backed up by experts (IEA, JRC, Boston Consulting Group, Eurelectric, etc.).

The scenario with the highest inconsistency as regards penetration level is Scenario X16: this is due to the fact that the parameter "new use" is set to "low" in this Scenario, which is not consistent with the value of the uncertainties u8 allocated to this scenario. This means that the level of penetration (at least for BEVs) is likely to have been underestimated in WP2. Although the penetration levels are very different in WP2 and 3 for X16, the globally estimated level of demand is unexpectedly the same: this is due to the fact that the demands for BEVs and PHEVs balance each other (demand from BEVs is higher in WP3 than in WP2, while demand from PHEVs is lower in WP3 than in WP2).

8.3.3 Impact on electricity demand estimation at 2050 for Heat Pumps

The differences between the results obtained by WP2 and by WP3 are mostly related to the discrepancies in the penetration levels, and – to a lower extent – to the Coefficients of Performance (which are slightly higher in WP3). These discrepancies and their impact are presented in the table below.

The biggest differences are found in Scenario X5 and X16, for which the penetration levels (in terms of %) greatly vary between WP2 and WP3. However WP3 estimate is based on available literature and reports and is therefore backed up by European experts.

Scenario X10, for which the penetration levels (in terms of %) are similar in WP2 and WP3, is the scenario with the best consistency between WP2 and 3 (only 4% difference)

2050		Scenario X5 Large scale RES & no emissions	Scenario X7 100% RES	Scenario X10 Big & Market	Scenario X13 Large fossil fuel with CCS & Nuc	Scenario X16 Small and local
HP - level of penetration WP3		**Medium**	**High**	**Low to medium**	**Low**	**High**
HP - level of penetration WP2		***High***	***High***	***High***	***High***	***Low***
Total units WP3		75	100	65	50	100
Residential - single house	billion units	69	90	60	46	90
Residential - apartment blocks	billion units	3.50	6.00	2.50	2.00	7.50
Tertiary		2.50	4.00	2.50	2.00	2.50
		75.00	100.00	65.00	50.00	100.00
Penetration rate						
Residential - single house WP3	%	69%	90%	60%	46%	90%
Residential - apartment blocks WP3	%	38%	65%	27%	22%	82%
Residential WP3 - (in terms of floor area)	**%**	**58%**	**81%**	**48%**	**37%**	**87%**
Residential WP2	*%*	***40%***	***40%***	***60%***	***60%***	***20%***
Tertiary WP3	%	**32%**	**51%**	**32%**	**26%**	**32%**
Tertiary WP2	*%*	***60%***	***60%***	***40%***	***40%***	***20%***
Characteristics						
Size-Residential WP3	kW (heat)	6	6	6	6	6
Size-Residential collective WP3	kW (heat)	26	26	26	26	26
Size-Tertiary WP3	kW (heat)	51	51	51	51	51
COP WP3		5	5.5	4.7	4.5	5.5
COP WP2 - without EE		*3*	*3*	*3*	*3*	*3*
COP WP2 - with EE		*4.5*	*5.5*	*5.0*	*4.5*	*5.5*
Full load heating hours per year[29]	h/year	1800	1800	1800	1800	1800

[29] after the Commission Decision 2013/114/EU

Corresponding electricity demand						
Residential – single house WP3	TWh	149.0	176.7	137.9	110.4	176.7
Residential – collective WP3	TWh	32.8	51.1	24.9	20.8	63.8
Tertiary WP3	TWh	45.9	66.8	48.8	40.8	41.7
Total demand WP3	**TWh**	**227.7**	**294.5**	**211.6**	**172.0**	**282.3**
WP2 without EE - including direct resistive heating		*1399.0*	*1399.0*	*833.0*	*833.0*	*373.0*
WP2 with EE factor - including direct resistive heating		*935.9*	*764.3*	*503.7*	*557.3*	*203.8*
WP2 without EE - HP only		*612.1*	*612.1*	*364.4*	*364.4*	*163.2*
WP2 with EE - HP only		***409.5***	***334.4***	***220.3***	***243.8***	***89.2***
Difference between WP2 with EE and WP3	%	-80%	-14%	-4%	-42%	68%

8.3.4 Synthesis and conclusion

Severity of impact of the identified bias

The global differences between WP2 and WP3 for the estimated demand related to new uses in 2050 are as follows. The color code indicates a degree of severity of impact of the identified methodological bias.

		Scenario X5	Scenario X7	Scenario X10	Scenario X13	Scenario X16
HP WP2						
WP2 without EE - including direct resistive heating	TWh	1399.0	1399.0	833.0	833.0	373.0
WP2 with EE factor - including direct resistive heating	TWh	935.9	764.3	503.7	557.3	203.8
WP2 without EE -HP only	TWh	612.1	612.1	364.4	364.4	163.2
WP2 - with EE - HP only	TWh	409.5	334.4	220.3	243.8	89.2
EV WP2						
WP2 - without EE	TWh	749.0	749.0	564.0	564.0	370.0
WP2 - with EE	TWh	501.1	409.2	341.0	377.3	202.1
Total WP2 with energy efficiency	TWh	**910.5**	**743.6**	**561.4**	**621.1**	**291.3**
HP WP3	TWh	227.7	294.5	211.6	172.0	282.3
EV WP3	TWh	300.0	268.0	201.5	201.5	206.3
Total WP3	TWh	**527.7**	**562.5**	**413.1**	**373.5**	**488.6**
Global difference between WP2 (with EE) and WP3	**%**	**42%**	**24%**	**26%**	**40%**	**-68%**

Diagnosis:

These differences result mostly from an internal inconsistency inherited from WP1 (i.e. value attributed to the parameter “new uses”). The ambiguity in the characterisation of this parameter indeed caused various discrepancies between WP2 and WP3 in the estimation of the penetration levels, which in turn led to differences in the estimation of corresponding electricity demand in 2050.