EUROPEAN COMMISSION

SEVENTH FRAMEWORK PROGRAMME

ICT Challenge 6: Mobility, environmental sustainability and energy efficiency
INFORMATION SOCIETY TECHNOLOGIES
Unit G5 - ICT for the Environment

Project Acronym:

SmartHouse/SmartGrid

Project Full Title:

Smart Houses Interacting with Smart Grids to achieve next-generation energy efficiency and sustainability

Proposal/Contract No: EU FP7-ICT-2007-2 STREP 224628

Deliverable 4.1

Case Study for 1 Million End-Users

Status:	**Draft**
Version:	**V0.2**
Dissemination Level:	**Public**
Date:	**15.10.2010**

Organization Name of the Lead Contractor for this Deliverable: MVV

Status Description

Scheduled completion date[1]:	31.08.2010 / 15.10.2010	Actual completion date[2]:	15.10.2010
Short document description:	This document gives an introduction into WP4 – Entry to Mass application with its first Task 4.1: "Scenarios for Case Study for 1 Mio End Users". Following the approach of discussing three country environments and customer groups, three scenarios are presented. All of them aim at comparing an advanced BAU scenario to reach EU EE/GHG and RE targets in 2020 later on with a similar scenario including additionally the developed Energy Management Systems (Power Matcher, BEMI/Energy Butler, Magic). In Task 4.2, sub-scenarios will be simulated for a large number of customers to get some quantitative results addressing target aspects/measurable objectives of the SmartHouse/SmartGrid project.		
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☐ ☐ Partner ↓ Contributions ↓ Peer reviews	☒ ☐ SAP ☒ ☐ ISET ☒ ☐ MVV ☒ ☐ ECN ☒ ☐ ICCS-NTUA ☒ ☐ PPC	**Report/deliverable classification:** ☒ Deliverable ☐ Activity Report	

Peer review approval :	☐ Approved ☐ Rejected (improve as specified hereunder)	Date:	[dd.mm.yyyy]
Suggested improvements:	[suggested improvements]		

[1] As defined in the DoW
[2] Scheduled date for approval

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Abbreviations

CCS	Carbon capture and storage
CHP	Combined heat and power plant
CIRED	International Center for research on environment and development (in French: Centre International de Recherche sur l'Environnement et le Développement)
DG	Distributed generation
E3M - NTUA	Energy - Economics - Environment Modelling Laboratory Research and Policy Analysis of the National Technical University of Athens
EE	Energy efficiency
ECO	Office of the Chief Economist
ETS	European Union Emission Trading System
EU15	European Union states in 2000 (before enlargement)
GHG	Greenhouse gas
IEA	International Energy Agency
IEKP	Integrated Energy and Climate Program of the German government
LV	Low voltage
MV	Middle voltage
OECD	Organization for Economic Co-operation and Development. The 31 member countries are: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
PV	Photovoltaic
RES	Renewable energy source
Toe	Tons of oil equivalent
WEM	World Energy Model
WEO	World Energy Outlook

1. Introduction and Objective of this Task

The overall objective of this work package 4 (WP4) is to "validate that the developed new control strategies and network architecture can be implemented for one million grid users and later on area wide". In other words, the new energy management systems should show their principal functioning and usefulness also for a large number of customers. However, questions of ICT signal transmission and scalability are to be addressed in Field Trial A. There, the SmartHouse/SmartGrid ICT architecture is tested under data traffic conditions of up to 1 Mio customers (partly real and partly mimicked). Therefore, ICT scalability is out of the scope here.

WP 4 aims at achieving additional information to answer some of the questions or measurable objectives not or hardly addressed by the field trials. This mostly covers the measurable objective D: The developed technology is able to achieve aggregate energy efficiency gains, and in particular gains, as a result of optimized energy management of devices (D2), a reduction of power grid losses by increasing local sustainable demand and supply solutions (D3), and gains through raising the accommodation ceiling of local networks for integration of local generation (D4).

It shall also be shown whether the implementation of intelligent energy management systems for a very large number of customers also can contribute towards achieving the EU targets for 2020 and beyond concerning renewable energy sources (RES) market penetration, and the energy efficiency (EE) and greenhouse gas (GHG) emission reduction targets. In order to achieve some results here, the specific objective of the subtask 4.1 is to "develop representative case studies which include 1 million users for specific regions with a focus on mass application of new control strategies and network architecture".

Following the approach of discussing three country environments and customer groups, three pairs of scenarios are presented. For each country/region and customer structure as a base case, an advanced BAU (1st) scenario is defined that already aims at reaching the EU EE/GHG and RES targets in 2020 and beyond. Then, as 2nd scenario this advanced BAU scenario is defined adding additionally the impact of the SmartHouse/SmartGrid ICT infrastructure. Separate studies will be performed into the impacts of the three functional building blocks: near-real-time balancing (PowerMatcher), day-ahead and intra-day planning (BEMI/Energy Butler), and reaction to critical situations (Magic). Thus, there will be a total of three times two scenarios (or three case studies with two scenarios each). These scenarios are based on similar models for the future BAU development as detailed in Sections 2, 3 and 4.1. However, they include also country-specific predictions as far as available.

In task 4.2, these scenarios will be broken down into sub-scenarios to provide more detailed answers to technical questions and to focus on the measurable objectives. These sub-scenarios of the three scenario pairs will be simulated for a large number of customers to obtain some quantitative results addressing target aspects / measurable objectives of the SmartHouse/SmartGrid project.

The number of 1 million end users is not meant literally to be exactly 1 million. It is to be understood as a very large number of connected users. The Dutch scenario takes as a basis the average of the Dutch consumers, i.e. some 16 million inhabitants (or more than six million households). For Germany, the data used represent the average of households. The German scenario chooses an area in the southwest of Germany which comprises approx. 1 million inhabitants. For Greece, an island grid was chosen, according to the specific target to study such issues as testing the control strategies for power quality (grid stability, black start, micro grid/island operation). Greece has some 36 island grids. Of this, Crete is the largest with some 0.5 million inhabitants but with more than 1 million consumers if the large number of tourists during the summer season is considered as well. It should be noted already here that the simulations done in the following subtask 4.2 will focus on subgroups as detailed in the corresponding report.

2. Potential Business as Usual Models as Reference Scenario

The following briefly describes some existing models that deliver input to the scenario analyses conducted in work package 4 of the SmartHouse/SmartGrid project, their value for the scenario inputs are highlighted.

2.1. The PRIMES Model

The PRIMES scenario was created within EC co-funded research projects. The principal actor was the University of Athens and particularly the Institute of Communication and Computer Systems (ICCS-NTUA) and the Energy - Economics - Environment Modeling Laboratory Research and Policy Analysis (E3M-Lab).

The "European Energy and Transport Trends to 2030 — Update 2007" issued by the European Commission Directorate, General for Energy and Transport is one major study based on the PRIMES model [Capros et al. 2008]. The study gives very detailed outlooks on the future energy consumption in the European Member States. Energy price developments and the CO_2 emissions linked to energy activities are also derived from the scenarios considered. All wide range of parameters is taken into account for the forecasts, such as technological, demographic and economic developments. For every country, the study provides tables with data on energy consumption and greenhouse gas emissions, detailed per sector and per fuel. Primary and final energy flows are distinguished.

The PRIMES model is a model that simulates market equilibria for energy supply and demand. This equilibrium is considered static (within each time period). The PRIMES model is a general-purpose model. It is conceived for forecasting, scenario construction and policy impact analysis. It covers a medium to long-term horizon. It is modular and allows either for a unified model use or for partial use of modules to support specific energy studies. The model can support policy analysis in the following fields:

- Standard energy policy issues: security of supply, strategy, costs etc.
- Environmental issues
- Pricing policy, taxation, standards on technologies
- New technologies and renewable sources
- Energy efficiency in the demand-side
- Alternative fuels
- Conversion decentralization, electricity market liberalization
- Policy issues regarding electricity generation, gas distribution and refineries

The baseline scenario is essentially a market driven least cost projection of future energy system developments without taking into consideration environmental costs and impacts. Figure 1 gives an overview of the PRIMES modules and how they are linked to each other.

The input that the PRIMES model delivers which can be valuable for SmartHouse/SmartGrid scenario analyses is summarized in the following:

Technological progress: PRIMES delivers an assessment of probable changes in the energy mix by the growing share of decentralized renewable generation like photovoltaic or CHP units, and its effect on the efficiency of electricity generation and distribution.

Demand growth: The biggest increase in energy demand across Europe will come from the service sector with a growing number of air conditioning units. The industry and agriculture sector demand is also projected to grow, but more slowly.

The residential energy demand: The projections of energy demand in the residential sector consider the more efficient use of energy, but also the increasing number of households. Demand projections are provided for electricity use and other forms of energy used in households.

Investment: The electricity market is detailed from the generation to the consumption. The investment in that sector is projected to grow in the next years; the model provides a detailed analysis on future investments.

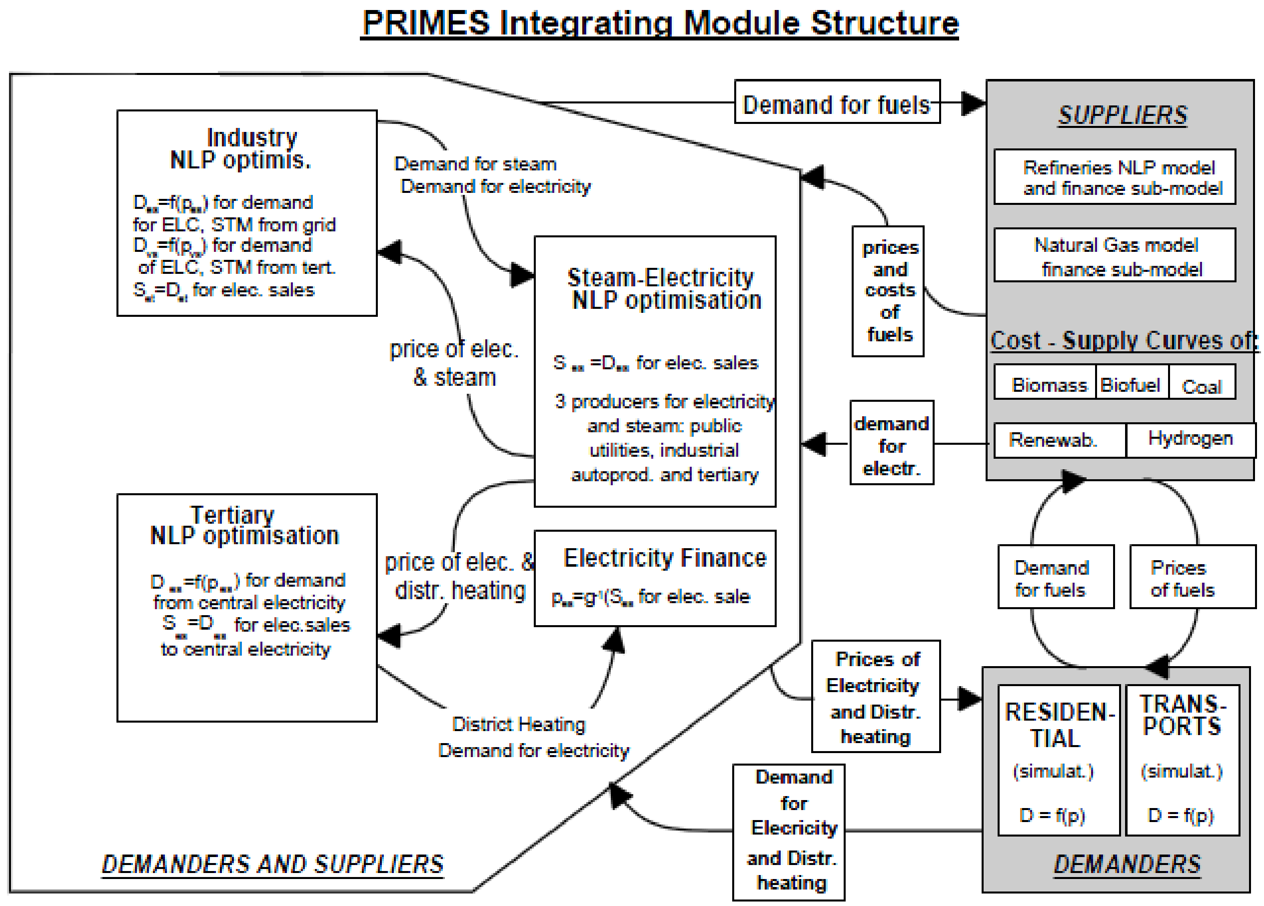

Figure 1: The PRIMES model structure

2.2. The IEA Scenario about the World Energy Production and Consumption

The International Energy Agency IEA regularly publishes the World Energy Outlook (WEO). The IEA is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to co-ordinate measures in times of oil supply emergencies. Today, its mandate has broadened to incorporate the "Three E's" of balanced energy policy making: energy security, economic development and environmental protection.

The WEO appears once per year; the last edition was published in 2009. It is divided into three parts.

- Global energy trends to 2030
- Oil and gas production prospects
- The role of energy in climate policy

Analysis of fossil fuels, especially oil and gas markets, still have the most important place in the WEO report. Besides, demographical and political developments and the change in the perception of ecological problems are also considered. Detailed data on greenhouse gas concentration, temperature increase, generation and wholesale prices as well as investment costs are given in the report. The scope is worldwide, with three regional clusters, i.e. "OECD+" countries (OECD and non-OECD but EU countries), "other major economies" (including China, Russia, India, Indonesia, Brazil and Middle East) and "other countries".

For predictions of future energy developments, the IEA basically uses two models: the World Energy Model (WEM) that they developed, and an economical model which was inserted into it. Helped by the Office of the Chief Economist (ECO) and the French International Center for Research on Environment and Development (Centre International de Recherche sur l'Environnement et le Développement CIRED), they created a General Equilibrium Model (called WEM-ECO) which provides a detailed representation of the energy sector. The model is updated every year in order to accommodate the latest economical, political and sociological changes.

For SmartHouse/SmartGrid scenario analyses, the WEO contains many chapters that deliver helpful input data. Valuable input data is delivered for the following domains:

Electricity market: Electricity prices, electricity demand, electricity generation and renewable energy developments are presented in detail in the WEO. Most of the projected growth in electricity demand occurs outside the OECD. In the OECD, electricity demand is projected to rise by just 1.1% per year on average, increasing by less than a third between 2006 and 2030. In contrast, demand in non-OECD countries grows by 146%, at an average annual rate of 3.8%. For the power generation, the part of the renewable energy is increasing. The combined heat and power generation will also grow in the next year, both in residential houses and in commercial buildings. More consumers will become also generators, and the energy system will be structured in a decentralized way [IEA 2008].

Investment into electricity generation: Investment needs into generation, transmission and distribution are also analyzed. There, costs have increased in the last few years, due to higher material costs. But investments in energy generation are also boosted by the renewable energy which will gain higher shares of overall generation until 2030, increasing from 16% to 26% in the European Union. All technologies will be used, and the structure of the European power network will change as a consequence. Price reduction in renewable energies thanks to the maturity of the technologies will help the development of this type of energy and will bring more decentralized electricity. The section "Grid integration of wind power and other variable renewable" of the WEO provides an analysis of how renewables will challenge the grid in the future and how it can be coped with.

2.3. WLO Scenarios for Energy – The Case of the Netherlands up to 2040

The Welfare, Prosperity and Quality of the Living Environment study (WLO, Dutch title Welvaart en Leefomgeving), executed by CPB and PBL, the Dutch planning offices for economy and environmental assessment respectively, contains scenario studies on all aspects of the Dutch society up to 2040. The energy chapter of the study has been developed by ECN. An overview can be found at *http://www.welvaartenleefomgeving.nl* (mainly in Dutch). The WLO study has also been used in the ITM project (Intelligent E-Transport Management, http://www.itm-project.nl) to assess the effects of electric mobility in the Netherlands. Hereto the WLO study is augmented with more detailed prognoses about penetration of flexible appliances (heat pump, electric vehicle), renewable sources (wind, PV), and the electricity network itself.

The long-term future of the Dutch population and economic development and, consequently, of its natural and built environment is highly dependent on international factors. Two critical factors of uncertainty stand out: (1) to which extent will nations and international trade blocks cooperate and exchange, giving up some of their cultural identity and sovereignty? (2) How will governments balance between market forces and a strong public sector? These international political choices determine four possible scenarios for the Netherlands:

- Global Economy: emphasis on international cooperation and private responsibilities.
- Strong Europe: emphasis on international cooperation and public responsibilities.
- Transatlantic Markets: emphasis on national sovereignty and private responsibilities.
- Regional Communities: emphasis on national sovereignty and public responsibilities.

The study builds on earlier work by CPB (2003, 2004) and RIVM et al (2004, 2005) in which these scenarios were translated into four development paths for the Dutch economy and demography.

The developments in the energy field in WLO are described in four scenarios. The energy supply is matched with the demand in the different end-user sectors. The energy demand is based on the volume growths per sector and the availability and cost of energy. Note that the energy prices will be dependent on the developments in the energy sector itself and the demand patterns. The determination of energy demand and energy supply therefore is an iterative process.

For the SmartHouse/SmartGrid project, the WLO Strong Europe (WLO-SE) scenario will be input. This WLO-SE scenario and the ITM study provide the base figures for the Case Study A, which is placed in a Dutch setting. The WLO-SE study contains quantitative data on the energy supply mix and the energy demand per sector. The ITM project augments this with figures on penetration of flexible appliances (heat pump, electric vehicle), renewable sources (wind, PV), and on the electricity network itself.

In WLO-SE, additional capacity will at first be gas based. On the longer term, also coal gasification with CCS will be applied. Due to climate policy also energy from wind, PV and biomass will grow, leading to a share of renewable electricity in 2040 of more than 30%.

2.4. Further Models and further Input Data

Besides the large models presented above, some smaller energy system models have been developed which may also serve as a reference for further extensions of the SmartHouse/Smart Grid scenario analyses. These are very briefly presented in the following.

