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H2020 REALVALUE

D3.1 ENERGY SYSTEM SCENARIOS IN REALVALUE

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List of Abbreviations

Abbreviation	Definition
CCS	Carbon capture and storage
CO_2	*Carbon dioxide*
DIW	*Deutsches Institut für Wirtschaftsforschung (German Institute for Economic Research)*
DHW	*Domestic hot water*
EU	*European Union*
ETS	*Emissions Trading System*
FP7	*7th Framework Programme of EU research funding*
GDP	*Gross Domestic Product*
GHG	*Greenhouse gas*
HVAC	*Heating, ventilation and air conditioning*
NTC	*Net transfer capacity*
PV	*Photovoltaics*
RES	*Renewable energy sources*
RTU	*Riga Technical University*
RWTH	*Rheinisch-Westfälische Technische Hochschule*
SETS	*Smart Electric Thermal Storage*
UCD	*University College Dublin*
UK	*United Kingdom*
UOXF	*University of Oxford*
TSO	*Transmission System Operator*
VTT	*Technical Research Centre of Finland*

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ABSTRACT

In this document, we present an overview of appropriate energy system study scenarios to be considered in the modelling activities of Work Package 3 of the RealValue project. Defining high-level scenarios is required because of the diversity of models to be applied in RealValue and respective differences in input parameter requirements. Different types of models will be used, including domestic thermal energy models, power and heat system scheduling models, distribution models, and reliability models. Analyses will be carried out for the years 2020, 2030 and 2050. These dates represent short-, medium- and long-run perspectives and correspond with important reference years of EU energy and climate policy. A range of complementary country case studies including Ireland (All-Island), UK, Germany, France, Latvia and Finland/the Nordic countries allows investigating the system value of SETS in different markets. These individual country analyses should be embedded in mutually consistent and policy-relevant pan-European energy system scenarios. We thus lean on the European Commission's well-established *Reference Scenario* 2013 as the Baseline for the years 2020 and 2030, supplemented/updated with parameter assumptions from other well-established scenarios wherever necessary. It will be complemented as a Baseline with subsequent individual parameter sensitivity analyses in order to address several major uncertainties. For the 2050 perspective, we draw on self-contained scenarios from the European *e-Highway* project. This differentiated approach allows dealing appropriately with broader uncertainties in the long-run.

1. INTRODUCTION

1.1. The RealValue project and its Work Package 3

The RealValue EU Horizon 2020 project aims to investigate how usage of electricity for local small-scale storage of heat to satisfy space and water heating demands in the residential building sector, optimised by controlled aggregation signals, could bring technical and economic benefits to the energy system overall. As a source of further information and background on the consortium, see the RealValue project website: http://www.realvalueproject.com.

There are two major constituent elements to the project. On the one hand, RealValue will use three physical deployments of Smart Electric Thermal Storage (SETS) appliances in 1,250 homes in Germany, Latvia and Ireland, as a proof of concept trial for aggregation of residential electric heat demands in real electrical power systems and energy markets.

On the other hand, to validate the trial at large scale, Work Package 3 of the RealValue project will use desktop techno-economic modelling to project the future potential of local small-scale energy storage in millions of homes across more broadly representative EU regions. Detailed sensitivity analysis can also be performed – in particular with respect to flexibility provision from other competitive sources and technologies in the future energy system. Any barriers associated with its integration into the electricity grid and energy markets will thus be identified. This will be varied out in tandem with Work Package 6, which analyses the potential European market for local small-scale energy storage as well as socio-economic, policy and regulatory aspects.

The potential benefits of a distributed and controllable domestic load resource can be summarised into the following anticipated value streams:

- **Energy arbitrage value:** Using energy from generally cheaper off-peak electricity generation sources or renewable surplus generation when compared to more expensive peaking plants. Optimised control of the domestic electric power demand profile in each day can minimise overall system fuel costs and offers an alternative strategy for variable renewable energy curtailment reduction;
- **Ancillary services value:** Demand side participation in power system frequency regulation, primary/replacement reserves provision, and system ramping requirement reduction across multiple intra-day timeframes can increase power system ‘flexibility’ in a European context with greater variable/forecast-uncertain renewable energy penetrations;
- **Network investment deferral value:** Localised network power flow congestion management tools can work in synergy with heating and hot water storage controls to postpone and/or avoid environmentally or socially challenging upgrades to the transmission and distribution wires and cables of the power system;
- **Capacity value:** Demand shifting away from the hours of the year where the system experiences overall greatest power demand, could reduce the installed electric power generation capacity requirement, and/or increase load service reliability levels resulting in deferred or avoided electricity generation investment.

