D1.1 Outlook for energy demand and PV penetration

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ABOUT THE NEMoGRID PROJECT

The increase of distributed energy resources (DERs) reduces the energy sales of the distribution system operators (DSO). Given the present tariff scheme, the utilities will likely counterbalance the missing income deriving from a reduction in the amount of energy sold by increasing grid tariffs. As a consequence, prosumers might decide to further increase self-consumption, invest in local storage technologies and even disconnect themselves from the grid, inducing the so called death spiral in the utility sector. The goal of the project is to design and evaluate innovative business models favoring the integration of DERs in the distribution grid by attaining an economic and technical optimum at community level, considering three scenarios: centralized DSO planned, voltage based tariff (decentralized), P2P distributed market using blockchain for energy transactions. The proposed scenarios will be evaluated in simulation and validated in two demo sites in Switzerland and Sweden.

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1 ENERGY EFFICIENCY AND EVOLUTION OF ENERGY DEMAND

The Reference Scenario reflects the policies that have been adopted in recent years regarding energy efficiency in the EU and in MS, including eco-design and labelling, the Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD). In the following, these measures are briefly discussed and a general overview of their effects on the energy system is provided, as well as their reflection in the PRIMES model. The PRIMES (Price-Induced Market Equilibrium System) energy system model is a development of the Energy-Economy Environment Modelling Laboratory at National Technical University of Athens, which can simulate different energy efficiency policies with different modelling techniques. The model-specific instruments used affect the context and conditions under which individuals - in the modelling represented by stylized agents per sector - make their decisions on energy consumption and the related equipment.

The way of modelling such policies and instruments is the modification of model parameters in order to mirror technology performance or the effects of building codes that are determined jointly in the process of calibrating the interdependent model output to the observations from the most recent statistical year. Another technique is the assumption of improved equipment and appliances under certain scenario conditions over time, which become available for future choices by consumers within the model projection. Further-more, there are specific modelling instruments for capturing the effects of measures that promote or impose efficiency performance standards (best available technology for industry, Eco-design). Such modelling instruments relate to individual technologies or groups of technologies and modify the perception of associated costs by the modelled agents or influence the portfolio of technologies that will be available for consumer choice. Another type of measures are those which improve consumer information through education, la-belling, correct metering and billing, energy audits and technology support schemes aiming at inciting consumers to select more efficient technologies. Such measures are dealt with through the modelling instruments discussed in this section or are directly reflected in the modelling mechanisms, where economic agents are per-se informed correctly about the prevailing and to some extent future prices. This depends on the sector, as there is limited foresight in final demand sectors with shorter equipment lifetimes compared to power generation. The penetration of energy service companies (ESCO) as explicitly incited by the EED leads to an environment with reduced risks for the consumers engaging in energy efficiency investments, which can include both changes in the building structure and changes in the energy equipment. As in the case for, e.g. labelling policies, the potential benefits of the penetration of ESCOs is represented in the modelling by reduced discount rates for certain sectors, mirroring the changes in the decision making conditions and constraints of e.g. households and services. In addition, these measures also induce lower technical and financial risk, hence reducing the perceived costs of new technologies and saving investments (see also point above on perception of costs). Another key modelling tool are efficiency values reflecting a variety of broad and sometimes un-specified instruments that bring about efficiency improvements. In the most concrete form these values represent the price of hypothetical White Certificates, reflecting the marginal costs of reaching energy savings obligations, e.g. for energy distributors and retail sellers regarding energy efficiency at final customers' sites. In the Reference Scenario these values represent the implementation of the EED energy savings obligations in domestic and service sectors, specific building renovation policy efforts or a large range of other pertinent measures, such as energy audits, energy management systems, good energy advice to consumers on the various benefits of energy efficiency investment and better practices, targeted energy efficiency education, significant voluntary agreements, etc. For the modelling of the energy savings obligation or alternative measures, it has been assumed that the possible exemptions for ETS installations and transport are used. The EED includes specific public procurement provisions and induces multiplier effects, as the public sector assumes an exemplary role, i.e. private consumers are imitating the public sector energy efficiency actions. Energy efficiency improvements also occur on the energy supply side, through the promotion of investments in CHP and in distributed steam and heat networks. These investments are combined with incentives on the consumer side to shift towards heating through district heating, both in the residential and the tertiary sectors. Improvements in the network tariff system and the regulations regarding the design and operation of gas and electricity infrastructure are also required in the context of the EED; moreover, the EED requires MS and regulators to encourage and promo e participation of demand side response in wholesale and retail markets. In this context, the EU Reference Scenario 2016 assumes that intelligent metering is gradually introduced in the electricity system. This enables consumers to more actively manage their energy use. It allows demand responses to decrease peak and over-charging situations, which generally imply higher losses in the power grids. Thus, efficiency is also improved because of the intelligent operation of systems. Finally, some policies and measures that do not target energy efficiency directly lead to significant additional energy efficiency benefits. Among these policies are the EU Emissions Trading System (EU ETS) Directive, the Effort Sharing Decision (ESD), and the CO2 standards for cars and vans.