2.4.1. EURPROG 2009

EURPROG Network of Experts (2009) provides statistics and prospects for the European electricity sector for different times and periods (e.g. for 1980-2000, 2004, 2005, 2006, 2010-2030). Selected information is used to fill data gaps or details, for example for the Greek case studies.

2.4.2. "Leitstudie 2008" for Germany

In October 2008, [Nitsch 2008] presented the "Leitstudie 2008", a study for the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). This study introduced and discussed an increased share of renewable energy technologies for Germany as compared to the PRIMES model so as to reach the German and EU targets for RE share which is hardly possible following the PRIMES scenario only. This "Leitstudie" contributes to the data set used in the scenarios for Germany. One target of this SmartHouse/SmartGrid project is to install energy management systems at the consumer side in order to allow for load shifts to accommodate a maximum of distributed and renewable-based electricity generation. Consequently, the highest share of RE in the generation mix is assumed for the scenarios in the present report.

2.4.3. A Tool for Creating Energy Market Scenarios

[Axelsson/Harvey 2009] present a model for price predictions for the different types of energy. This model is heavily based on mathematical equations. A lot of data must be calculated outside the model, such as oil, natural gas or coal prices. For this purpose, the model needs to be coupled to other scenarios from PRIMES or IEA. Only the electricity price is of importance to evaluate whether people will invest in decentralized renewable energy to reduce their energy budget.

2.4.4. Analysis of 100% Renewable Energy Systems

[Lund/Mathiesen 2009] present a case study of the Danish energy system switching to 100% renewable energies. This is considered for a period between 2030 and 2050. The study presents the necessary developments to achieve the goal of 100% renewable energy within the next 40 years. The analysis given can help to determine the necessary changes in the electricity system and markets, which are also relevant for the SmartHouse/SmartGrid scenario analyses.

3. Input Data for Scenario Analyses

3.1. Electricity Generation Projections

In the PRIMES study provides forecasts for electricity generation until the year 2030. It aggregates steam and electricity generation; however, steam represents only a minor part as compared to electricity, the given data is interpreted as data for electricity only.

For the three countries studied in SmartHouse/SmartGrid, the PRIMES gives the most complete, detailed and significant information about the actual and the future electricity generation capacity. The data suggests a growth rate of 0.7 % per year in installed generation capacity for the European Union. The biggest increase goes to the account of renewable energies:

- Solar: + 5,5% annual change
- Wind: + 1,9% annual change
- Biomass: +3,4% annual change
- Other renewable: +7,3% annual change

The consequences of this fact will be to increase the penetration rate of the RES. In 2030, renewable energies are projected to account for 325 GW of the 833 GW of installed electricity generation capacity in the European Union, which is depicted in Figure 2. This will also increase the part of decentralized generation (DG). A part always bigger of the capacity will be in the households or in other buildings directly connect to the low and medium voltage grid.

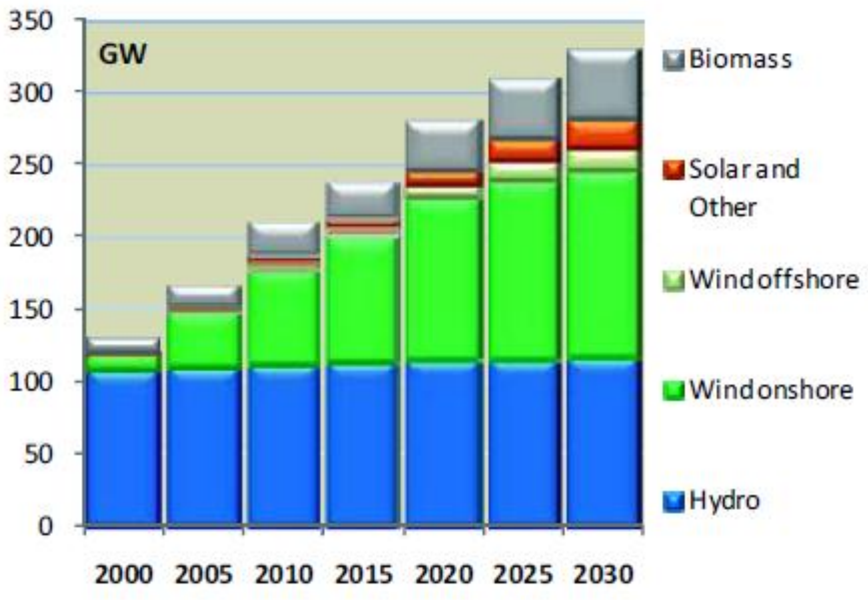

Figure 2: Capacity of renewables in the European Union[3]

The publications of PRIMES model data do not distinguish between large centralized generation and smaller units for decentralized generation. In order to derive an estimation of the DG capacity, all renewable (solar PV, wind, geothermal, biomass) and CHP plants could be grouped as DG capacity. However, this calculation is inaccurate to some extent, as CHP also includes larger industrial installations (which explain that the CHP generation capacity represents between 25% and 50% of the global thermal power generation capacity).

[3] "European Energy and Transport – Trends to 2030", Page 64

The according figures for total installed generation and renewable and CHP generation for 2020-2030 are given in Table 1 to Table 3 for Germany, the Netherlands and Greece, respectively [Capros et al. 2008].

Electric generation capacity [MW]	2020	2025	2030
Installed power generation capacity in the Netherlands	32,033	34,117	35,928
Installed decentralized power generation capacity in the Netherlands	17,354	17,981	18,413
Share of decentralized generation capacity	54%	53%	51%
Installed wind generation capacity	2,872	3,289	3,439
Installed PV-panel capacity	523	787	1,131
Installed CHP capacity	12,151	11,964	11,838
Installed biomass generation capacity	1,808	1,941	2,005
Installed geothermal generation capacity	0	0	0

Table 1: Dutch electricity generation capacity 2020-2030

Electric generation capacity [MW]	2020	2025	2030
Installed power generation capacity in Germany	151,017	155,562	152,045
Installed decentralized power generation capacity in Germany	82,846	86,279	82,478
Share of decentralized generation capacity	55%	55%	54%
Installed wind generation capacity	32,446	37,177	35,254
Installed PV-panel capacity	4,303	4,829	5,266
Installed CHP capacity	40,829	39,067	36,200
Installed biomass generation capacity	5,260	5,194	5,744
Installed geothermal generation capacity	8	12	14

Table 2: German electricity generation capacity 2020-2030

Electric generation capacity [MW]	2020	2025	2030
Installed power generation capacity in Greece	19,889	21,131	23,956
Installed decentralized power generation capacity in Greece	4,184	4,601	6,551
Share of decentralized generation capacity	21%	22%	27%
Installed wind generation capacity	2,683	2,759	4,448
Installed PV-panel capacity	494	678	877
Installed CHP capacity	847	966	951
Installed biomass generation capacity	132	170	177
Installed geothermal generation capacity	28	28	98

Table 3: Greek electricity generation capacity 2020-2030

The same as for the generation capacity, the PRIMES study does not provide detailed data about which part of the electricity generation amount is done in decentralized plants. So the assumption was made that all the solar, wind, PV, biomass and geothermal energy can be considered as decentralized installations. CHP electricity generation has only been studied for the large-scale electricity production, so it does not enter into the decentralized production listed in Table 4 to Table 6 [Capros et al. 2008].

Generation [GWh]	2020	2025	2030
Total generated energy	151,535	158,379	168,110
Total decentralized generated energy	17,520	20,662	23,079
Share of decentralized generated energy	12%	13%	14%
Wind energy generation	7,455	8,699	9,444
PV generation	3,117	3,989	4,501
Electricity generation from biomass	6,948	7,974	9,134
Geothermal electricity generation	0	0	0

Table 4: Electricity generation in the Netherlands 2020-2030

Generation [GWh]	2020	2025	2030
Total generated energy	672,778	687,490	693,818
Total decentralized generated energy	129,667	148,415	158,865
Share of decentralized generated energy	19%	22%	23%
Wind energy generation	65,628	78,689	84,876
PV generation	15,189	17,271	18,457
Electricity generation from biomass	46,594	49,967	52,973
Geothermal electricity generation	2,256	2,489	2,559

Table 5: Electricity generation in Germany 2020-2030

Generation [GWh]	2020	2025	2030
Total generated energy	80,002	84,632	88,151
Total decentralized generated energy	15,110	16,361	21,693
Share of decentralized generated energy	19%	19%	25%
Wind energy generation	6,757	6,943	10,909
PV generation	3,187	3,675	4,071
Electricity generation from biomass	4,445	5,021	5,388
Geothermal electricity generation	721	721	1,326

Table 6: Electricity generation in Greece 2020-2030

3.2. Electricity Consumption Projections

With the EU Primes scenario, a growth of 0.9% per year is predicted for the electricity consumption in the Netherlands and in Greece between 2020 and 2030; the predicted growth rate for Germany is 0.3% per year. For the European Union overall, the PRIMES scenario predicts a growth of 0.8% per year between 2020 and 2030 [Capros et al. 2008]. Those projections are comparable with the projection of the International Energy Agency in her World Energy Outlook [IEA 2008]. For the European continent, she projects a growth rate in electricity consumption of 14.7% between 2015 and 2030, which corresponds to an annual rate of 0.9%.

Consumption [TWh]	2020	2025	2030
Electricity consumption in the Netherlands	140.18	147.39	153.60
Electricity consumption in Germany	600.40	613.87	620.11
Electricity consumption in Greece	68.19	71.57	74.66

Table 7: Electricity consumption in the Netherlands, Germany and Greece 2020-2030

3.2.1. The Residential Sector Consumption

The electricity consumption of the residential sector is not provided in detail neither in the PRIMES study nor in the IEA WEO. The PRIMES data states figures for the share of electricity consumption as a percentage of the overall energy consumption of households. This share was 23% in 2005 and is projected to account for 26% in 2020 and 27% in 2030 [Capros et al. 2008]. This is provided as an average value for all countries considered. According to [AGEB 2010] the share of electricity in the overall final energy consumption in Germany was 20% in 2008 (*as data are not available so far from Greece and the Netherlands, German data are used indicatively*). If the given shares are multiplied with the overall projected electricity consumption, this provides a good estimate of the residential electricity consumption for 2020-2030.

Another figure that is given by [Capros et al. 2008] is the electricity consumption by sectors. There, the share of all electricity consumption that can be assigned to the residential sector is 28% in 2005 and the same share in 2030. If this value is multiplied with the overall electricity consumption, this also allows for estimating the residential electricity consumption. The values for this second calculation are given in Table 8.

		2020	2025	2030
Residential electricity consumption as a share of overall residential energy consumption		28%	28%	28%
The Netherlands				
	Residential electricity consumption [TWh]	39,25	41,27	43,01
	Per household [kWh]	4,618	4,663	4,675
Germany				
	Residential electricity consumption [TWh]	168	172	174
	Per household [kWh]	4,245	4,330	4,363
Greece				
	Residential electricity consumption [TWh]	19,09	20,04	20,91
	Per household [kWh]	4,440	4,607	4,751

Table 8: Residential electricity consumption in the Netherlands, Germany and Greece 2020-2030

Some studies offer more detailed data about which appliances are responsible for how much energy consumption. Table 9 displays this data for German households, based on [AGEB 2010]. Of these loads, several could be managed by a smart house gateway, contributing to demand response. The most significant of them concern the room and water heating, but also cooling processes. Those applications can, to some extent, be schedule to night-time without much loss of comfort. The part of the manageable appliance can reach 55% of the whole electrical consumption of the residential sector [EA NRW 2006].

Appliance	Consumption			
	Overall [TWh]	Per house-hold [kWh]	In % of overall	Manageable
Room heating	17.8	457.0	13%	Yes
Water heating (including washing machines and dishwashers)	24.4	628.4	17%	Yes
Refrigerator and freezer	22.5	578.5	16%	Yes
Lighting	11.4	292.8	8%	No
Information and communication	15.6	399.9	11%	No
Drying	13.3	342.8	9%	Yes
Cooking, electric iron and other heating process	13.9	357.1	10%	No
Entertainment and other	22.2	571.3	16%	No
Sum	141	3627.8	100%	

Table 9: Electricity load by application in Germany in 2007

Similar overviews for electricity consumption by separate household appliances are also given for the European Union, such as depicted in Figure 3 [Bertoldi/Atanasiu 2007].

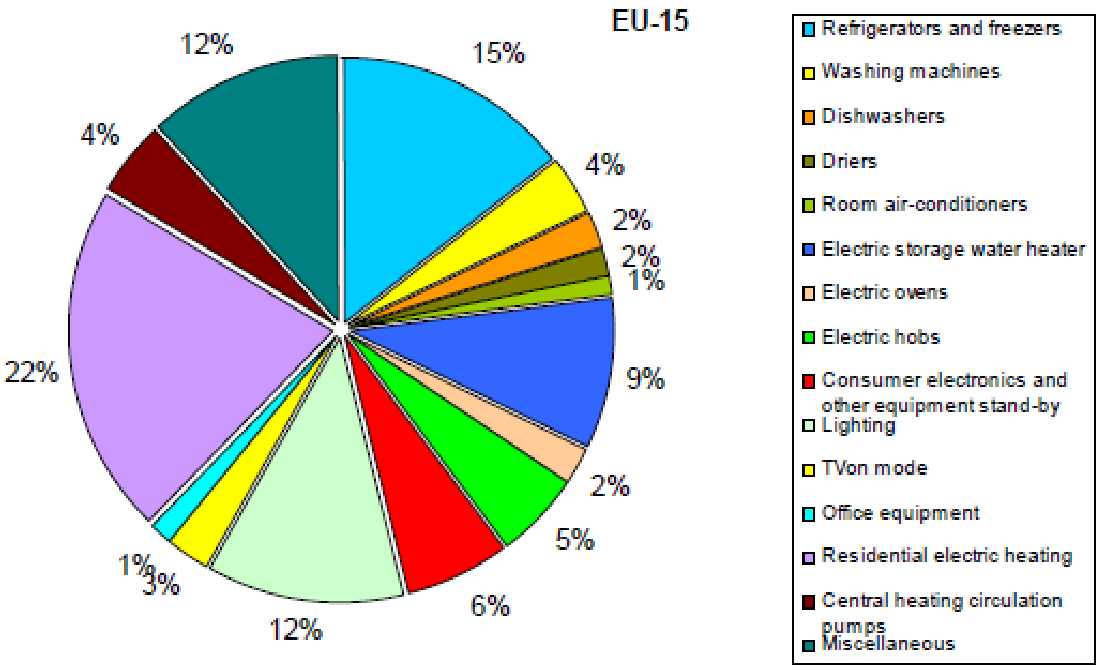

Figure 3: Electricity consumption of household appliances in Europe

3.2.2. The Industrial, Services and Commercial Sector

The same as for the household consumption the PRIMES data does not give any details about electricity consumption in the industrial sector. The energy demand of this sector grows with a rate of 0.3% per year. With the same calculation as for household consumption, industrial electricity consumption is estimated based on the industrial share of overall electricity consumption; this is given in Table 10 [Capros et al. 2008].

	2020	2025	2030
Residential electricity consumption as a share of overall residential energy consumption	39.0%	39.0%	39.0%
Industrial electricity consumption [TWh] in the Netherlands	26.59	27.91	29.12
Industrial electricity consumption [TWh] in Germany	234.16	239.41	241.84
Industrial electricity consumption [TWh] in Greece	26.59	27.91	29.12

Table 10: Industrial electricity consumption in the Netherlands, Germany and Greece 2020-2030

The detailed electricity consumption per type of usage in the industry sector in Germany is given in Table 11, based on [AGEB 2010][4]. In 2007, the largest share of the electricity used could be attributed to mechanic and heating process.

Appliance	Consumption	
	Overall [TWh]	In % of overall
Heating process	59.4	26.2%
Roam heating	0.8	0.4%
Mechanic energy	145.3	64.1%
Information and communication	9.7	4.3%
Lighting	11.4	5.0%
Sum	226.7	100%

Table 11: Industry electricity consumption per final energy usage in Germany 2007

The same data for overall consumption and consumption per type of usage is also given for the services and commercial sector in Table 12 and Table 13, based on [Capros et al. 2008] and [AGEB 2010], respectively. The energy demand of this sector grows with a rate of 0.1% per year.

	2020	2025	2030
Residential electricity consumption as a share of overall residential energy consumption	27.0%	27.5%	28.0%
Industrial electricity consumption [TWh] in the Netherlands	37.85	40.53	43.01
Industrial electricity consumption [TWh] in Germany	162.11	168.81	173.63
Industrial electricity consumption [TWh] in Greece	18.41	19.68	20.91

Table 12: Services sector electricity consumption in the Netherlands, Germany and Greece 2020-2030

[4] Similar data for Greece and the Netherlands are so far not available; if needed, data of Germany are used indicatively

Appliance	Consumption	
	Overall [TWh]	In % of overall
Heating process	36.7	25.3%
Roam Heating	8.9	6.1%
Mechanic Energy	58.6	40.4%
Information and Communication	13.1	9.0%
Lighting	27.8	19.2%
Sum	145.0	100%

Table 13: Service electricity consumption per application in Germany

3.2.3. Daily Load Profiles

The use of household and industrial appliances that consume electricity results in typical profiles of daily electricity loads. For household customers, these load profiles are well examined and also serve for procurement planning and billing. The load profiles are rather stable in the mid-term. However, trends in energy usage also lead to changes in typical load curves. It can be expected that electric heating systems that rely on heat-pumps will play a more prominent role in heating, which changes demand patterns. The introduction of electric vehicles also changes the usage patterns.

Within the SmartHouse/SmartGrid system, smart meters have been installed in the houses participating in the field trials. With the 15 minutes metering data, we will gain more knowledge about the houses' real energy consumption, and we can gain insights into whether the standard load profiles still reliably describe the current household load patterns. For larger scale simulations, however, we should still rely on the widely used load profiles, because these are still well established and we only have small samples of metering data available from the field trials, which might not accurately reflect the average households' electricity usage. A graphical representation of typical Dutch load profiles is given in Figure 4 [Veldman et al. 2010].