Work Package 3 thus contains a number of sub-tasks and a suite of combined heat/electricity sector techno-economic models to estimate the value contribution of SETS in each category.

These models require specific input parameter and technology choice assumptions. This report for Task 3.1 of the RealValue project thus aims to broadly assess what parameters could be included, and provide estimates/ranges for these parameters for later modelling efforts in other Work Package 3 Tasks.

1.2. Geographical scope and time horizon

Different modelling groups within the consortium will focus on specific countries with respect to the analysis of SETS and other power-to-heat options. In particular, dedicated analyses on Ireland, UK, Germany, France, Latvia and Finland/the Nordic countries will be performed. These countries, which differ with respect to climatic conditions, generation portfolios, interconnection, housing stock and heating technologies, have been selected as they provide interesting and complementary case studies.

Ireland serves as an example for an island grid setting with high wind penetration. As for the power system, the whole Irish island will be modelled, while specific analyses of the housing sector might focus on the Republic of Ireland only. The UK is a potentially large market for SETS due to its specific housing and demographic structure. Germany is a front-runner with respect to the deployment of variable wind and solar power in the context of its ‘Energiewende’. France has a long history of residential electric heating related to its large nuclear power plant fleet. Finally, Latvia and the Nordic countries provide interesting complementary case studies not only because of different generation portfolios, but also because of long heating seasons and – in the case of Latvia – weak interconnection with the European power system. Detailed results from these heterogeneous country studies may then be projected to several other European countries in which the respective conditions are comparable.

As the European power system is already interconnected today, and markets are likely to be even more integrated in the future, analyses of individual countries always require a range of assumptions on developments in neighbouring countries, or even of the European interconnection at large. The definition of common pan-European energy system scenarios ensures that such assumptions are consistent across the different modelling activities.

The model analyses have been chosen to cover the years 2020, 2030 and 2050. This corresponds to short-, medium- and long-run perspectives of European power system developments. Uncertainties with respect to power supply and demand as well as costs and availabilities of different technologies generally increase over time. The relevance of respective sensitivity analyses accordingly grows with longer time horizons.

1.3. Building on well-established European scenarios

The objective of Work Package Task 3.1 is to specify an appropriate range of energy system study scenarios to consider in the modelling activities of Work Package Tasks 3.2, 3.3, 3.4, 3.5 and 3.6. In order to ensure policy relevance of modelling results as well as comparability with other studies, RealValue draws on European energy scenarios. These scenarios are well-established and consistent with relevant European policy directives and assumptions.

RealValue modelling activities will pursue a differentiated approach for the years 2020, 2030 and 2050. For the years 2020 and 2030, Work Package 3 model analyses will lean on the so-called *Reference Scenario 2013* of the *EU Energy, Transport and GHG Emissions Trends to 2050* publication as the Baseline scenario (European Commission 2014). This scenario constitutes a consistent pan-European projection of energy supply and demand trends under current European policy conditions. Aside from the Baseline scenario, alternative assumptions on the development of different power-to-heat options, batteries, electricity demand side, thermal efficiency of the building stock, as well as fuel and carbon prices will be considered by means of sensitivity analyses. These sensitivities will vary individual parameters, without changing the remaining Baseline assumptions. Naturally, the scope for such sensitivity analyses is greater for the medium term (i.e., 2030) than for the short term (2020).

For the 2050 perspective, RealValue will draw on scenarios from the European *e-Highway* project (e-Highway 2014). These were developed by European TSOs in a FP7 project. Here, individual sensitivity analyses are less applicable. Rather, it is intended to use consistent, self-contained scenarios from the *e-Highway* project with varying assumptions on the role of, amongst others, fluctuating renewables, European market integration, regulatory support for demand-side response and local solutions. Accordingly, there is no Baseline scenario in the narrower sense for 2050.