Policies on promoting renewable energy sources (RES) also indirectly lead to energy efficiency gains; in statistical terms, many RES, such as hydro, wind and solar PV, have an efficiency factor of one; thus, the penetration of RES in all sectors, in particular in power generation, induces energy savings in primary energy terms. Other measures that foster energy efficiency relate to taxation, in particular excise duties (including those reflecting emissions); they are directly modelled in PRIMES by Member State and type of fuel, al-lowing for the full reflection of the effects of energy taxation and other financial instruments on end user prices and energy consumption. By assumption, current tax rates per Member State are kept constant in real terms throughout the projection period.

1.1 Buildings

Global incremental energy efficiency investment in buildings, including appliances and lighting, has been increasing and was USD 118 billion in 2015. Total spending on energy efficient products and services in buildings worldwide was USD 388 billion in 2015. This is 8% of total building construction spending, a share that has been rising.

1.2 Space heating and water heating

Heating energy use (for both space and water heating) accounted for 50% of total buildings energy consumption in 2015, a decrease from 60% in 1990. This downward trend is a result of improved efficiency standards for buildings and heating equipment.

In terms of standards for space heating equipment, policy makers have made significant performance improvements over the past decade. However, as 50%of the market remains unregulated, significant potential exists to increase efficiency towards BAT performance levels and to cut energy use in half (see Chapter 3). Canada has the highest-performing MEPS for regulated space heating equipment, at 48%of global BAT. In many countries, however, not all heating equipment is regulated by MEPS.

When considering regulation coverage across all heating equipment and fuel types, the proximity of existing MEPS to global BAT is significantly lower for countries that allow the purchase of unregulated equipment. For water heating equipment, the European Union achieved the largest performance increase between 2005 and 2015; its plan to implement new standards in 2017 will continue this trend. By contrast, Korea has not strengthened its MEPS though the performance level is among the highest of countries reviewed. In China and Korea, regulated equipment is relatively close to global BAT, but a significant proportion of unregulated equipment remains in circulation. For China, factoring in non-regulated equipment, the minimum performance of water heating equipment is only 27% of global BAT.

1.3 Market trends for energy efficient buildings

Heating energy use (for both space and water heating) accounted for 50% of total buildings energy consumption in 2015, a decrease from 60% in 1990. This downward trend is a result of improved efficiency standards for buildings and heating equipment.

In terms of standards for

1.4 Emerging issues for energy efficient buildings

Global commitments to reduce GHG emissions create major challenges and new opportunities for the building construction and renovation sector. Existing buildings, usually built to much less energy efficient building codes, will account for 45% of buildings heating and cooling energy demand to 2050. Over the same period, demand for space cooling will rise rapidly as populations and incomes increase in relatively hot regions of the world. These two trends affect member and non-member countries of the Organisation for Economic Co-operation and Development (OECD) very differently. For example, OECD countries are primarily located in climates that have limited space cooling needs and have a high share of buildings that will still exist in 2050. Many non-OECD countries are in climates that are likely to see significant increases in space cooling demand, but new construction dominates through 2050 (Figure 5.6). Thus, there is opportunity to take on the new challenge with more assertive new building energy codes and equipment standards in non-OECD countries. Another emerging trend in building energy efficiency is the move towards 'zero energy buildings' (ZEBs). Such ZEB policies are in their infancy in most countries and yet USD 15 billion of investment occurred in 2015, including USD 12.5 billion for energy efficiency and 2.5

billion for renewable energy (Navigant, 2015). To achieve global climate targets, policies are needed to integrate energy efficiency and renewable energy investment to achieve ZEBs in new construction although under current market and policy conditions this is not cost-optimal for investors. The European Union currently dominates the market for ZEB construction at more than USD 14 billion (Navigant, 2015); this reflects the enactment of a nearly zero energy building policy framework that prompted recent growth and is expected to stimulate further growth through to 2020.