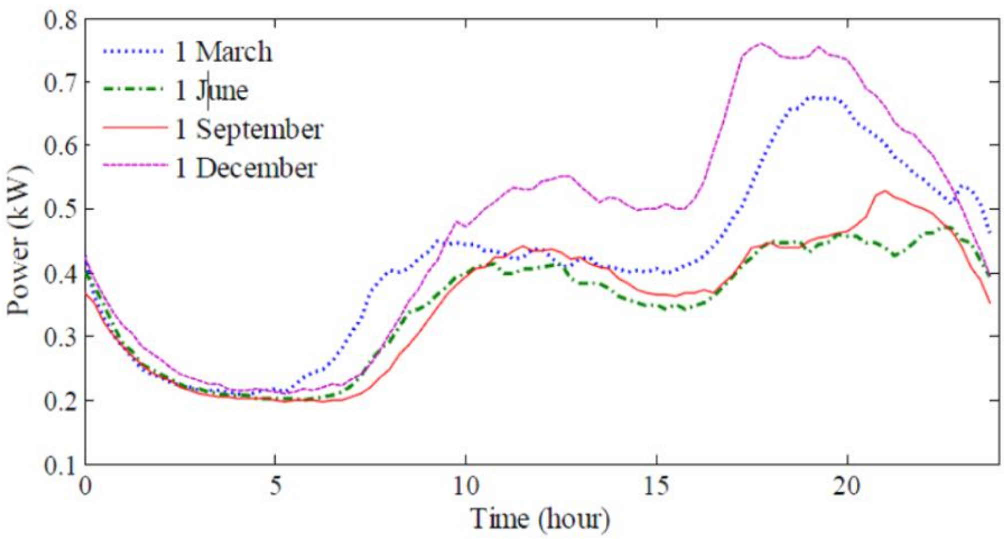

Figure 4: Load profile for the Netherlands

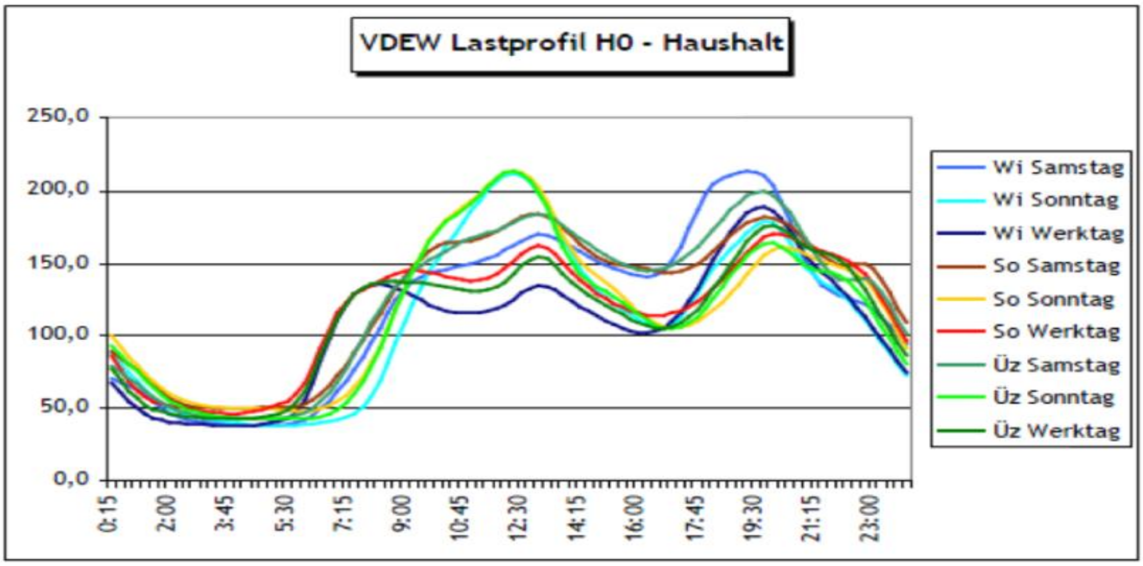

Figure 5: Standard load profile for a German household

The daily load profiles for households used in the German market are depicted in Figure 5 as a normalized profile for a consumption of 1,000 kWh per year [VDEW 1999]. Load profiles for other types of consumers, such as small business and agricultural farms are also provided by VDEW (that is, by its successor federation BDEW). A graphical representation of typical Greek load profiles is given in Figure 6 [Psiloglou et al. 2009].

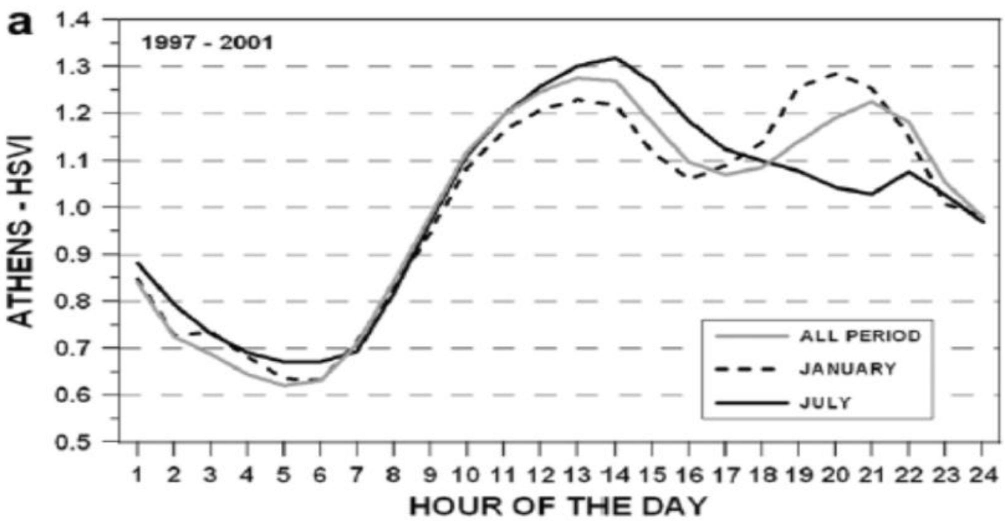

Figure 6: Load profile for Greece

All those three graph detail per years (and week) period the load in the different countries. The differences have to be considered in the different simulations.

3.3. Energy Costs, Efficiency and CO_2 Emissions

All the following data are valid for all the three considering countries. Economic data and future efficiency of each power plant type can be considered as being the same. Projected primary energy and electricity costs for 2020-2050 are given in Table 14 and are based on [IEA 2009].

Data	2020	2025	2030	2035	2040	2045	2050
Oil [$/Barrel]	110.0	116.0	122.0	128.0	134.0	140.0	146.0
Gas [$/MBTu]	12.7	13.5	14.2	14.9	15.7	16.4	17.2
Coal [$/Ton]	116.7	113.3	110.0	106.7	103.3	100.0	96.7
Electricity [EUR/MWh]	101.8		105.0				

Table 14: Projected primary energy and electricity costs

Table 15 gives an overview of how generation efficiency is projected to develop until 2030. Data for 2015 is based on [Graus/Worrell 2009]; data for 2030 is based on [Capros et al. 2008].

Data	2015	2030
Efficiency of coal-fired power plants	39%	41%
Emission from coal-fired power plants [tCO_2/MWh]	0.87	
Efficiency of gas-fired power plants	46%	50%
Emission from gas-fired power plants [tCO_2/MWh]	0.40	
Efficiency of oil-fired power plants	40 %	42%
Emission from oil-fired power plants [tCO_2/MWh]	0.72	

Table 15: Efficiencies and carbon intensities of fossil generation options

According to the PRIMES scenario, the average CO_2 emission will be in the EU15 equal to 0.29 tons per MWh in 2020. In Table 16, carbon dioxide intensities of electricity generation are given for the Netherlands, Germany and Greece [Capros et al. 2008].

Emission data	2020	2025	2030
CO_2 emissions from electricity generation in the Netherlands [tCO_2/MWh]	0.34	0.32	0.33
CO_2 emissions from electricity generation in Germany [tCO_2/MWh]	0.44	0.45	0.44
CO_2 emissions from electricity generation in Greece [tCO_2/MWh]	0.56	0.54	0.49
CO_2 emissions from electricity generation in EU15 [tCO_2/MWh]	0.29	0.29	0.27
CO_2 price per tCO_2	22 €	23 €	24 €

Table 16: CO_2 emissions in electricity generation and CO_2 prices 2020-2030

The PRIMES scenario assumed that the current emissions trading system operates and clears at a carbon price of 20 EUR/tCO_2 in 2010 mainly, based on free allocation of allowances. For the post-Kyoto period, it is assumed that the carbon prices increase smoothly to 24 EUR/tCO_2 in 2030. This is also shown in Table 16 [Capros et al. 2008].

3.4. Choice of a Reference Model and Time Period covered for the Projection

The PRIMES model is used as general reference model. However, it does not give data for households and household appliances in detail, and although the data of the PRIMES model are given per country, more specific models such as the Dutch WLO scenarios provide additional and more detailed data. Similarly, the EURSTAT or the German “Leitstudie” provide additional data. Where such more detailed data are available and not contradictory to the perspectives given in the PRIMES model, such additional information is combined with general trends reflected in PRIMES. Further details on the data used for the prediction into the future are presented in the chapters dealing with the different regional scenarios.

The time period considered for the projection is mostly defined by the data available in the required detail. For PRIMES, this is the period up to 2030, for selected data in the WLO projection, this is the period until 2040. Therefore, the considered time period is up to the years 2030 to 2040.

4. Description of the Scenarios and Planned Simulations

4.1. General Overview, Common Elements and Specific Approaches of the Three Case Study Simulations

This section presents the different case studies (scenarios). As the simulations in the following subtask 4.2 will be linked to these scenarios, the general approach for the simulations is also presented here, however without going into detail and without giving results (as the simulations so far are not done).

There will be three different case studies (scenarios) following the SmartHouse/SmartGrid approach of comparing different regions and client mixes within Europe. At the beginning, the general approach of the scenarios is shortly presented, together with common elements and specific approaches for the three case studies.

Common elements of all three case studies are:

- All case studies define a first scenario with ambitious efforts to reach the EC's targets for RE, EE and GHG emissions in the future, i.e. in 2020 and the following ten to 20 years. This scenario considers ambitious efforts according to the PRIMES model or partially even beyond as described in the previous section but **WITHOUT** using the energy management systems PowerMatcher (NL), BEMI/Energy Butler (D), Magic (GR). This scenario will be called the base case or Business as Usual (BAU).
- All case studies define a second scenario as described above but **WITH** using the energy management systems PowerMatcher (NL), BEMI/Energy Butler (D), Magic (GR), the three functional parts of the SmartHouse/SmartGrid approach. A comparison of the simulation results for the two scenarios aims at showing the impact of the energy management on reaching the RE generation (and related GHG reduction) targets and at giving insight in other measurable objectives such as power quality. This scenario will be called SmartHouse/SmartGrid scenario (or referring to the 3 case studies PowerMatcher/BEMI/Magic scenario).
- The time horizon for the simulations will be 2030 (up to 2040 in the Dutch case) given by the base data available to this time horizon.

Specific Approaches for the three case studies include:

- Input data are specific fuel mix predictions of the PRIME (or more detailed) model for the Base Case for the regions covered
- In all cases, the customers are households. However, whereas for the Case Study B (D) these are mostly residential areas / clients, the clients in the Dutch Case Study A include SMEs. The Greek Case Study C includes electricity users (clients) to a larger fraction, also hotels and agricultural consumers (e.g. pumps used for irrigation).

4.2. Case Study A

According to the DoW, ECN in WP4 will focus on the following aspects:

- The impact of an aggregation of large numbers of active houses on energy efficiency enhancement
- The contribution of local power grids to efficient management (e.g. improve network load factors)
- Increased integration capacity of large amounts of renewable energy resources

The Case Study A will be based on the energy trends in the WLO scenario. This scenario focuses on the period between 2030 and 2040, and is based on mass integration of RE and DG. The case study performs simulation studies in two different scenarios:

- Business as Usual – also to be called fit-and-forget.
- Business as Usual plus the presence of new control strategies. The PowerMatcher technology will be the core of the active control.

Case study A will target the following SmartHouse/SmartGrid objectives:

D.2: Gains as a result of optimized energy management of devices and of specific energy technologies in use (e.g. heat waste reduction in commercial/home CHP units by better ICT-based control, CO_2 reduction potential).

- Show the energy efficiency increase due to lower peak power usage.
- Show the reduction in needed reserve power.

D.3: Reduction of power grid losses by increasing local sustainable demand and supply solutions.

- Reduction of grid losses: recent studies (e.g. from [IMPROGRE]) indicate the potential of active control to reduce grid losses, mainly by better matching of local supply and demand. Simulations with and without PowerMatcher control will be fed into steady state network simulations to quantify this reduction of grid losses.

D.4: Gains through raising the accommodation ceiling of local networks for integration of local generation.

Today's "fit and forget" connection policy for local environmentally friendly energy resources puts a ceiling to the share of local generation to be accommodated in local power grids. The technology lifts this ceiling to allow for a substantially larger share of DER/RES in distribution grids, reducing centralized fossil-fuelled power generation (>10%).

- Determine the accommodation ceiling: simulation with and without PowerMatcher.

The following data will be needed to achieve these objectives.

- Electricity demand
  - Demand patterns per household
  - Demand pattern per household appliance – only feasible for flexible appliances under PowerMatcher control
  - Penetrations of flexible appliances and installations
- Electricity supply:
  - Percentages of renewable energies: solar, wind
  - Energy mix, both renewable (solar, wind) and fossil (gas, oil, coal); also an indication should be available on the type of energy mix for peak power capacity and reserves.
  - Types (PV, wind, micro-CHP) and percentages of distributed generation (DG), proportion DG to local peak demand.
- Network Topology
  - Distribution cell topology

4.2.1. Definition of the Case Study for Optimized Energy Management

Optimized energy management should

- Show the energy efficiency increase due to lower peak power usage.
- Show the reduction in needed reserve power.

The PowerMatcher simulation tool will be used for simulation of clusters of electricity generating and consuming devices and installations, with large amounts of renewables of intermittent nature (wind, PV and large penetration of distributed generation (wind, PV micro-CHP). The simulations will focus on the Dutch situation and therefore the input data will be based on the Dutch WLO-SE model, augmented with data from the ITM studies [de Boer 2009; Bowman 2010]. The approach will be as:

- Device clusters will be configured based on the 2030 / 2040 WLO-SE model. The data requirements follow from the case study scenarios.
- A Business as Usual (BAU) scenario will be simulated based on non-controlled operation of the household appliances in the distribution cells.
- Based on the same patterns as the BAU case, the simulation will be repeated using the PowerMatcher technology as a control system for the flexible devices in the households. The PowerMatcher will enable an adaptation of distributed energy resources based on availability of intermittent renewable supply.

Previous small simulations have already shown a number of effects of the PowerMatcher control, e.g. in [Kok/Venekamp 2010]. First, the peak power usage is expected to decrease due to the effect of response of flexible consumption and generation to higher market prices. This removes the peak power plants from the market which are known to have the least energy efficiency. The savings on peak power capacity will be quantified by comparing BAU with PowerMatcher control.

A second effect of PowerMatcher control is that the clusters of devices within the distribution cells can be utilized as virtual power plants to reduce imbalance caused by deviations from their predictions of e.g. actual wind power. The savings on reserve capacity will be quantified by comparing BAU with PowerMatcher control.

Overview of Current Simulation Potential

The PowerMatcher software can be used in different settings: peak reduction, virtual power plant (VPP) control and islanding. Peak reduction aims at reducing peak power from the market, leading to a more flat load curve. VPP control aims at the value of energy at any moment in time, which for example may depend on the availability of wind. This may create demand peaks during periods of high wind power availability. Islanding focuses mainly on the match between local demand and supply. The PowerMatcher simulation software can be run in two different states: (i) a *base case* simulation in which all running device agents would model a devices' control independent from the current market price, i.e. using current non-controlled structure. (ii) A controlled case simulation in which the PowerMatcher technology is used. A comparison between the two cases reveals the potential of smart control.

The PowerMatcher is a multi-agent based system that uses electronic exchange markets to coordinate a cluster of devices to match its electricity supply and demand. A multi-agent system is a structured framework for implementing complex, distributed, scalable and open ICT systems in which multiple software agents are interacting in order to reach a system goal. Such a software agent is a self-contained software program that acts as representative of something or someone (in this case a device or an energy demand from the user). A single software agent carries out a specific task. For this task, it uses information from and performs actions in its local environment. It is able to communicate with other entities (agents, systems, humans) for its task. When designed well, the intelligence level of the over-all system is high, while the complexity of individual agents is low. The different PowerMatcher agents and their interactions are shown in Figure 7.