1.4. Required adjustments

Neither the *Reference Scenario 2013*, nor the *e-Highway* scenarios include all parameters required by Work Package 3 modelling activities, or not all are publicly available. Missing parameters will be requested from the respective scenario authors, wherever possible. If necessary, additional inputs will be inferred by Work Package 3 modellers. Some parameters may also be replaced with appropriate assumptions in line with the general scenario setup. In particular, both European Commission (2014) and e-Highway (2014) only include limited information on SETS and other power-to-heat options. Appropriate assumptions and potential adjustments of respective generation portfolios or demand patterns will be jointly made by RealValue Work Package 3 modellers.

As the European and global energy market and policy space evolves, updated versions of the above-mentioned scenarios and/or other relevant energy system scenarios may become available over the course of the project (e.g. Balta-Ozkan et al. 2013). In this case, adjustments compared to what is outlined in this document may be required. The same is true for individual parameter sensitivities. Additional sensitivities may become of interest, or some of the planned ones listed herein may turn out to be obsolete after the first model runs have been carried out. If necessary, RealValue partners will make appropriate adjustments in later stages of the project in order to ensure up-to-date and accurate modelling results. A comprehensive list of all assumptions and input parameters used by the various models to be applied in Work Package 3 Tasks 3.2, 3.3, 3.4 and 3.5 will be documented in the techno-economic report Deliverable 3.6 delivered in month 30.

The remainder of this report is structured as follows. Section 2 briefly introduces the portfolio of models to be used in Work Package 3 and discusses some specific inputs required by particular models. Section 3 provides details on the scenarios and sensitivity analyses for the years 2020 and 2030, while section 4 focuses on 2050 scenarios. The final section summarises and concludes.

2. THE PORTFOLIO OF MODELS TO BE USED IN WORK PACKAGE 3

The various models to be developed and applied in Work Package Tasks 3.2-3.6 differ, amongst other factors, with respect to their analytical setup, temporal and spatial resolution and technological coverage. This applies to not only the different types of models to be developed in Work Package Tasks 3.2 (domestic thermal energy models), 3.3 (power and heat system scheduling models), 3.4 (distribution models) and 3.5 (reliability models), but also to the heterogeneity of models to be developed within Work Package 3 by the different project partners.

On the one hand, such complementarity is an asset for the RealValue project, as it allows evaluating the system value of SETS and other power-to-heat options from different perspectives. On the other, it is also a challenge for the definition of common scenarios, as distinct models used by the different partners may require different and sometimes very specific input parameters. What is an exogenous input in one model may be an endogenous variable in another model. For example in Task 3.5, this concerns power generation capacities in pure dispatch models or dynamic investment models.

In order to ensure consistency and comparability of the different model analyses, the definition of common scenarios particularly focuses on consistent inputs with respect to power and heat demand, the role of renewable and nuclear power generation, fuel prices, CO_2 regulation and the use of similar base years for historic hourly demand/meteorology profiles.

2.1. Domestic thermal end-use and building models

Domestic thermal end-use models will be required to model the environment in which the SETS systems are installed, i.e. residential buildings. The models need to account for the thermodynamic behaviour of the buildings and the SETS units themselves when deployed at scale.

Conventional building models, e.g. EnergyPlus (US DoE 2015), allow for the detailed performance analysis of single buildings and their HVAC (Heating, Ventilation and Air Conditioning) technology. These building models are highly complex and can require hundreds of inputs. The aim of Work Package 3 is to explore the impact of SETS units on the power system when deployed at scale. In order to efficiently model large numbers of buildings and SETS units, reduced-order building models are required. Reduced-order models are computationally inexpensive and operate using a small number of inputs, e.g. Kramer et al. (2012) and Lauster et al. (2014). However, careful calibration of the reduced-order models is required to ensure that their outputs are representative. Work Package Task 3.2 will involve developing new reduced-order building models while leveraging existing, conventional and validated detailed models for calibration purposes.