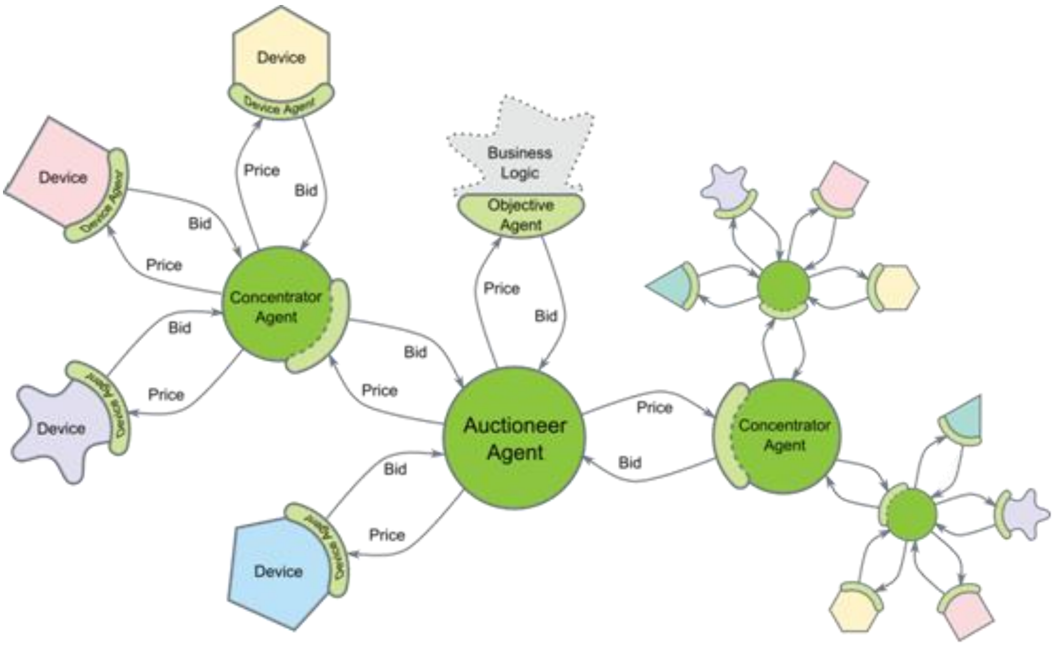

Figure 7: Schematic overview of the PowerMatcher concept

Every device in a cluster is represented by a *device agent*, a piece of software that looks after the interests of that device. Such agents attempt to operate the associated processes in an economically optimal way, whereby no central optimization algorithm is necessary.

Using an electronic market (the *auctioneer*) in the multi-agent system allows the agents to trade scarce resources that are necessary for the agent to carry out its task. The only information that is exchanged between the agents and the auctioneer are bids. These bids express to what degree an agent is willing to pay or be paid for a certain amount of electricity. Bids can thus be seen as the priority or willingness of a device to turn itself on or off. For example, a freezer that has almost warmed up is more eager to pay a higher price for its electricity than a freezer that is still cold. Device agents are assumed to be rational, i.e. its behavior follows the basic economical principles. This means that it will be less eager to buy and more eager to sell electricity when prices are higher. Therefore a bid function must always be continuously monotonically decreasing. Furthermore, although prices may only be used as a control signal and not for billing purposes, it is assumed that device agents always bid against their actual marginal costs.

Bids are sent at irregular (event-based) intervals, i.e. only when an agent's bid has changed. This keeps the communication between PowerMatcher entities to a minimum. The auctioneer collects the bids and calculates the market clearing price. This is the price at which the sum of all bids is zero, such that there is no net consumption or production. The market clearing price is communicated back to the device agents, which react appropriately by either starting to produce or consume electricity, or wait until the market price or device priority (state) changes. The auctioneer is always a passive entity, thus it only acts if it receives new bids that results in a change in price. Actions are triggered at the lowest level, i.e. the device agents, in the PowerMatcher network hierarchy, therefore creating a bottom-up approach.

Simulation Requirements

In order to set up this case study, the households in the distribution cell have to be configured. Since the focus is on controllable / flexible devices, discrimination will be made between typical household demand from non-controllable appliances (lighting, multi-media, and similar appliances) and controllable devices. The latter will at least consist of space and tap water heating devices, i.e. heat pumps and micro-CHPs. The houses will be provided with photovoltaic and some regional wind power.

In order to scale up the simulation to larger amounts of households, a clustering approach will be followed, in which only part of the households will be modeled on an individual base: a distribution cell with individual households will be simulated. Other distribution cells will be simulated by a single agent representing the behavior of the total number of households in this distribution cell. The total simulation thus will include the flexibility that households can offer, yet the total number of agents in the simulation will remain manageable.

The total electricity supply mix will be determined from the WLO-SE model, containing a large share of intermittent wind power. This allows for adapting the demand based on the variability of solar and wind power and providing quantification of the two D.2 objectives:

- Show the energy efficiency increase due to lower peak power usage.
- Show the reduction in needed reserve power.

4.2.2. Definition for the Case Study for Reduction of Power Grid Losses

Recent studies, e.g. [IMPROGRES] indicate the potential of active control to reduce grid losses, mainly by better matching of local supply and demand. Simulations with and without PowerMatcher control will be fed into steady state network simulations to quantify this reduction of grid losses.

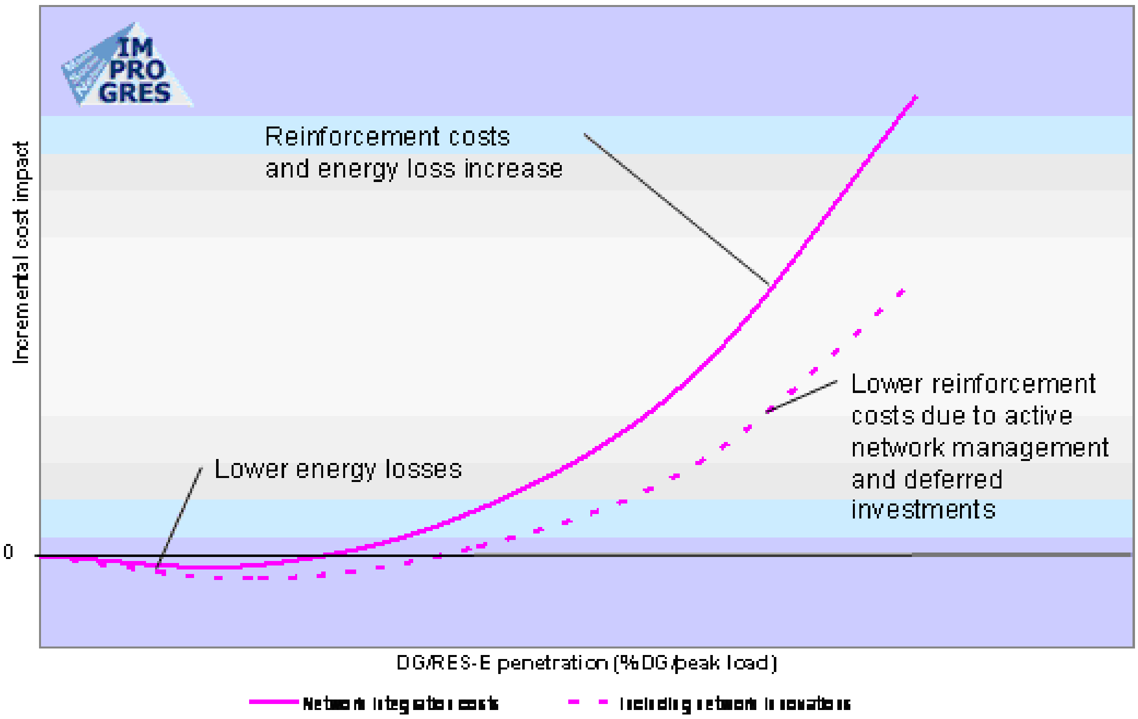

Figure 8: Grid losses related to the penetration of distributed generation[5]

The grid losses will be quantified by interfacing the PowerMatcher simulations with a network simulation model. The following paragraph describes the approach.

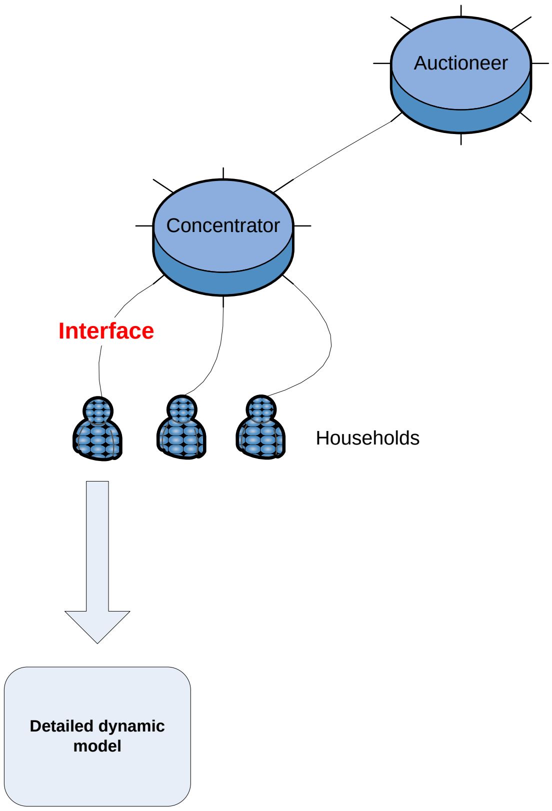

Figure 9: Overview PowerMatcher diagram and detailed model

[5] IMPROGRES

Objective

The focus will be on a steady-state *(ss)* simulation. The model should include an LV distribution system of a typical street with a number of households. The main purpose of this model is to investigate the following:

- Quantify the potential reduction in line losses when the PowerMatcher technology is employed in a LV cell with a large share of distributed generation.

Modeling Approach

The modeling environment in *Matlab/Simulink* has been selected for the LV distribution system. If required, the *SimPowerSystems* toolbox of *Simulink* will be used as well. The following steps should be taken:

- Define a typical LV network including the required system parameters
- Define the interface with the PowerMatcher (PM) model; e.g. data type, data format and time-steps
- Develop a model which enables us to address the objectives of this work, meaning the ability to quantify the potential reduction in line losses

Ideally, the model should have the following characteristics:

- A low order model but still accurate enough to meet the objectives of this work in a reasonable amount of time
- The model should be easily scalable

The proposed approach is a causal model which means that the PM model and the LV network model do not have to run in parallel. In this case, the PM model produces an output file which will be used as an input file for the LV network model.

Description of the Network Model

Although the exact architecture still has to be defined, the LV distribution network in principle consists of a number of households, half of them being equipped with heat pumps, the other half equipped with micro-CHP devices. The network under consideration will be everything downstream from the secondary side of the transformer. Experiments will also be conducted with a diesel generator and a wind turbine connected to the primary side of the transformer. Another experiment will consider a number of smaller (local) wind turbines rather than one larger central wind turbine.

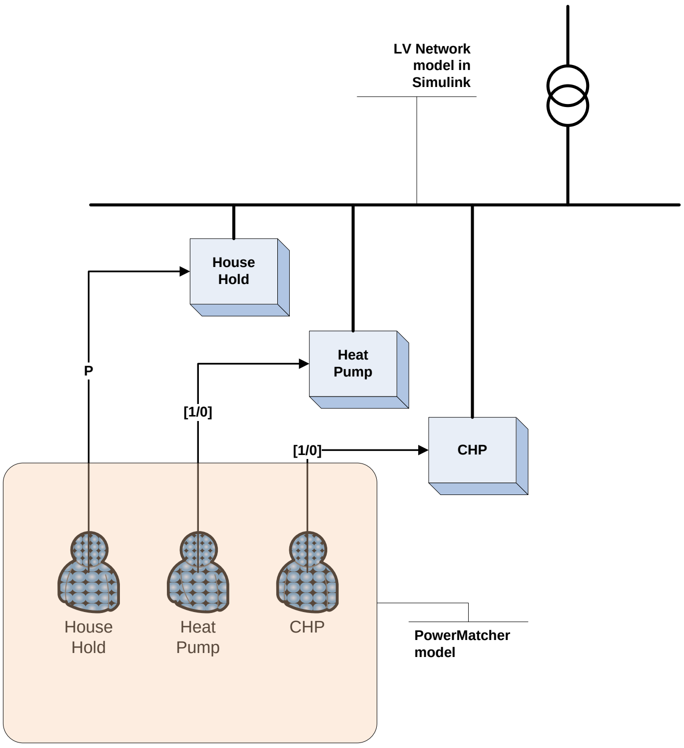

Figure 10: Description of network model

Interface between PowerMatcher and Network Model

The interface between the PM and LV network model works as follows. By running the PM simulation, the agents create data output files. These data files contain different variables such as timestamp, power [P] and a power production/consumption which can be converted into a discrete or to a binary signal (switching on/off [1/0]). Three types of agents are considered: HouseHold (HH) agents, Heat Pump (HP) agents and Combined Heat and Power (CHP) agents. The HH and HP absorb electrical power, whereas the CHP produces power and absorbs a small amount of power at the beginning of its cycle.

Description of Experiments

A precise description of the tests/experiments has to be defined upfront in order for the models to be utilized in a cost and time effective manner.

The steps taken can broadly be defined as follows:

- Use two HH and HP models; use the output data files of these agents as an input file for a HH and HP Simulink model; observe the effect on the electrical network
- Expand the model to a larger number of HH models, with partly HP and partly CHP
- Include wind turbine (both central and distributed) and diesel genset model

Figure 11 shows a screenshot of the network model with two house models. The house models contain one HH and one HP model each.

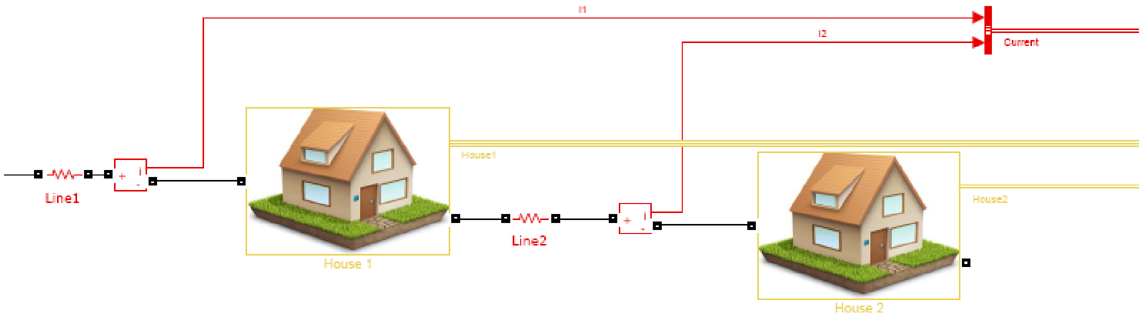

Figure 11: Simulink network model

Grid losses *P* (power) are a function of the current *I* and the resistance *R*. This can be expressed in the following relationship: $P = I^2R$. By producing electricity locally, the transmission losses emerging from a production in large power plants can be avoided. In that case, less current has to be transported over the transmission lines. According to the above described equation, this means less power loss. However, if the amount of locally produced electricity becomes too large, and it has to be exported from the LV cell to be used elsewhere, grid losses will be higher than transmission losses of electricity from large power plants. PowerMatcher control can increase the percentage of locally consumed electricity (the simultaneity factor) in such cases. The simulations focus on this effect.

4.2.3. Summary of Available Data for WLO-SE

Several models may be used to create scenarios for the expected energy mix in 2040/2050. One of these models is the PRIMES model described in chapter 2.1. However, ECN uses several models and case studies that include or emphasis the Dutch situation. The WLO-SE model described in chapter 2.3 gives representative data for The Netherlands in a strong Europe with emphasis on international cooperation and public responsibilities. The ITM [de Boer 2009] study augments this with data on penetration of flexible appliances. Table 17 gives an overview of the main characteristics of the WLO scenarios for energy.

	Global economy	**Strong Europe**	**Transatlantic market**	**Regional communities**
Inhabitants 2040 in million	19,7	18,9	17,1	15,7
Gross domestic product 2040 in % (2001 = 100%)	221	156	195	133
Capacity nuclear energy	0	0	6,000	0
Share of renewables	1	34	2	24
Development in 2040 in % with respect to 2002				
Energy demand	+55	+10	+40	-5
Energy usage/head	+30	-5	+35	-5
Usage of coal	+195	+40	+155	+35
Usage of oil	+90	+35	+65	+10
Use of natural gas	+5	-25	-25	-35
Natural gas depletion	-95	-85	-85	-57
CO_2-emissions	+65	-20	+30	-10

Table 17: Main characteristics of the WLO scenarios for energy for NL[6]

[6] Farla 2006

Data [TWh]	2002	Share in 2002	2020	Share 2020	2030	2040	Share 2040
Production							
• Coal	25	23%	18	13%	No data	39	34%
• Gas	34	31%	50	36%		34	31%
• Nuclear	4	4%	4	3%		0	0%
• Renewable	4	4%	23	16%		56	34%
• Decentralized	26	24%	38	27%		44	27%
Net import	17		4			-9	
Final demand	108		138			162	

Table 18: Electricity production for the WLO-SE scenario for NL[7]

Data [TWh]	2000	2020	2030	2040
Central	9	13		10
Joint-ventures	13	26		33
Industry	7	5		5
Refineries	3	1		1
Agriculture	3	3		2
Others	2	3		2
Total production	37	50		52

Table 19: Electricity production from CHP for the WLO-SE scenario for NL[8]

(domestic micro-CHP not included)

Data [TWh]	2000	2020	2030	2040
Wind				
• Onshore	0.9	4.2		4.4
• Offshore	0.0	10.5		35.2
Biomass				
• Cogeneration	1.1	4.6		9.7
• Waste	0.9	1.4		1.4
• Others	0.5	2.3		2.6
Photovoltaic	0.0	0.2		2.4
Hydro	0.1	0.1		0.1
Total production	3.6	23.2		55.8
Total demand	108.0	138.0		162.0
Percentage renewable	3%	17%		34%

Table 20: Electricity production from renewables for the WLO-SE scenario for NL[9]

[7] Farla 2006
[8] WLO-Energy
[9] Farla 2006

Data [MW]	2010	2020	2025	2030	2035	2040
Wind onshore	1,269	1,901	2,000	2,000	2,000	2,000
Wind offshore	1,700	3,000	4,500	5,300	7,800	10,000

Table 21: Installed capacity wind energy in the Strong Europe (SE) scenario for NL[10]

Data [MW]	2010	2020	2025	2030	2035	2040
Wind onshore	1,269	3,013	3,463	4,013		
Wind offshore	700	3,532	6,023	9,000		

Table 22: Installed capacity wind energy in the SE-Green4Sure (SE-G4S) scenario for NL[11]

Data	2010	2020	2025	2030	2035	2040
Number of heat pumps installed		900,000				1,500,000
• WLO		150,000		200,000		240,000
• Objective		440,000		640,000		700,000
• All-heat pump		900,000		1,250,000		1,400,000

Table 23: Scenarios for heat pump development in the Netherlands[12]

Data	2010	2020	2025	2030	2035	2040
Number of heat pumps installed		900,000				1,500,000
Installed capacity (GW)		2.7				4.5
Annual demand (GWh)		3,200				5,300

Table 24: Heat pump development in the Netherlands[13]

(all heat pumps)

Data	2010	2020	2025	2030	2035	2040
Number of plug-in vehicles installed		900,000				6,500,000
Charging capacity (GW)		2.7				6.5
Annual demand (GWh)		2,600				19,000

Table 25: Plug-in vehicle development in the Netherlands[14]

[10] ITM 2008
[11] ITM 2008
[12] ITM 2008
[13] ITM 2008
[14] ITM 2008

Data	2010	2020	2025	2030	2035	2040
Total electricity demand (GWh)		137,000				161,000
Electricity demand heat pumps + EV (GW)		5,800				24,300
HP and EV percentage		4.2				15.1

Table 26: Share of heat pump and plug-in vehicle electricity demand as % of the final electricity demand in the SE scenario for NL[15]

4.3. Case Study B

4.3.1. Addressed Aspects

Case study B, similar to the other case studies, considers a high amount of end-users for developing a scenario and proper data basis within WP4.1. This scenario will subsequently be broken down to a smaller number of customers to be simulated in WP4.2. Hence, the WPs are strongly linked. Therefore this document contains part of the data to be used in the simulation setup. Also, the term Case Study B refers to both, the end-user scenario presented herein and the simulation case studies.

The following aspects are considered within Case Study B:

1. **Aggregated reactions to variable electricity prices due to load shifting** by customers and by automated devices. This aspect is also tested in real environment in Field Trial B.
2. **Technical constraints of electric networks** (line loads, possible voltage violations). Special attention will be given to situations where technical constraints may hinder market participation of smart houses, e.g. the need for derating of local decentralized generators.
3. **New aspects for grid planning and design** and impact of smart house operation thereupon.
4. **Optimization of grid operation**, e.g. minimizing grid losses.
5. **Provision of ancillary services by smart houses**, e.g. local voltage control.

The investigation of how smart house operation influences these aspects can be considered the goal of the simulations done in WP 4.2. The simulations will focus on the BEMI approach given in more detail in D2.2, chapters 2.2 and 3.3. The aspects highlighted in the list above need to be mapped onto existing IWES simulation software which will be further developed to support the simulations. However, there is no need for major software changes since the software is an appropriate basis for contributing to the named aspects.

The research aspects already define the need for a corresponding data basis. For example, grid topology data are needed for investigating grid operation aspects. The review of available sources for this database is described in section 4.3.2. The definition of the Case Study B is summarized in section 4.3.3. Sections 4.3.4 and 4.3.5 describe the simulation scope. Section 4.3.6 describes which additional data are used for completing simulation data requirements. The expected contribution to the SmartHouse/SmartGrid measurable objectives is summarized in section 4.3.7.

4.3.2. Data Basis for Case Study B – Source Review

Principally, the scenarios for Case Study B contain a Business as Usual (BAU) part and a SmartHouse/SmartGrid part. According to the definition in section 4.1, both scenarios will be defined in such a way to reach ambitious goals for energy efficiency increase. Since Case Study B refers to the German situation, it will focus on national energy allocation plans that map international policy goals.

[15] ITM 2008

The PRIMES study summarized in Section 2.1 (data input from PRIMES in Section 3) gives, as already mentioned there, a least cost projection of future energy system developments without taking into consideration environmental costs and impacts. Data for Germany are especially given in Tables 2, 5, 7 and 8 of this document. However, PRIMES does not specifically aim at describing a scenario for reaching the most ambitious goals for energy efficiency increase. Therefore additional sources were reviewed as described in the following subsection.

Electric Energy Consumption and Generation Mix

Germany has undertaken substantial political activities to increase the share of renewable and decentralized generation resources to reach the EU 2020 goals. National energy allocation plans also cover the time period between 2020 and 2050. One of the latest planning milestones is the "Integriertes Energie- und Klimaprogramm" (Integrated energy and climate package, IEKP) announced by the German Government in 2007. It aims at a reduction of the overall CO_2 emissions by 20% until the year 2020 as compared to the situation in 1990. These emissions not only derive from electricity related applications, but also include e.g. heat energy as well as energy use in the industrial and mobility sector. [BMU 2007; BMWi 2007]. Given the total CO_2 emissions of 1,033 million t in 1990, this means needed savings of about 207 million tons. Given CO_2 emissions of 1,007 million tons in 2006 [BMU 2007], only 26 million tons were saved during the first 16 years of the period 1990-2020. This leaves well over 85% of the needed savings to be done in the remaining 14 years. This gives a clear indication on how ambitious this goal is. Reaching it only seems feasible by combining savings from different sectors [UBA 2009] and by a quick application of the most appropriate measures. The IEKP proposes 29 measures which are further detailed by the Meseberg Conclusions from autumn 2007 [UBA 2007].

Measures related to the SmartHouse/SmartGrid context and potentially relevant to Case Study B are [BMU 2007, Table 1] are the following:

- Increase of the share of renewables in the electricity sector, improve grid integration of renewables
- Intelligent measurement technology for electricity consumption
- Introduction of modern energy management systems
- Introduction of energy efficient products, law for energy saving
- Electric mobility
- Law for combined heat and power plants (cogeneration)
- Replacement of electric storage heating by more energy efficient heating technologies

In October 2008, the German Federal Ministry for Environment, Nature Conservation and Reactor Safety (BMU) published a study named "Leitstudie 2008" [Nitsch 2008] that describes a scenario which not only allows reaching the CO_2 emissions goals set for 2020, but even allows a reduction of CO_2 by 80% until 2050 as compared to 1990. [Nitsch 2008, Table 2] provides figures for the German electric energy generation from renewable sources. These figures were used to modify Table 5 in this document to give corresponding figures for the Case Study B scenarios. The result is shown in Table 27.

A comparison with the figures from the PRIMES study (Table 5) shows that [Nitsch 2008] assumes a lower total in generated energy. The reason for this is that PRIMES also includes generation from outside Germany and that [Nitsch 2008] predicts a lower electric energy demand than the PRIMES study due to enhanced energy efficiency measures. Furthermore, [Nitsch 2008] predicts roughly 60% higher energy generation from renewables than PRIMES, the main part of this being attributed to wind energy and smaller parts to PV and geothermal energies.

Unfortunately, [Nitsch 2008] does not include figures for the installed generation capacity of distributed and renewable resources. However, it can be assumed that the full-load hours of each generation technology match those known today, which seems feasible since the technologies are quite mature. The only exception to this is geothermal power, which – as can be seen comparing the Table 27 and Table 28 – [Nitsch 2008] predicts to generate roughly 100 times as much energy in 2020 than today. This obviously is due to the fact that this technology is still in an early stage of development in Germany. By using the figures for installed capacity and energy generated from the different technologies as given in [BMU 2009], average full load hours can be calculated as given in Table 28. Given the named assumption, this results in figures for the installed power in [Nitsch 2008] as summarized in Table 29.

	2020	2030	2040	2050
Total electric end energy [GWh]	497,500	468,611	450,556	440,556
Total electric energy consumption [TWh]	586	562	565	583
Total generated electric energy from renewables [GWh], including imports	173,333	252,500	331,667	387,889
Share of generated energy from renewables	35%	54%	74%	86%
Wind energy generation [GWh]	87,200	142,200	186,700	209,300
PV generation [GWh]	15,500	21,900	25,300	27,700
Electricity generation from biomass [GWh]	46,200	51,400	53,800	53,800
Geothermal electricity generation [GWh]	1,800	6,000	14,700	35,700
Hydropower [GWh]	24,300	24,600	24,800	24,800
EU-Imports and others	3,000	35,800	82,000	121,000
Cogeneration coal, gas	70,000	88,000	80,000	90,000
Nuclear	35,000	0	0	0
Other fossils	300,000	190,000	90,000	18,000

Table 27: Electricity generation per year in Germany 2020-2050[16]

Technology	Installed capacity [MW]	Electric energy generated [GWh]	Full-load hours
Wind energy	25,777	37,809	1,467
PV generation	9,800	6,200	633
Electricity generation from biomass	4,509	25,515	5,659
Geothermal electricity generation	6.6	18.6	2,818
Hydro power	4,760	19,000	3,992

Table 28: Average full-load hours[17]

	2020	2030	2040	2050
Wind energy [MW]	59,441	96,933	127,267	142,672
PV [MW]	24,487	34,597	39,968	43,760
Biomass [MW]	8,164	9,083	9,507	9,507
Geothermal* [MW]	639	2,129	5,216	12,669
Hydro power [MW]	6,087	6,162	8,801	8,801

* Figures considered likely to be too high because of unknown technology evolvement

Table 29: Estimated installed capacity of renewables[18]

[16] According to Nitsch 2008
[17] Calculated on the basis of BMU 2009

Data on Usage of Electricity in Households

Since Case Study B focuses on end users in private homes as typical smart house customers, Table 9 also gives relevant data about the electric energy consumption for different household applications. However, there are also other data available that were already used in previous IWES simulations. These data are summarized in Table 30.

<table>
<tr><th></th><th colspan="5">Source</th></tr>
<tr><th>Application</th><th>PRIMES Table 9</th><th>Stadler</th><th>Stromprinz</th><th>BDEW</th><th>Nipkow et al.</th></tr>
<tr><td>Fridges</td><td rowspan="2">16%[19]</td><td>10%</td><td rowspan="2">19%</td><td rowspan="2">29%</td><td>13%</td></tr>
<tr><td>Freezers</td><td>9%</td><td>6%</td></tr>
<tr><td>Washing machines</td><td rowspan="3">17%</td><td>4%</td><td>6%</td><td rowspan="3">17%</td><td>7%</td></tr>
<tr><td>Water heating</td><td>11%</td><td>12%</td><td></td></tr>
<tr><td>Dish cleaners</td><td>4%</td><td>6%</td><td>6%</td></tr>
<tr><td>Tumble dryers</td><td>9%</td><td>3%</td><td>8%</td><td rowspan="2">19%</td><td>10%</td></tr>
<tr><td>Electric oven, cooking, baking</td><td>10%</td><td>11%</td><td>10%</td><td>9%</td></tr>
<tr><td>Lighting appliances</td><td>8%</td><td>11%</td><td>10%</td><td>8%</td><td>14%</td></tr>
<tr><td>Heating system pumps</td><td></td><td></td><td>4%</td><td></td><td></td></tr>
<tr><td>TV sets, HiFi</td><td></td><td>7%</td><td>7%</td><td rowspan="2">12%</td><td>7%</td></tr>
<tr><td>PC and ICT</td><td>11%</td><td></td><td>8%</td><td>4%</td></tr>
<tr><td>Electric (storage) heating</td><td rowspan="2">13%</td><td>14%</td><td></td><td rowspan="2">15%</td><td></td></tr>
<tr><td>Direct electric heating</td><td>3%</td><td></td><td></td></tr>
<tr><td>Others</td><td>13%</td><td>13%</td><td>10%</td><td></td><td>24%</td></tr>
<tr><td>Sum of controllable applications (total)</td><td>55%</td><td>58%</td><td>55%</td><td>61%</td><td>42%</td></tr>
<tr><td>Sum of controllable applications (user-independent)</td><td>29%</td><td>36%</td><td>23%</td><td>44%</td><td>19%</td></tr>
</table>

Table 30: Electricity use in households per application

It can be observed that the studies give different figures even for considering similar applications. This can be attributed to the fact that different customer groups were used for obtaining the data. This is also the reason why some studies seem to disregard certain electric appliances. However, the data still give an indication on the range of electric energy consumption for each application. The sum of applications that can be considered controllable by an automatic energy management system in total is given by the last but one table row, whereas the last row gives the sum that can be considered controllable without the user noticing or interacting.

For the daily total load profile of a customer group, Case Study B will assume that there will be no difference to today's load profiles as given in Figure 5 for the BAU scenario as long as no new electric appliances with different times of use are considered (e.g. electric cars or heat pumps). For the SmartHouse/SmartGrid scenario however, load profiles will considered to be influenced by the smart house behavior.

[18] Nitsch 2008

[19] Note that some of the sources give only percentages for a combination of different applications. This is indicated in the table by combined lines.

Finally, electric energy cost projections and CO_2 emission figures to be used are given in Table 14, Table 15 and Table 16.

4.3.3. Case study B – Scenario for 1 Million End-Users

First of all, the "scenario" to be described here should already contain the most important data needed for the simulation study to be done in SmartHouse/SmartGrid project progress. Furthermore, the term "end users" can apply to all sorts of electricity end users. However, since the SmartHouse/SmartGrid research scope is strongly focusing on private homes, Case Study B will also focus on private homes or households as end users. Thus, the term "scenario" for Case Study B is defined to contain the following:

- Time (projection period) to be considered
- Type of area, especially considering characteristics of the electric network, there focusing on middle- and low-voltage grids
- Installed power of different types of DG and renewables when considering a grid area with 1 million end user connection points
- Generated electricity from different types of DG and renewables
- End-user electricity consumption attributed to applications
- Electric load curve of end users
- Estimation of fraction of DG / renewables situated in residential buildings / smart houses
- Average power of single DG units
- Generated electricity from fossil sources
- Primary energy cost, CO_2 emissions, average efficiency of generation using fossil sources

All data are needed for BAU as well as SmartHouse/SmartGrid scenario. Most of the data can be obtained from the sources already described in this document. The following subsections will present selections of this data that make up the BAU and SmartHouse/SmartGrid scenarios for Case Study B.

Timeframe to be Considered

The PRIMES data as well as the data from [Nitsch 2008] are both available for the year 2030. Therefore, this year is selected for the Case Study B scenarios time period.

Type of Area and Electric Network

Germany's land area is 357,111 km². According to the German Federal Statistical Office (DESTATIS), in 2009 there were roughly 40.2 million households with 82 million inhabitants. Therefore, an average number of 1 million private households – or, respectively, 2.04 million inhabitants – would be expected on an area of 8,883 km². This of course does only apply to areas with average population density. When, for example, considering the area around the city Mannheim, where Field Trial B takes place, we find roughly 2,098 million inhabitants on 3,591 km². This area is highlighted in Figure 12. It contains nine German administrative districts and represents 1% of whole Germany.

The electric distribution network in Germany is operated by roughly 900 DSOs throughout the country, which are all unbundled, independent corporations. Thus, it is not possible to get detailed specific data about the electric network specifications within the whole area of consideration. Therefore, network topology data of a part of Mannheim will be used in the simulations. Given the basic knowledge about network layout in Germany, this topology is to be considered as quite a strong and highly interconnected grid.

The type of area will be the same for BAU and SmartHouse/SmartGrid cases. However, the simulations will allow for modifications to the electric grid's topology, since these modifications are part of grid operation and planning, which is again to be considered as research aspect.

More precisely, network changes for supporting the high ratio of DG indicated by the BAU scenario will, if necessary, be allowed. It has been found that distribution grid operators are highly interested in the question whether network deconstruction will be possible - or at least less reinforcement needed - due to rising DG in-feed when implementing smart grid technologies. The SmartHouse/SmartGrid scenario will be give special consideration to this question.

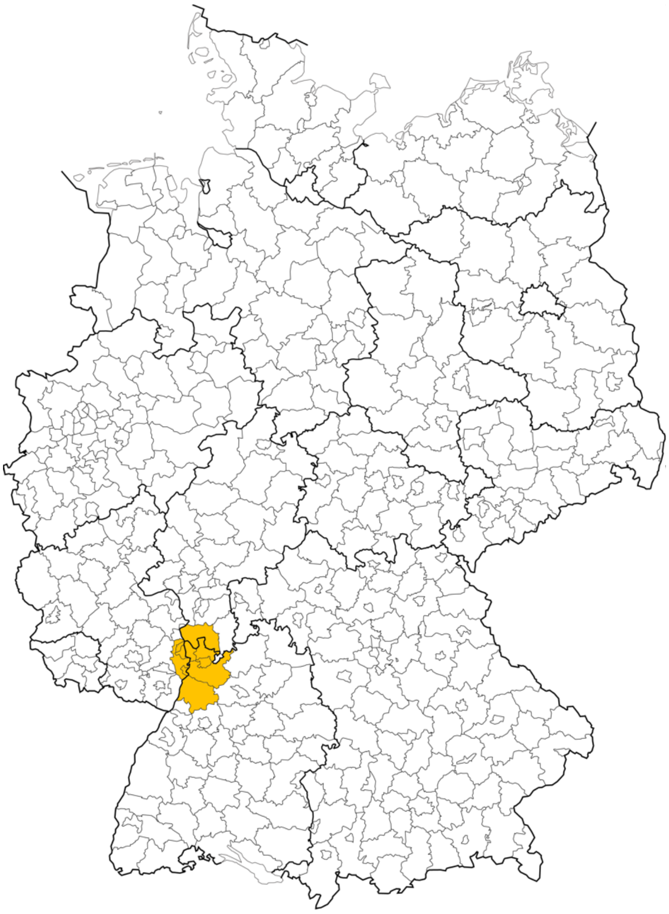

Figure 12: Area around Mannheim resembling Case Study B scenario[20]

DG and renewables installed power

For a simple estimate of the installed power and energy generated from DG, it seems appropriate to use a fraction of the figures predicted by PRIMES and [Nitsch 2008]. However, the question is whether it can be assumed that the potential of renewables in the area considered is unlimited by local restrictions.