For Work Package Task 3.2 a ‘bottom-up’ modelling approach (Kavgic et al. 2010) will be the most appropriate i.e., model a small number of archetypal houses that have an energy performance indicative of a much larger number of dwellings, see Swan and Ugursal (2009), Good et al. (2015) and Mata et al. (2014). The results from the archetype models can then be extrapolated to national scale. As an example, over 80% of the Irish housing stock can be described by just 5 archetypal housing geometries: detached, semi-detached, terraced, mid-floor flat and top-floor flat (Neu et al. 2014a, 2014b). The geometries are then assigned fabric and envelope properties to represent houses built in different eras using different construction techniques and materials.

Building occupant behaviour is one of the dominant drivers of building energy consumption. For this reason, occupant behaviour will be accounted for using occupancy models. Such occupancy models use inputs on thermal comfort preference, occupant interactions with heating and ventilation systems, occupant schedules (whether occupants are present, absent, asleep etc.), and occupant interactions with domestic hot water (DHW) systems.

A key modelling challenge is realistically capturing the energy impact of occupant behaviour when aggregated at national scale. To address this issue, Work Package 3 will apply the development of stochastic models that use probability matrices to predict the behaviour of thousands/millions of building occupants (Richardson et al. 2008, 2010).

Multiple heating technologies are present in homes throughout Europe. These include, among others, gas-fired central heating, direct-resistance heating, district heating, storage heating, heat pumps etc. Some combinations of heating technologies may also be combined to form hybrid systems (e.g. gas-fired boilers with electric heat pumps). Work Package 3 models will account for the diversity in European domestic heating technologies.

Data will be required to populate the building archetype models with representative information on building construction, fabric, insulation, HVAC systems, air tightness etc. Data sources are highly country dependent and these will be utilised in respective countries. There have also been recent European-wide efforts to collate the necessary data to enable national scale building modelling and these will also be used when applicable. European sources include, but are not limited to, the following projects/actions: TABULA (2012), ENTRANZE (2014) and EPBD (2015).

A building modelling sub-group was formed under Work Package Task 3.2 in order to communicate modelling issues, challenges and solutions amongst RealValue partners. The sub-group is composed of researchers from UCD, DIW Berlin (including RWTH-Aachen), VTT and RTU. The sub-group was formed to ensure that building modelling will be consistent in models, inputs and assumptions where practically possible across Work Package 3.

2.2. Integrated power and heat sector – scheduling, distribution system, and reliability models

In Work Package 3 Tasks 3.3, 3.4 and 3.5, different types of models are to be developed. These include co-optimised scheduling models, distribution system models and reliability models respectively. These models differ with respect to exogenous input parameters and endogenous model outcomes (Table 1).

Table 1: Inputs and outcomes of power system, distribution and reliability models

	Work Package Task 3.3	Work Package Task 3.4	Work Package Task 3.5
Type of model	Co-optimised power system & SETS models	Distribution network models	Generation adequacy reliability models
Important input parameters	• Time series for electric and thermal loads as well as wind power, hydro and PV generation • Fuel and CO_2 prices • Power plant characteristics • Generation capacities (static models) • Specific investment costs (dynamic models) • Provisions for demand-side response/flexibility	• Typical distribution grid topology and control schemes/standards • Voltage levels, network impedances and thermal limits • Estimates of residential demand diversity • Rooftop solar PV penetrations	• Availability profiles of conventional/thermal and renewable plants • Coincident heat and electricity demand profiles • Availability of demand-side response • Long-run meteorological patterns
Model outcomes	• Generation portfolios (dynamic models) • Dispatch of various capacities • Value of SETS in the energy system in particular with respect to arbitrage and system services	• Impact of SETS on network investment requirements and respective system value • Limitations of network standards on dispatch operability of SETS at market level	• Loss of load expectation • Expected energy not served • Capacity value of SETS

Distinct yet complementary power system models will be refined or developed in Work Package Task 3.3 by the different RealValue project partners looking at the different geographical regions mentioned in Section 1.2. All of these models have specific advantages and strengths, for example with respect to the representation of thermal generations, constraints related to combined heat and power generation, reserve provision or stochastic elements. In order to preserve the respective strengths of these models, common energy system scenarios must not be over-restrictive when it comes to concrete parameter choices. Accordingly, the definition of common scenarios should be as high-level and generic as possible. The different models can then be calibrated using appropriate parameters for specific model features and regional applications. More information on the types of models to be refined or developed in Work Package Task 3.3 is provided in Karlsson and Meibom (2008), Meibom et al. (2011), Sauhats et al. (2015), and Zerrahn and Schill (2015).

In any case, it is important to ensure consistency of hourly time profiles. This particularly concerns hourly profiles of fluctuating renewables, electric load, heat demand, net transfer capacities (NTCs) and meteorological data. With respect to heat demand and renewable power generation, it should also be ensured that not only ‘average’ weather years, but also relevant climate extremes are considered. The models to be applied in RealValue generally have an hourly resolution. Yet the central European intraday market already offers quarter-hourly settlements and prices today, and future market design reforms may further strengthen sub-hourly markets. The effects of such sub-hourly granularity on model results will be explored and discussed.

3. SCENARIOS FOR 2020 AND 2030

3.1. Baseline scenario

For the years 2020 and 2030, the RealValue project intends to lean on the *Reference Scenario 2013* of the *EU Energy, Transport and GHG Emissions Trends to 2050* publication as the Baseline scenario (European Commission 2014). This scenario, which has been approved by the European Commission, constitutes a consistent pan-European projection of energy supply and demand trends under current European policy conditions. In general, data on electric power supply and demand is available on a country-specific basis. European Commission (2014) provides, amongst others, yearly gross electricity consumption, gross generation by source, renewable shares, net generation capacities as well as fuel and carbon prices. Some of the most important parameters with respect to the calibration of various Work Package 3 models are summarised in Table 2 (for 2020) and Table 3 (for 2030).

Table 2: Important calibration parameters for 2020 provided by European Commission (2014)

	Finland	France	Germany	Ireland	Latvia	UK
Gross electricity generation in GWh	80,083	583,539	586,628	27,686	7,651	356,074
Hydro capacity in MW[1]	3,361	21,260	5,195	296	1,672	1,622
Wind capacity in MW	2	25,687	48,956	3,561	428	38,627
Solar capacity in MW	50	7,470	49,089	0	1	5,985
Nuclear capacity in MW	4,321	62,857	6,808	0	0	3,708
Renewable share in gross electricity generation in %	36.4	27.1	38.6	44.0	67.1	40.9

1 Without pumping

Table 3: Important calibration parameters for 2030 provided by European Commission (2014)

	Finland	France	Germany	Ireland	Latvia	UK
Gross electricity generation in GWh	100,382	631,997	590,722	32,358	8,714	373,960
Hydro capacity in MW[1]	3,441	21,760	5,748	312	1,733	1,622
Wind capacity in MW	2,556	47,354	69,949	5,992	681	50,721
Solar capacity in MW	60	13,913	53,584	674	1	8,853
Nuclear capacity in MW	6,843	54,021	0	0	0	4,402
Renewable share in gross electricity generation in %	30.3	37.7	52.5	66.1	67.7	50.3

1 Without pumping

In line with actual provisions of the European Emissions Trading Directive, we assume that the European CO_2 cap decreases by 1.74 % every year. According to the assumptions made by European Commission (2014), this can be translated into EU Emissions Trading System (ETS) allowance prices of 10 € per tonne CO_2 in 2020 and 35 € per tonne CO_2 in 2030.

As regards other important calibration parameters such as fuel prices or investment costs of different technologies, European Commission (2014) does not provide many details. Moreover, more up to date projections with respect to, for example, natural gas prices or investment costs of renewable technologies may be required in order to ensure policy-relevance of modelling results. For example, the EU *Reference Scenario 2013* uses specific investment cost projections for nuclear and solar power which have in the light of recent developments been discussed as being too high, or too low, respectively (von Hirschhausen et al. 2013). The use of complementary sources may thus be required, including country-specific sources as well as periodical publications of the International Energy Agency, such as the World Energy outlook or the Ten-Year Network Development Plan projected by European TSOs (ENTSO-E 2014), which will be updated in 2016. These sources may also be used to update selected country-specific assumptions made in the *Reference Scenario*.