Considering the area indicated above, this seems feasible because it is large enough to support any kind of DG. Wind power plants could be installed in the hill regions Odenwald or Pfälzer Wald, which are located in the north and west of the considered area. The river Rhine and smaller contributors give possible locations for hydropower installations. Even a geothermal plant with 3 MW_e installed power is currently under installation in the city of Landau, which lies in a district to the south west of the considered area. Hence, such plants could potentially be installed within the area itself when the technology becomes more mature. Therefore, there is no need to assume that there are special restrictions which hinder installation of decentralized generation in the considered area. Hence, data for generated energy is taken from [Nitsch 2008].

However, a major part of the installed power predicted by the studies is attributed to offshore power plants. For the year 2030, [Nitsch 2008] predicts that 41% of energy generated by wind power plants is attributed to

[20] Source of map : Wikimedia Commons, http://upload.wikimedia.org/wikipedia/commons/f/f1/Landkreise%2C_Kreise_und_kreisfreie_St%C3%A4dte_in_Deutschland_2007-07-01_-_2008-07-31.png

onshore installations. If we assume that the full-load hours of the onshore installations match today's average of about 1500 h/a and estimate the full-load hours of the offshore installations to be 3500 h/a, 38.9 GW of onshore and 24 GW of offshore installed power can be expected.

Using the resulting ratio and combining data from Table 27 and Table 29, figures representing the expected installed power and generation capacity of decentralized generators within the chosen area can easily be calculated for BAU and SmartHouse/SmartGrid case. If it is furthermore assumed that 75% of the installed PV power is placed at individual private end user connection points and considering that the chosen area contains 1 million of such connection points, a differentiation between PV installed within and outside of private homes can be made. The results are summarized in Table 31 and are to be used for both BAU and SmartHouse/SmartGrid scenarios.

	Installed capacity [MW]	Generated energy [GWh/a]
Wind energy onshore	389	584
PV within smart homes	646	219
PV outside smart homes	86.5	29
Biomass	91	514
Geothermal	21	60
Hydro power	62	246
Cogeneration coal, gas	362*	880
Other fossils	-	1900

* According to PRIMES

Table 31: Installed power and generated capacity of predicted generation mix for 2030 alluded to 1% of German land area resp. 1 million connection points

However, these figures can only be interpreted as expectancy values for the considered region, since real installation of decentralized generators will always depend on local circumstances.

Load and Load Curve of End-Customers

As already mentioned, today's load profiles will also be assumed to be valid for the scenario customers. For the total electric energy consumption, PRIMES suggests 620 TWh/a for 2030, while [Nitsch 2008] suggests 565 TWh/a. However, only part of this consumption is attributed to households. PRIMES predicts this part to be 28% of the total consumption, which results in 174 TWh resp. 158 TWh. This again suggests an average yearly energy consumption of 4328 kWh resp. 3935 kWh per end user household. This gives an interval for the average that is finally needed as a direct input for the simulation.

Table 27 gives various figures for the attribution to applications. For Case Study B, it seems unlikely that there is still substantial amount of electricity used for direct or storage heating even for the BAU case. If the percentages for these applications are removed from Table 27 and the remaining figures are averaged, we obtain new percentages as presented in Table 32. These will be considered typical for a Case Study B household.

Type of Appliance	Share of house-hold consumption
Fridges, freezers	22%
Washing machines, dish cleaners	14%
Tumble dryers	10%
Electric oven / cooking, baking	11%
Lighting appliances	11%
TV sets, HiFi	9%
PC and ICT	8%
Others	15%
Sum of controllable applications (total)	46%
Sum of controllable applications (user-independent)	22%

Table 32: Electric consumption of households attributed to applications

4.3.4. Simulation Study I: Low-Voltage Grid

Using this data basis, different simulation studies are planned. The description of these studies given in this and the following section is detailed as far as possible. Further detailing will be done as soon as first results of the BAU simulations are available and will be included in D4.2.

For the SmartHouse/SmartGrid simulations, an existing simulation tool developed by IWES will be used. Modifications and extensions will be made to that tool if needed. The tool allows for simulation of generators, household consumers, BEMIs and the electric network.

Due to performance issues, the tool can only simulate 100-300 electric network nodes. If one node is associated with one single end user connection point, the maximal number of end users to be simulated is thus restricted. However, if a network node is defined to resemble a higher number of end user connection points, the network can be scaled, but the detail depth of the simulation regarding power grid characteristics (power flows, voltages) gets lower. The scenarios defined in 4.3.3 therefore have to be broken down to the simulation capabilities.

In simulation study 1, each network node will resemble a single end user. A low-voltage grid containing approximately 100-300 BEMI-equipped households shall be modeled which are equipped with photovoltaic decentralized generators (DG). DG situated outside households can possibly be included as well. The scenario will focus on line loads and voltages along low voltage lines on high feed-in of photovoltaic generators (PV). The model for PV power fed into the grid will preferably use actual measurements, e.g. for solar irradiation. This data is expected to be available, but has yet to be prepared. The simulation of the SmartHouse/SmartGrid scenario will aim at lowering voltage and line load levels by load switch–on using variable tariffs. The electric network used for this simulation will be considered to be deconstructed when compared to today's situation in order to tackle the question to which extent Smart Houses can be beneficial to network stability in a deconstructed grid.

A temporal resolution of 60 sec and a simulation time scope of 1-7 days is considered sufficient for this scenario since the effects to be considered will appear within this timeframe.

4.3.5. Simulation Study II: Middle-Voltage Grid

In this study, each network node will represent approx. 100-300 end user connection points. The simulation will focus on line load and grid loss issues in middle voltage grid. The number of households involved will be multiplied approx. by the factor 100-300 compared to scenario 1. The simulation system used already allows for parallel simulations using PC clusters. The BEMI/household simulation should nevertheless be able to simulate each single household individually without too much performance problems, so it is expected that the whole simulation can still run on one or two standard PCs.

Unlike simulation study I, this study will also include wind and hydro power feed-in. The wind power generation fed into the grid will be modeled with preferred use of actual measured wind data. As with the PV irradiation data, this data is expected to be available[21] but has yet to be prepared.

A temporal resolution of 60 sec and a simulation time scope of 1-7 days is considered sufficient for this scenario since the effects to be considered will appear within this timeframe.

4.3.6. Additional Data Used for Simulation Studies

For the simulated electric network to resemble a situation close to reality, grid topology and connection point data from a real grid area in Mannheim will be used.

In the Mannheim grid there can be identified "low voltage grid cells" which are basically low voltage grid areas connected to the MV grid over one or more transformers (typically three) and can be connected with other LV grid cells. This causes three typical types of LV/MV grids:

Study 1: Not Meshed Island Grid Cells

Here, single LV grid cells are not connected to other LV grid cells but only to the MV grid. See Figure 13 for the structure considering multiple cells and a single cell structure.

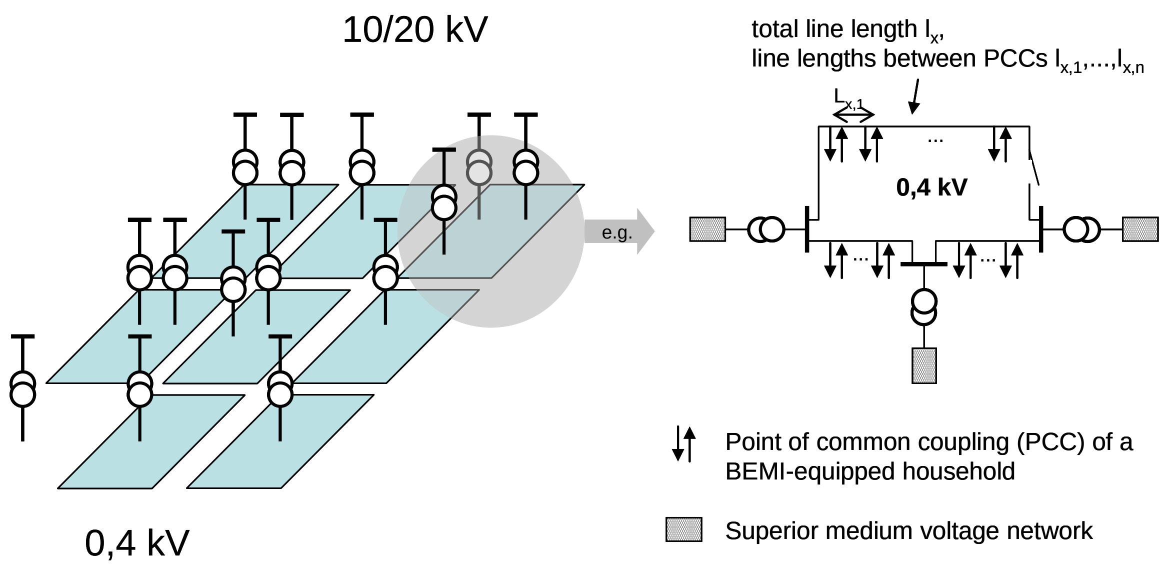

Figure 13: Not meshed island grid cells

Study 2: Longitudinally Connected Grid Cells

Here, each LV grid cell has connections to typically two neighboring cells. Therefore, the grid cells get concatenated. See Figure 14 below for the structure considering multiple cells and a single cell structure.

[21] The reason for this is that this kind of data is also used for tariff generation in Field Trial B.

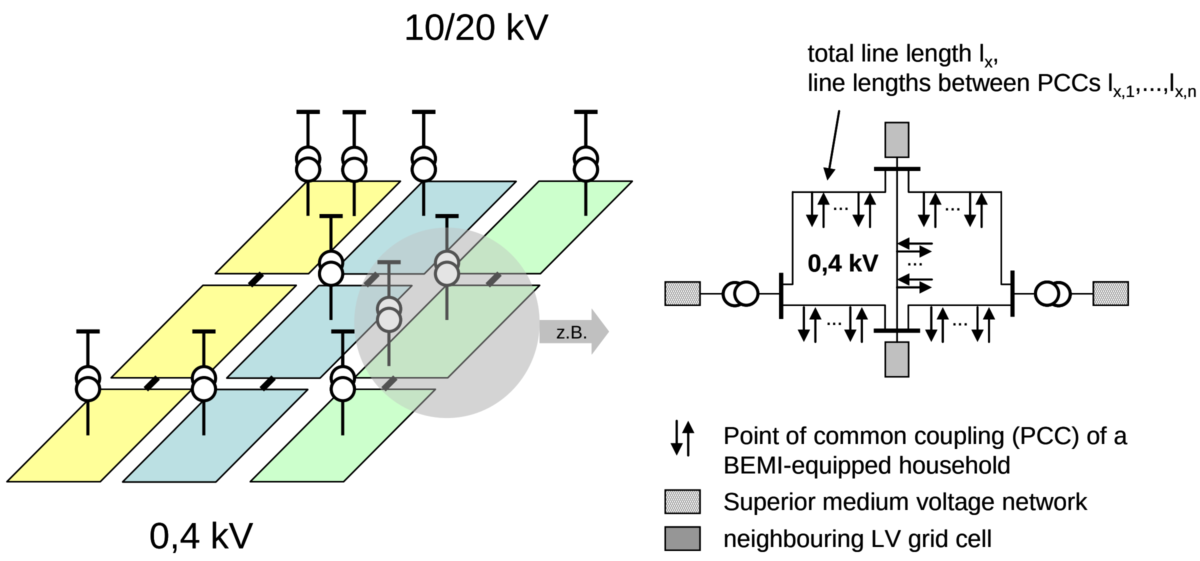

Figure 14: Longitudinally connected grid cells

Study 3: Cross Connected Grid Cells

This type of grid cell is connected in any other form with other grid cells, such that the cells form a ring or meshed structure which typically gives quite a strong network. MVV tends to deconstruct those grids because of high short-cut currents and difficult fault detection in case of a faulty transformer. Case Study B therefore disregards this grid cell connection type.

The network data obtained from MVV represent a part of Mannheim-Wallstadt which is a type 2 grid. This grid will be allowed to be modified to resemble a deconstructed version. In simulation study II, the grid cell will be simplified and duplicated with slight modifications to form similar grid cells. These will be connected by a middle-voltage (MV) grid with similar topology to existing MV networks in Mannheim.

The used data for the network contains the following:

- Position of busbars for LV grid node points
- Busbar interconnections:
    - Line lengths
    - Used cable type for each interconnection
- Number of connection points along each interconnection line.
    - Number, connection points and ratings of transformers connecting the cell to the MV grid
- Type, connection point and standard operating mode of other network components (e.g. switches)
- Energy consumption and type of connected end users

4.3.7. Case Study B Contribution to SmartHouse/SmartGrid Measurable Objectives

As already mentioned in SmartHouse/SmartGrid Deliverables D1.1, Section 3 and D3.2, Section 3, the simulations carried out in WP 4 are expected to contribute to specific SmartHouse/SmartGrid measurable objectives. Due to the scope of Case Study B, simulations carried out here can only contribute to a sub-part of these measurable objectives:

D.2: Gains as a result of optimized energy management of devices

- It is already stated in D1.1 that these gains are to be expected from Smart Houses using generation from distributed and high-efficient generators immediately and directly in the neighborhood of that generation. For the BEMI approach, smart house behavior of loads is indirectly controlled by the day-ahead consumption tariff. In order to estimate possible energy efficiency gains, the modeled smart houses will be operated with a standard constant tariff for the reference (BAU) scenario and with a variable tariff[22] that incentivizes load switch-on during increased feed-in of high-efficiency generators, e.g. PV and Wind generation (SmartHouse/SmartGrid scenario). Energy efficiency gains will be calculated thereafter by comparison of the results, where it will be assumed that the power not delivered by regional generators will be coming from centralized plants. Simulation study II is expected to contribute most here since it includes higher numbers of end users as well as higher installed power from renewables (wind power generation).

D.3: Reduction of power grid losses by increasing local sustainable demand and supply solutions.

- The consideration of power grid load and consequently power grid losses is core of simulation study II. Losses and grid load will be considered for the BAU scenario and the SmartHouse/SmartGrid scenario where the tariff for the latter scenario will be designed such as to incentivize optimal use of high-efficient generators as outlined above. If grid deconstruction is considered due to reduced line load using a specifically designed variable tariff, the effects on grid load and losses will also be investigated.

D.4: Gains through raising the accommodation ceiling of local networks for integration of local generation

- For investigating a possible increase of the share of local generation, grid operation parameters (voltages and line loads) will be assumed to be the limiting factor. The share will be compared for the case of a constant tariff (BAU) and a specifically designed tariff (SH/SG) while in both cases, the installed decentralized power will be chosen such that the grid operation parameters will be within pre-defined, allowed limits.

- From the research questions therefore defined, it is concluded that several simulation cases can be conceptualized. Table 33 summarizes these simulation cases and their contribution to the research questions.

Simulation case	Corresponding scenario	Corresponding simulation study	Tariff	Grid modification	Contributes to
Ia	BAU	I	const	No	
Ib	BAU	I	const	Yes	
Ic	SH/SG	I	var.	No	D.2,D.4
Id	SH/SG	I	var.	Yes	D.2, D.4, (*)[23]
IIa	BAU	II	const	No	
IIb	BAU	II	const	Yes	
IIc	SH/SG	II	var.	No	D.2, D.3
IId	SH/SG	II	var.	Yes	D.2, D.3, (*)

Table 33: Summary of projected simulation studies in Case Study B

[22] Since the focus of the simulation studies is on technical aspects, the design of the variable tariffs will not consider economical issues. However, the report on simulation results will also contain information about economical implications, if applicable.

[23] (*) contributes to grid planning aspects, e.g. the question if SmartHouse/SmartGrid technology allows for grid deconstruction compared to BAU cases.

4.4. Case Study C

Similarly to Case Studies A and B, two scenarios will be developed Case Study C:

- Scenario 1: Business as Usual
- Scenario 2: Mass application of new control strategies and network architecture (SmartHouse/SmartGrid scenario)

The first scenario will identify critical operation states of the future electricity grid, as well as other aspects of the grid (e.g. power quality) that can be improved in order to achieve efficient operation and optimal load service. The aforementioned critical operation states occur during peak load hours which most likely coincide with hours of higher marginal price. Thus, economic criteria such as system marginal price can be used as means for designing energy management strategies.

The critical operation states being identified, the contribution of the mass application of intelligent meters to the optimization of the grid operation will be examined (Scenario 2). By defining the percentage of the load that is available to be controlled at any time, several problems regarding the grid operation, that – according to Scenario 1 – are likely to emerge, can be solved. In other words, the controllable loads provide support to the grid by means of ancillary services: scheduling and dispatch, energy imbalance and voltage control to mention a few. In that case the TSO contracts in real-time part of the flexible loads for its real-time balancing actions. Furthermore, controllable loads can contribute to the congestion management of the distribution grid, thus offering enhanced network utilization and deferral of grid reinforcements. In this case, the DSO – who is the one interested in keeping a stable load profile at the transformer station, avoiding peak loads – benefits from the flexibility of the household loads.

More particularly, control of loads includes mainly load shifting from peak hours to off-peak hours in order to relieve the power grid from several problems that have to do with power losses and the limited capacity of the power lines, thus leading to more efficient use of the electricity grid and the electricity production units. The contribution of controllable loads management to the efficient use of the electricity grid and the electricity production units will be quantified by means of network losses reduction and by the avoided fuel costs required by expensive units that serve peak loads. Additionally, the formulation of a load curve with higher load factor (as the one achieved by applying load management on flexible loads) improves greatly the accommodation ceiling of local power networks for integration of local generation.

Thus, by simulating the management of controllable loads as described above – at an aggregated level, especially during peak hours (by shifting to off-peak hours) – the contribution of the smart homes concept to the following objectives – as described in DoW – can be measured:

Objective D.1: Efficiency gains through interactive feedback to users on optimal energy use.

Objective D.3: Reduction of power grid losses by increasing local sustainable demand and supply solutions.

Objective D.4: Gains through raising the accommodation ceiling of local networks for integration of local generation.

4.4.1. Simulation Procedure

In order to simulate the impact on the operation of the electricity system due to mass application of intelligent meters, the autonomous power system of the island of Crete is used as a study case with the assumption of large scale integration of smart houses.