3.2. Additional sensitivity analyses

The future development of both the supply and the demand side of power and heat systems is generally uncertain. While this already applies to the 2020 parameters of the *Reference Scenario 2013* to some extent, it is especially relevant for 2030. In the context of the RealValue project, we are particularly interested in the effects of different developments of smart electric thermal storage and other power-to-heat options, electrochemical batteries, electricity demand side, thermal efficiency of the building stock, and varying fuel and CO_2 price assumptions. Importantly, these sensitivities will be carried out as variations of individual parameters, while the remaining assumptions are unchanged in the Baseline scenario.

Table 4 provides a projected list of sensitivities as currently planned. The sensitivities 'Demand-side breakthrough' and 'Battery breakthrough' represent alternative assumptions on other options that provide power system flexibility. 'Heat pump breakthrough' and 'Hybrid heating system breakthrough' relate to alternative power-to-heat options that compete with smart electric thermal storage devices. While heat pumps consume electricity to make use of environmental heat, hybrid heating systems combine conventionally-fired boilers with resistive electric heating elements. The 'Thermal efficiency breakthrough' sensitivity assumes a much-reduced residential heating demand due to potential improvements in the building stocks, which may open up new markets for electric heating systems. The 'Fuel and CO_2 price changes' sensitivity will help to assess the robustness of results with respect to alternative price developments of fossil fuels, in particular natural gas, as well as CO_2. Finally, a 'Policy-induced portfolio changes' sensitivity may help to assess the impacts of early retirements of specific thermal plants, for example emissions-related retirements of hard coal and lignite plants.

Table 4: Projected list of sensitivity analyses

Sensitivity name	Description
Demand-side breakthrough	Large flexibility potentials on the electricity demand side can be realised at low costs. These include load shifting and temporary load shedding of large consumers. Controlled charging of future fleets of electric vehicles may also play a role.
Battery breakthrough	Large installations of distributed Li-ion (or other) batteries, caused by cost decreases, political support and/or other drivers.
Heat pump breakthrough	Increased shares of heat pumps in residential heating systems. This development may be driven either by cost decreases or by dedicated policy measures.
Hybrid heating system breakthrough	Increased shares of residential hybrid heating systems, i.e. gas boilers with integrated electric heating rods. This development may be driven either by cost decreases or by dedicated policy measures.
Thermal efficiency breakthrough	Very low space heating demand due to much-increased refurbishment rates, potentially combined with lower demand for hot water via changing consumer behaviours. This could potentially open up new markets for SETS.
Fuel and CO_2 price changes	Alternative developments of natural gas import prices and EU ETS emission allowance prices, reflecting different developments of the world market for natural gas or alternative, policy-induced restrictions on carbon emissions.
Policy-induced portfolio changes	Early retirements of thermal plants, for example due to emissions regulation or changes in nuclear policy.

Over the course of the project, concrete parameter choices for these sensitivities will materialise, corresponding to ongoing energy market and policy developments. This concerns, for example, concrete and country-specific numbers for alternative assumptions on load-shifting capacities, battery cost, or installed capacities of power-to-heat technologies. Sensitivities may also be guided by the different 'visions' projected for 2030 in the Ten-Year Network Development Plan (ENTSO-E 2014). The list of sensitivities presented here is thus indicative, though by the time of publication of Deliverable 3.6 it may not be exclusive. Additional sensitivities may become required at later stages, or on the other hand, some of these sensitivities listed in Table 4 may turn out to be less policy-relevant than initially thought. By the time of writing, it is planned to report in Deliverable 3.6 the impacts of at least one alternative parameter choice per sensitivity listed in Table 4, i.e. seven different sensitivities overall.

4. SCENARIOS FOR 2050

Because of ever-growing uncertainties in the longer-run perspective, scenarios from the *e-Highway project* (e-Highway 2014) are projected to be used for long-term model simulations. In this European FP7 project, European TSOs have developed a set of five scenarios representing different developments of demand, storage, cross-border power exchange, and generation capacities:

- 'Large scale RES'
- '100% RES electricity'
- 'High GDP growth and market-based energy policies'
- 'Large fossil fuel deployment with CCS and nuclear electricity'
- 'Small and local'

These represent consistent, self-contained scenarios which differ not only with respect to single input parameters, but with respect to all demand- and supply-side developments. For example, overall power demand is assumed to be highest in the 'Large scale RES' scenario and lowest in the 'Small and local' scenario. This is, amongst other factors, driven by different energy efficiency assumptions (Table 5). Likewise, the 'Large scale RES' scenario assumes higher shares of residential electric heating than 'Small and local'.

Table 5: Electricity demand in 2050 in GWh (e-Highway 2014)

	Finland	France	Germany	Ireland	Latvia	UK
Large scale RES	101,119	795,247	815,155	52,759	25,690	537,632
100% RES electricity	82,580	649,447	665,705	43,086	20,980	439,063
High GDP growth and market-based energy policies	83,528	657,057	660,937	41,871	21,769	388,699
Large fossil fuel deployment with CCS and nuclear electricity	92,417	726,987	731,280	46,328	24,086	430,068
Small and local	66,059	479,001	466,152	28,392	16,108	321,117

The *e-Highway* scenarios also differ strongly with respect to generation capacities, both in absolute and relative terms. In particular, assumed deployment of fluctuating renewables varies not only between countries, but also between scenarios (Figure 1). Installed wind capacities are substantial in most countries across scenarios. Generally PV capacities are assumed to be particularly high in Germany, but PV also gains importance in other countries in the ‘100% RES electricity’ scenario.

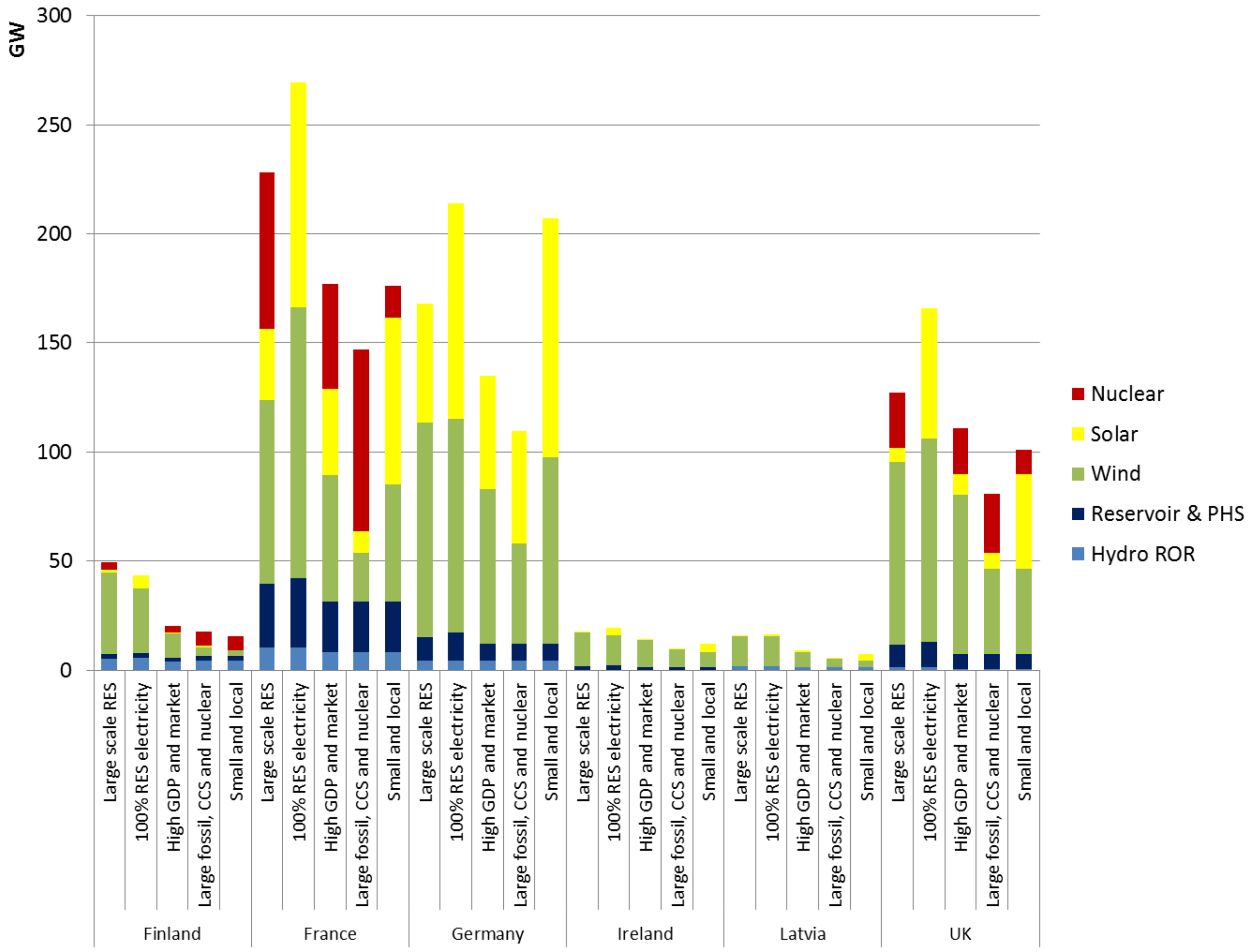

Figure 1: Installed capacities in 2050 (e-Highway 2014)

The different scenarios will be considered and evaluated equally, i.e. there is no Baseline scenario in the narrower sense for the 2050 perspective. As the 2050 scenarios from the *e-Highway* project are self-contained with respect to consistent developments of supply and demand technologies, sensitivity analyses of individual parameters such as fuel prices or power storage are not as applicable and may not be required to the same extent as in the 2030 case. Selected sensitivities with respect to specific power-to-heat assumptions may nonetheless be uncovered by initial model run outputs.

As already discussed above, some of the modelling work in Work Package Task 3.3 will utilise generation planning models with integrated building heat dynamics. This allows estimation of the long term impact of flexible electric heating on the power generation fleet. However, this approach requires that capacity assumptions are generally not treated as exogenous input parameters, but as endogenous variables. Instead, cost assumptions have to be tuned to produce similar results as the *e-Highway* scenarios.

5. SUMMARY AND CONCLUSIONS

The objective of Work Package Task 3.1 is to specify an appropriate range of energy system study scenarios to consider in the modelling activities of Work Package 3. These scenarios should be as policy-relevant as possible in order to ensure meaningful, up-to-date and accurate modelling results. A proper definition of scenarios appears to be particularly relevant as RealValue utilises a range of complementary models which require various and partly heterogeneous input parameters.