In autonomous power systems – such as the Cretan, demand changes can cause load imbalance leading to voltage and/or frequency instability. That being the case, the effect of high smart grid houses penetration on the power system of Crete is investigated.

Crete is the largest autonomous system in Greece with 690 MW_e installed capacity from three thermal power plant sites in Chania, Linoperamata and Atherinolakos with altogether 25 thermal units. Various types of thermal units with different response and start-up times have been installed, from slow steam turbines, and combined cycle units to much quicker diesel units and gas turbines.

The installed wind power capacity is 166 MW (December 2009), mostly installed in the eastern part of the island and additional 20-30 MW are foreseen to be installed within the next 3 years. Since 2000 wind energy accounts for around the 10 % of the annual energy demand of the island.

The software package Eurostag will be used as a simulation tool for the study. Eurostag is software dedicated to the analysis of both steady state analysis and dynamic simulation of electric power systems. It covers the full range of transient, mid and long term stability, from electromechanical oscillations up to daily load evolution. It enables the study of large scale power system over long periods with no modeling interrupts. Eurostag has been designed to solve efficiently conventional problems, typical examples of which are:

- Finding the critical fault clearance time
- Checking the keeping up of synchronism after various disturbances
- Plans for automatic load-shedding
- Contingency analysis under abnormal operating conditions (preventive security)
- Behavior of the power system in emergency or in extreme conditions (voltage collapse, loss of synchronism, resynchronization, etc.)
- Dynamic stability of the machines, regulations, transmission system around an operating point of the power system
- Design and tuning of the local control systems (speed governors, AVR, transformer tap controllers)
- Design, co-ordination and adjustment of protection systems for power plants and transmission networks
- Design of centralized control and protection systems
- Opportunity studies on different technologies
- Analysis of the behavior of industrial systems

Moreover, all those possibilities are available for balanced or unbalanced network conditions. The ergonomics and modular nature of the product make it also an excellent teaching tool for the speeding up of training experts in the field of network dynamic behavior. The algorithm used in EUROSTAG, while respecting guidelines provided by the user, controls the simulation automatically. It is thus possible to maintain complete system modeling throughout the simulation and shed light on the inter-relation of dynamic phenomena. The EUROSTAG software package is also very user-friendly. New models can be specified graphically, thus avoiding the risk of human error associated with translating network diagrams into program code. As an aid for interpretation, it offers a series of interactive graphics tools to present and analyze results.

Modeling of the system includes the components of transmission system (lines, transformers, and loads) as well as its dynamics such as generators, voltage and frequency regulators and renewable energy sources.

As mentioned earlier, the study focuses on characteristic operating states, where the power system is vulnerable (e.g. peak load, or low load with high RES penetration) and how smart houses can contribute in enhancing the operation of the system. For each one of these operating states, load flow analysis is performed either by using load curves or load duration curves using Eurostag.

However, since the behavior of customers to load shed/increase commands is stochastic, the available load for shedding is not a priori known. In order to model this stochastic nature, a large number of representative customer responses is considered and simulated in the time domain using Eurostag. System variables such as branch flows, frequency and voltage deviations are recorded.

As far as the distribution system concerns, the same procedure as described above is applied for the case study of an urban area distribution feeder, thus providing insight of the impact of large smart house penetration to the distribution level.

4.4.2. Load Modeling

The simulation will take into account energy consuming yet easily controllable household appliances, with the purpose of examining how they can contribute to the optimal operation of the power grid. Modeling of the electric load attributed to a certain appliance/device is therefore necessary.

Individual preferences as well as availability, or behavior in general, constitute a determinant for the formulation of the electricity consumption of a household. By combining the proclivity of each individual to use a specific appliance at a certain time of the day with the operation cycle of the same appliance, a probabilistic profile of the daily use of the appliance in question is constructed. Let $P_i(t)$ be the probability of using appliance i at time t and $O_i(t)$ the electricity consumption of the same appliance during an operation cycle. Then, the total daily load attributed to the i-th appliance is (daily load for t=24h):

$$L_i(t) = \int_0^t P_i(\tau) O_i(t-\tau) d\tau$$

As expected the above modeling procedure presents variations from appliance to appliance due to the different operational characteristics (in P_i, O_i as well as t). This is further detailed below for the case of electricity-based hot water generation as a quite electricity-demanding application.

For the case of hot water loads, the model representing the electrical system load due to hot water consumption is as follows [Orphelin 1999]: Under the assumption that the use of hot water by domestic consumers is random, the number of households n out of a total population of N_{tot}, which use hot water at time t, can be represented by the normal or Gaussian probability density function:

$$n(t) = N_{tot} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-t_0}{\sigma}\right)}$$

where t_0: time at which most people use hot water
σ: standard deviation of the distribution

The number of water heaters which are in operation at time t is given by:

$$N(t) = \frac{N_{tot}}{2}\left[erf\left(\frac{t-t_0}{\sqrt{2}\sigma}\right) - erf\left(\frac{t-t_0-\Delta t_{on}}{\sqrt{2}\sigma}\right)\right]$$

where

Δt_{on}: time the water heater stays on after the hot water is used (h), $\Delta t_{on} = \frac{m \cdot c_p \cdot (T_{set} - T_{cold})}{3600 \cdot P}$

m: mass of water heated (kg)

c_p: specific heat capacity of water ($4{,}1813 \cdot 10^3$ J/(kg·K))

T_{set}: hot water temperature

T_{cold}: cold water temperature

P: rated power of water heater (W)

After making the simplifying plausible assumption that all the water heaters are characterized by a uniform rated power, the aggregated power is given by the following equation:

$$P_{tot}(t) = P \cdot N(t)$$

With the total demand for electricity by the water heaters known at any time, the model enables the prediction of the effects of load control to the aggregated load curve, which in turn is further employed in examining technical issues regarding the operation of the electricity grid.

By following a similar procedure, the hourly probability factors for each appliance are obtained in the form of load curves. Each load curve pertains to the aggregated load of each appliance and is further used as an input in the simulation of the operation of the electricity grid (Scenario 2).

For the sake of simplification, normalized energy use profiles for various household appliances will be used, as found in the literature by making all the appropriate adjustments for the case of Crete [Hendron 2008].

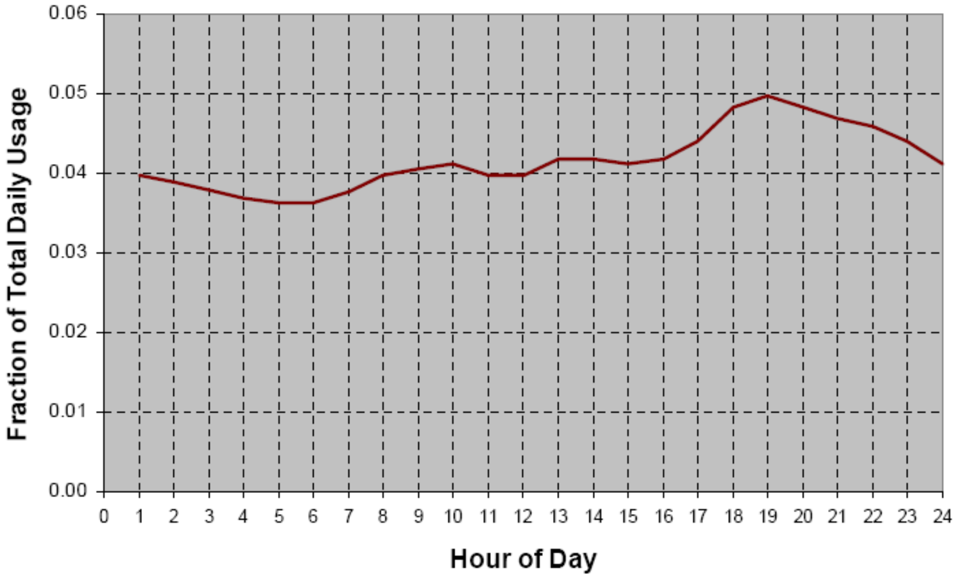

Figure 15: Refrigerator normalized energy use profile

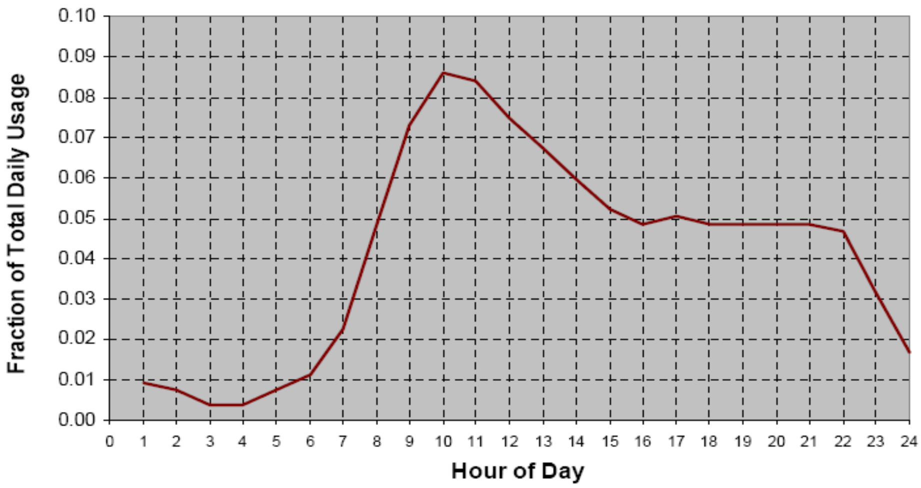

Figure 16: Clothes washer normalized machine energy use profile

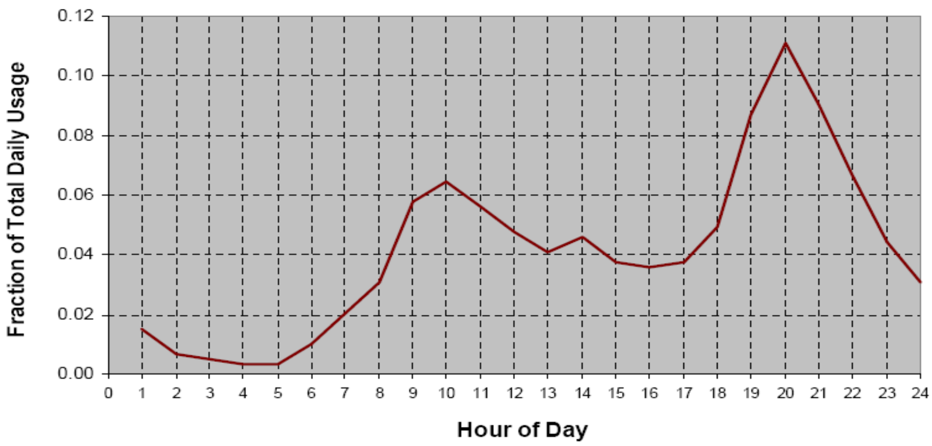

Figure 17: Dishwasher normalized energy use profile

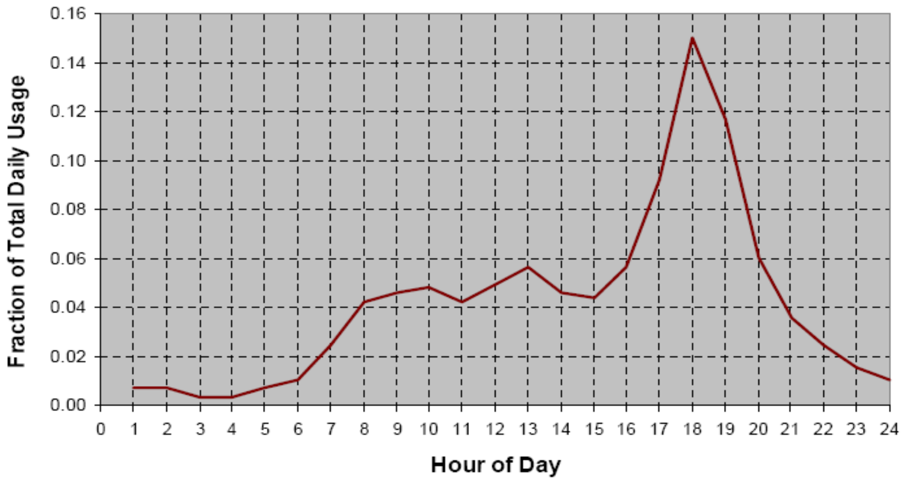

Figure 18: Oven normalized energy use profile

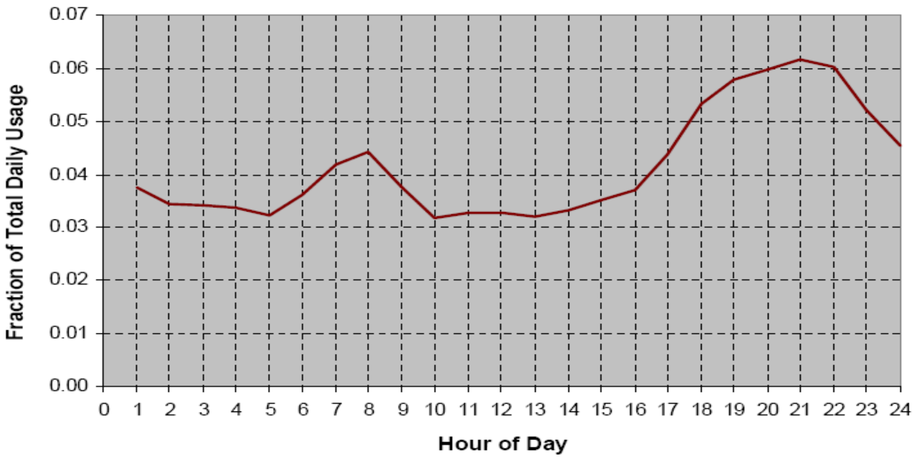

Figure 19: Miscellaneous electric loads normalized energy use profile

4.4.3. Scenario 1: Business as Usual

For the Business as Usual scenario the following data will be used as input:

Hourly demand curve per MV/LV transformer (or per household type and then aggregate individual load curves taking into account the type mix of consumers connected to the specified transformer): obtained by adjusting the current typical demand curve to the projected consumption for the target years as obtained from studies such as [Capros 2010] or [EURPROG 2009].

Note: the projected consumption possibly refers to the total electricity consumption and not the households. In that case, the annual consumption of the households is derived as a percentage of the total consumption. Assuming that the proportion of household consumption remains constant with respect to the total consumption, this multiplicative factor is calculated from annual consumption data per region (and thus for Crete) made available by the Hellenic Statistical Authority.

Demand [ktoe]	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Final energy demand – residential	4,486	5,489	5,703	6,250	6,435	6,355	6,377
Final energy demand – electricity	3,710	4,377	4,644	5,172	5,584	6,107	6,501

Table 34: Final energy demand of the residential sector and final electricity demand in total[24]

Demand [Mtoe]	**2000**	**2005**	**2006**	**2010**	**2020**
Final energy demand – residential	1.3	2.0	5.4	2.2	2.8
Final energy demand – total	18.4	23.5	22.5	23.9	27.3

Table 35: Final energy demand – total for residential consumers[25]

Total system	**2000**	**2005**	**2006**	**2010**	**2020**
Peak demand [MW]	8531	9635	9961	11246	14607
Total demand [TWh]	49.9	59.5	59.9	68.6	84.1
Date of peak demand	7	8	8	7	7
Connected system	**2000**	**2005**	**2006**	**2010**	**2020**
Total demand [TWh]	45.4	54.5	54.6	61.1	79.3
Use factor of connected peak demand [h/a]	5321	5657	5478	5431	5431

Table 36: Total and peak system demand – total and connected system[26]

Breakdown of total demand [TWh]	**2000**	**2005**	**2006**	**2010**	**2020**
Final demand – residential	14.2	16.9	17.7	20.1	24.7
Network losses	4.5	6.1	5.0	5.5	6.7
Total electricity demand	49.9	59.5	59.9	68.6	84.1

Table 37: Electricity demand – total, residential, network losses[27]

[24] Capros 2010
[25] EURPROG 2009
[26] EURPROG 2009

- Distribution/transmission network topology: only the necessary grid reinforcements of the existing lines will be considered (and not possible expansions)
- Installation of DG – mainly in the form of PVs: investment in PVs is considered today as a profitable one (high feed-in-tariff, various financing opportunities by means of loans). The interest expressed both by households as well as banks is only attenuated due to the present decline of the economy.
- Production units: future energy mix (units decommissioning, target for 40% contribution of renewables in the gross electricity consumption)

[MW$_e$]	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Net generation capacity – RES	2,585	2,887	3,843	6,195	9,612	11,126	13,001
Hydro	2,359	2,395	2,395	2,576	2,871	2,926	3,329
Wind	226	491	1,371	2,936	5,138	6,137	7,187
Solar	0	1	76	682	1,602	2,062	2485
Other	0	0	0	0	0	0	0
Net generation capacity – thermal	7703	9,039	11,124	12,866	13,600	14,922	16,469
of which cogeneration units	200	361	575	760	905	1,115	1,116
Solids fired	4,507	4,799	4,799	4,241	4,375	4,056	4,056
Gas fired	1,114	1,899	3,618	6,198	6,743	8,635	10,122
Oil fired	2,054	2,282	2,622	2,335	1,940	1,607	1,575
Biomass-waste fired	28	59	85	85	511	579	647
Fuel cells	0	0	0	0	0	0	0
Geothermal heat	0	0	0	8	31	45	69

Table 38: Electricity generation – breakdown per type of RES and of thermal power plant[28]

[MW]	**2006**	**2010**	**2020**
Fossil fuel fired	9,692	11,419	15,355
Coal	0	0	3,060
Brown coal (lignite)	4,808	4,794	4,508
Oil	2,439	2,631	1,559
Natural gas	2,445	3,994	6,228
Hydro	3,135	3,418	3,418
Conventional	2,435	2,719	2,719
Pumped and mixed	699	699	699
Other renewables	807	4,792	5,043
Solar	5	5	700
Geothermal	0	0	0
Wind (onshore)	749	1,727	4,273
Biogas	23	30	40
Biomass	0	0	0
Waste	30	30	30
Total	13633	16629	23816

Table 39: Maximum net generating capacity by primary energy[29]

[27]EURPROG 2009
[28] Source: Capros (2010)

[MW]	2006	2010	2020
Steam thermal units	6,105	4,794	7,568
Gas turbine units	520	523	311
Combined cycle units	2,232	3,994	6,054
Internal combustion units	887	2,168	1,492
Hydro	3,135	3,418	3,418
Non-fuel renewables	754	1,732	4,973
Total	13,633	16,629	23,816

Table 40: Maximum net generating capacity by technology[30]

	CHP capacity [MW]			Electricity generation in CHP [TWh]			
	2006	2010	2020	2006	2010	2020	2030
Multifuels	33	33	33	0.1	0.1	0.1	-
Coal	740	768	768	5.1	5.2	5.2	-
Oil	136	136	136	0.7	0.7	0.7	-
Natural gas	95	106	131	0.2	0.2	0.3	-
Renewables	0	0	0	0	0	0	-
Other non-renewables	0	0	0	0	0	0	-
Total	1,004	1,043	1,068	6.1	6.2	6.3	-

Table 41: Maximum net generating capacity by technology[31]

[TWh]	2006	2010	2020
Steam thermal units	35.5	37.6	53.5
Gas turbine units	0.5	0.5	0.5
Combined cycle units	9.3	18.7	17.5
Internal combustion units	2.4	3	3.7
Hydro	6.5	4.6	4.2
Non-fuel renewables	1.5	4.3	4.7
Total	55.7	68.7	84.0

Table 42: Annual electricity production by technology[32]

*Note: All the data acquired by PRIMES and EURPROG refer to the **entire Greece** up to 2020 or 2030. Therefore, adjustments should be made for the system of Crete and projections for the designated time horizon (2030-2050).*

Simulation Procedure

The above described data will be used for the simulation of the electricity transmission and distribution grid operation. By running a load flow analysis, either by using load curves or load duration curves, critical operation states (e.g. line or transformer overload) are identified. Furthermore, by applying an economic dispatch algorithm, the production cost for serving the given load is calculated. Under the assumption that the elec-

[29] Source: EURPROG (2009)
[30] EURPROG 2009
[31] EURPROG 2009
[32] EURPROG 2009

tricity load of the households is affected only by weather conditions and the personal preferences of the consumer that achieve the maximum comfort level i.e. the household electricity load remains uncontrollable, it is to be expected that the load curve is characterized as imbalanced (high peak demand, low minimum demand), thus posing an impediment in the installation of local stochastic generation.