We have decided to carry out model analyses for the years 2020, 2030 and 2050. This represents short-, medium- and long-run perspectives of European power system developments and also corresponds with important reference years of EU energy and climate policy. A range of complementary country case studies will be carried out, including Ireland, UK, Germany, France, Latvia and Finland/the Nordic countries. These allow investigating the system value of SETS in markets that differ with respect to power plant portfolios, housing stock and heating technologies. However because of ongoing European market integration, analyses of individual countries require appropriate assumptions on developments in the European interconnection. Consistent pan-European energy system scenarios are thus required for RealValue modelling activities.

We have selected the *Reference Scenario 2013* of the *EU Energy, Transport and GHG Emissions Trends to 2050* publication (European Commission 2014) as the Baseline scenario for the years 2020 and 2030. This scenario is both well-established in the political and scientific domains and consistent with relevant European policy assumptions. If necessary, the assumptions made by the European Commission (2014) will be supplemented/updated with country-specific parameters from other established sources such as ENTSO-E (2014). The Baseline will be complemented with sensitivity analyses in order to address major uncertainties with respect to alternative developments of power-to-heat options, other flexibility options, and fuel and CO_2 prices. For the year 2050, we use self-contained scenarios from the European *e-Highway* project (e-Highway 2014). Compared to the approach for the years 2020 and 2030, this allows dealing appropriately with growing long-run uncertainties as regards the development of, amongst others, power demand, storage, cross-border power exchange and generation capacities.

As the European and global energy market and policy space evolves, adjustments compared to what is outlined in this document may be required in order to maintain policy-relevance of modelling outcomes. Moreover, at the stage of model calibration several input parameters may have to be modified with appropriate own assumptions in order to ensure consistency with the general scenario setup. The final parameter choices will be disseminated in the publicly available Deliverable 3.6, which is due in project month 30.

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