4.4.4. Scenario 2: Mass Application of New Control Strategies and Network Architecture

In order to simulate the contribution of controllable loads to the overall operation of the electricity system, load curves of various household appliances will be used as input data in addition to the input data mentioned in paragraph 4.4.3. By considering various load control actions e.g. different levels of controllable load and different categories of load (shiftable or not), various aggregate load curves derive each one defining a different sub-scenario. Thus the new set of input data is comprised by:

1. Hourly demand curve per MV/LV transformer for various load control sub-scenarios
2. Distribution/transmission network topology
3. Installation of distributed generation (DG)
4. Production units

Input data 2-4 are – as expected – the same as in paragraph 4.4.3.

Simulation Procedure

Having already identified the critical operation states from Scenario 1, load control actions will be considered that assist the electricity system in operating more efficiently. The simulation procedure will be as described in paragraph 4.4.3. The only difference pertains to the load curve: in Scenario 2 various load curves will be considered by assuming different load control sub-scenarios that assist in gaining insight in the multidimensional contribution of flexible loads to a more efficient – both operationally as well as economically – electricity system.

More specifically, the contribution of the load control actions in achieving each one of the three measurable objectives will be quantified as follows:

Objective D.2: By applying the economic dispatch algorithm for the different load control sub-scenarios, the respective production cost for serving the differentiated load will be calculated.

Objective D.3: Load control actions that aim at reducing peak demand undoubtedly result in reduction of power grid losses, which will be calculated by using the results of load flow analysis.

Objective D.4: In addition to load control actions that aim at reducing peak demand, valley filling will be considered, thus formulating a load curve with higher load factor that will facilitate the integration of local generation through higher accommodation ceiling of local networks.

The above results will be compared to those obtained from the BAU scenario, thus quantifying the contribution of flexible controllable loads to a more efficient operation of the electricity system with higher levels of local generation.

4.4.5. Expected Simulation Results

Given the aggregated load curves per household appliance, the load curve as well as the grid topology for the indicated time horizon, load flow analysis and time domain simulation of the electricity transmission grid in Crete will be performed for the two scenarios described previously using Eurostag.

Scenario 1: Business as Usual

Operation of the future electricity grid will be simulated, in order to identify possible critical situations that could result in:

- Inefficient use of the electricity grid (when the load curve is characterized by low load factor)
- High power losses and inefficient use of the production units (mainly due to extremely high peak load)
- Rejection of power produced by local generation units (due to grid constraints regarding the accommodation ceiling)

Scenario 2: Mass application of New Control Strategies and Network Architecture

The results from the above described simulation will be used as a touchstone in order to compute as well as evaluate the contribution of the mass application of new control strategies (introduced by large-scale installation of smart metering equipment) in:

- Achieving higher efficiency in the use of the electricity grid through congestion management: measured/represented by the % reduction of peak load achieved through shifting/curtailment of large volumes of controllable load (*Objective D.1*)
- Enhancing the operation of the electricity grid and the electricity production units: measured by the % reduction of power grid losses and the avoided fuel costs for peak units respectively (*Objective D.3*)
- Achieving higher penetration of local generating units: derives directly by the absolute increase of the minimum demand as a result of load shifting policies (*Objective D.4*)
- Thus identifying appropriate measures for load control in order to achieve the threefold objective.

5. Impact of Chosen Case Studies on Measurable Objectives

This chapter gives a summary of the measurable objectives addressed in the context of WP 4.1/4.2. Details of the measurable objectives expected from the simulation results for each of the case studies were presented in the previous chapters 4.2 to 4.4.

Table 43 gives an overview on the contribution of each case study to the measurable objectives. WP 4 mostly contributes to Measurable Objectives D: The developed technology is able to achieve aggregate energy efficiency gains.

Objective	Case Study A	Case Study B	Case Study C
Measurable Objective D: The developed technology is able to achieve aggregate energy efficiency gains > 20%			
Objective D.1: Efficiency gains through interactive feedback to users (about 10%)			
Objective D.2: Gains as a result of optimized energy management of devices and of specific energy technologies in use (e.g. reduction of heat waste in commercial and home CHP units by better ICT-based control, CO2 reduction potential; (about 5%)	x	x	x
Objective D.3: Reduction of power grid losses by increasing local sustainable demand and supply solutions (4-8%).	x	x	x
Objective D.4: Gains through raising the accommodation ceiling of local networks for integration of local generation. (>10%)	x	x	x

Table 43: Contribution of each case study to the measurable objectives

Objective **D.2** is addressed by Case Study A by searching for an energy efficiency increase due to lower peak power usage and a reduction in needed reserve power.

Case Study B addresses objective D.2 by looking for electricity from distributed generation to be used in the nearby neighborhood and thus increasing efficiency. As Case Study B also includes the MV (medium voltage) level, it covers also RE DG from wind power (and potentially medium-size hydro), and is not restricted to PV on households feeding in on LV (low voltage) level.

Case Study C contributes to objective D.2 and possibly D.1 by achieving higher efficiency in the use of the electricity grid through congestion management: measured/represented by the % reduction of peak load achieved through shifting/curtailment of large volumes of controllable load.

Case Study A simulations address **objective D.3**, *Reduction of power grid losses by increasing local sustainable demand and supply solutions* by looking on reduction of grid losses: Simulations with and without PowerMatcher control will be fed into steady-state network simulations to quantify this reduction of grid losses.

For Case Study B the consideration of power grid load and consequently power grid losses is core of the simulation study II. Losses and grid load will be considered for both scenarios, possibly for the SmartHouse/SmartGrid scenario with a tariff designed to incentivize optimal use of high-efficient generators. Grid deconstruction (as it is already considered for some areas in Mannheim due to reduced line load if using a specifically designed variable tariff) might affect line losses as well which will be also considered.

For Case Study C the use of new control devices is expected to enhance the operation of the electricity grid and the electricity production units (avoiding high power losses and inefficient use of the production units (mainly due to extremely high peak load) measured by the % reduction of power grid losses and the avoided fuel costs for peak units respectively

Case Study A addresses **objective D.4**, *Gains through raising the accommodation ceiling of local networks for integration of local generation* by using the new control technology to lift the ceiling to allow a substantial greater share of DER/RES in distribution grids, reducing centralized fossil-fuelled power generation.

Case Study B focuses on grid operation parameters in the simulation as limiting factors for the possible share of local generation, possibly including tariff incentives to increase the share of RE/DG.

In Case study C the rejection of power produced by local generation units (due to grid constraints regarding the accommodation ceiling) is a critical target to study. Here the new control strategies are expected to help reducing such rejections, finally achieving higher penetration of local generating units directly derived by the absolute increase of the minimum demand as a result of load shifting policies.

There will be additional, possibly indirect proofs or impacts on measurable objectives which need to be investigated during the simulation. This possibly includes Objective D.1 *Efficiency gains through interactive feedback to users* (possibly covered by Case Study C). Objective C.2, *there is a solid business case for energy utilities and energy service providers to step into ICT-enabled energy efficiency technology* is indirectly supported by the simulations: if the simulations prove a significant benefit of the control technologies, this will be a necessary (but maybe not sufficient) criterion for a solid business opportunity for utilities and service providers.

Objective A.1: *Scalability* will be addressed in a simulation of the ICT and other issues in case of a very large number of customers (households) within Case Study A (i.e. it is a mimicking of up to 1 million end users but is not part of the WP 4 simulation). Objective B.2, *The developed technology is affordable in terms of financial investment and operational costs* will be covered by a separate small economic study on potential cost development in the future and with mass production.

References

[AGEB] AG Energiebilanzen e.V. (2010): Energieverbrauch in Deutschland (Electricity demand in Germany), http://www.ag-energiebilanzen.de/viewpage.php?idpage=65, last accessed in August 2010.

Axelsson, E., S. Harvey, T. Berntsson (2009): A tool for creating energy market scenarios for evaluation of investments in energy intensive industry, Energy 34 (12), pp.2069-2074.

[BDEW] Bundesverband der Energie- und Wasserwirtschaft (2007): Struktur des Stromverbrauchs im Haushalt, http://www.bdew.de/bdew.nsf/id/DE_7T9HWU_Grafiken, accessed in May 2010.

[BDEW] Bundesverband der Energie- und Wasserwirtschaft (2008): Press release on household energy consumption, Berlin, Germany, 17.01.2008.

Bertoldi, P., B. Atanasiu (2007): Electricity Consumption and Efficiency Trends in the Enlarged European Union - Status report 2006, Institute for Environment and Sustainability, EUR 22753EN, http://re.jrc.ec.europa.eu/energyefficiency/pdf/EnEff%20Report%202006.pdf, accessed in August 2010.

[BMU] German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (2007): Kosten und Nutzen des Energie- und Klimaprogramms der Bundesregierung, Berlin.

[BMU] German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (2010): Erneuerbare Energien in Zahlen – nationale und internationale Entwicklung, June 2010, http://www.erneuerbare-energien.de/inhalt/2720/42038, accessed in Sept 2010.

[BMWi] German Federal Ministry of Economics and Technology (2007): Eckpunkte von Meseberg für ein integriertes Energie- und Klimaprogramm, http://www.bmwi.de/BMWi/Navigation/energie,did=254042.html, accessed in Sept 2010.

Bouwman, S. et al. (2010): Different options how to prepare the electricity grid for the usage of electric vehicles & electric heat pumps, ITM project WP2 report, 2010, available at http://www.itm-project.nl/

CapGemini (2008): Demand Response: a decisive breakthrough for Europe - How Europe could save Gigawatts, Billions of Euros and Millions of tons of CO2, Technical Report Energy, Utilities and Chemicals, http://www.capgemini.com/insights-and-resources/by-publication/demand_response _a_decisive_breakthrough_for_europe.

Capros, P., L. Mantzos, V. Papandreou, N. Tasios (2008): European Energy and Transport - Trends to 2030 - Update 2007, Report to the European Commission, Directorate-General for Energy and Transport.

Capros, P., Matzos L., Tasios N, De Vita A., Kouvaritakis (2010): EU energy trends to 2030 - Update 2009, European Commission, Directorate-General for Energy in collaboration with Climate Action DG and Mobility and Transport DG.

De Boer, P. et al. (2009): Trends in Electricity demand and supply effects on grids in the Netherlands, Synthesis report ITM project WP1, available at http://www.itm-project.nl/.

De Boer-Meulman P. et al. (2010): Effect of scenarios and alternatives for electric vehicles and heat pump implementation on grid reliability, sustainability and socio-economy, ITM project WP3 report, 2010, available at http://www.itm-project.nl/.

[EA NRW] Energieagentur Nordrhein-Westfalen (2006): Prozentuale Anteile der 12 Stromverbrauchsbereiche gemittelt über alle Haushaltsgrößen, http://www.ea-nrw.de/_infopool/page.asp?InfoID=4106 and http://www.ea-nrw.de/_database/_data/datainfopool/prozentuale_anteile_diagramm.pdf.pdf and http://www.ea-nrw.de/_database/_data/datainfopool/prozentuale_anteile_tabelle.pdf.pdf.

ECN: Monit data supplied by ECN Policy Studies.

European Climate Foundation: Various reports, e.g. Roadmap 2050: A practical guide to a prosperous, low-carbon Europe, http://www.europeanclimate.org/index.php?option=com_content&task=view&id=72&Itemid=79.

EURPROG Network of Experts (2009): Statistics and prospects for the European electricity sector (1980-2000, 2004, 2005, 2006, 2010-2030), 36th edition.

Farla, J.C.M. et al. (2006): Hoofdstuk Energie in Achtergrondrapport WLO, Technical Report ECN-B-06-002, ECN Petten.

Graus W., Worrell E. (2009): Trend in efficiency and capacity of fossil power generation in the EU, Energy Policy, 37 (6), pp. 2147-2160.

Hendron, R. (2008): Building America Research Benchmark Definition (Update), Technical Report, National Renewable Energy Laboratory, NREL/TP-550-44816.

[IMPROGRES] Improvement of the Social Optimal Outcome of Market Integration of DG/RES in European Electricity Markets: Various sources, http://www.improgres.org/.

International Energy Agency [IEA} (2008): The World Energy Outlook 2008.

Kamphuis, R. et al. (2010): Market mechanisms and ICT architecture for control of flexible load systems, ITM project WP4 and WP5 report, 2010, available at http://www.itm-project.nl/.

Kok, K., G. Venekamp (2010): Market-based Control in Decentralized Electrical Power Systems, First International Workshop on Agent Technologies for Energy Systems, ATES2010, Toronto; accessible at http://users.ecs.soton.ac.uk/acr/ates2010/Paper_09.pdf.

Lund, H., Mathiesen, B. (2009): Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050, Energy 34 (5), pp.524-531.

Nipkow, J., Gasser, S., Bush, E.: Der typische Haushalt-Stromverbrauch, Bulletin SEV/VSE 19/2007, http://www.electrosuisse.ch/display.cfm?id=115199 (Accessed in Sept 2010)

Nitsch, J. (2008): Leitstudie 2008, Study for the German federal ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Executive summary, Stuttgart, Germany, October 2008.

Orphelin, M., Adnot, J. (1999): Improvement of methods for reconstructing water heating aggregated load curves, IEEE Transactions on Power Systems 14 (4), pp. 1549-1555.

Paauw, J. et al. (2009): Energy Pattern Generator; Understanding the effect of user behaviour on energy systems, Proceedings of the First European Conference Energy Efficiency and Behaviour, Maastricht, The Netherlands.

Psiloglou B.E., C. Giannakopoulos, S. Majithia, M. Petrakis (2009): Factors affecting electricity demand in Athens, Greece and London, UK: A comparative assessment, Energy 34 (11), pp. 1855-1863.

Stadler, I.: Demand Response - Nichtelektrische Speicher f¨ur Elektrizitätsversorgungssysteme mit hohem Anteil erneuerbarer Energien. Habilitation, University of Kassel, Germany, October 2005.

Strom-Prinz.de: Stromverbrauch Privathaushalt, http://www.strom-prinz.de/Stromverbrauch/#c1487 (Accessed in Sept 2010)

[UBA] Umweltbundesamt (2007): Wirkung der Meseberger Beschlüsse vom 23.08.2007 auf die Treibhausgasemission in Deutschland im Jahr 2020, German Federal Environment Agency, Dessau, October 2007.

[UBA] Umweltbundesamt (2009): CO_2-Emissionen nach Quellkategorien, published by the German Federal Environment Agency, http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/theme.do?nodeIdent=2842, accessed in Sept 2010.

Ummels, B.C. (2009): Power system operation with large-scale wind power in liberalised environments, Dissertation TU Delft.

[VDEW] Verband der Elektrizitätswirtschaft (1999): Standardisierte Lastprofile (Standard load profiles), http://www.pvu-netze.de/media/Standardlastprofil%20VDEW.pdf

Veldman, E., Gaillard, M., Gibescu, M., Slootweg, J.G., Kling, W.L. (2010): Modelling future residential load profiles, Proceedings of the Innovation for Sustainable Production 2010 (I-SUP 2010), Bruges, Belgium, pp. 64-68, http://alexandria.tue.nl/campusonly/Metis237435.pdf.

[WADE] World Alliance for Decentralized Energy (2006): World Survey of Decentralized Energy (2006) http://www.localpower.org/documents/report_worldsurvey06.pdf.