2 MARKET PRICES OF PV SYSTEMS AND ELECTRICAL STORAGE

2.1 COST OF PHOTOVOLTAIC SYSTEMS

Techno-economic improvements in the solar PV industry, having surpassed previous expectations of costs, have been re-estimated using updated data. The development of PVs therefore starts from lower costs than previously expected and continues to exploit learning potential in the future. However, costs hit a floor that is justified by the incompressible costs of the modules and components such as inverters, frames and installation costs [02].

	2000	2010	2020	2025	2030	2040	2050
Wind Offshore	173	152	123	114	105	95	90
Wind Onshore	99	103	89	84	80	75	72
Solar PV – South of EU	383	124	77	71	65	59	55
Solar PV – North/Central EU	505	172	108	101	95	89	84
Solar Thermal	434	365	255	223	192	165	157
Geothermal	109	108	99	95	92	86	81
Large Hydro	135	135	135	135	135	135	135
Small Hydro	110	110	108	107	106	104	101

Table 1. Forecasted LCOE for different source of electric energy, expressed in EUR/ MWh.

2.2 COST OF STORAGE SYSTEMS

The cost of batteries is one of the major hurdles standing in the way of widespread use of electric cars and household solar batteries. By storing surplus energy, batteries allow households to reduce power bought from the electricity grid. Unfortunately, batteries have so far been prohibitively expensive.

However, research published recently in Nature Climate Change Letters [01] shows battery pack costs may in some cases be as low as US$300 per kilowatt-hour today, and could reach US$200 by 2020. This cost development is notably cheaper and faster decreasing than I and many others expected.

Falling prices will pave the way for what could be a rapid transition to a cleaner energy system.

Björn Nykvist and Måns Nilsson of the Stockholm Environment Institute analyzed 85 sources of data including journal articles, consultancy reports, and statements by industry analysts and experts. They report that since 2011 the number of electric vehicles worldwide has doubled each year.

The core conclusion of the new paper is that the cost of full automotive Lithium ion battery packs has already reduced to around US$410 per kWh industry-wide. Market-leading manufacturers such as Nissan and Tesla are already seeing prices around US$300 per kWh. In our previous work, we estimated these levels to be reached only in 2018 and 2022, respectively. The new battery cost analysis suggests even lower costs.

The analysis also estimated that the industry as a whole is currently seeing annual battery cost reductions of 14%, while for leading players with already lower costs this is closer to 8%. It is therefore predicted that battery cost for all involved should converge to around US$230 per kWh in 2017-2018. This is seven years earlier than estimated in our previous analysis. Assuming continued electric vehicle sales growth, the authors suggest costs as low as US$200 per kWh are possible without further improvements in the cell chemistry.

In [03] IRENA shows the results of an accurate analysis of more than 150 literature sources combined with expert interviews, to obtain a reliable forecast on the future of different technologies for energy storage. In *Table 2* - *Table 11* are summarized the forecasts.

2.2.1 Flywheel

	Unit	2016	2020	2025	2030
Cycle life	-	200k	225k	260k	303k
Calendar Life	Years	20	22.5	26.1	30.3
Round Trip efficiency	%	84	85	86	87
Self discharge	% per day	60	53.1	45.6	39.2
Energy installation costs	USD/kWh	3000	2656	2281	1958
Power installation costs	USD/kW	300	257	228	196

Table 2. Forecasted reduction cost for flywheel technology.

2.2.2 Lithium-Ion Batteries (NMC/LMO)

	Unit	2016	2020	2025	2030
Cycle life	-	2000	2046	3031	3819
Calendar Life	Years	12	13.6	15.8	18.4
Round Trip efficiency	%	92.0	92.5	93.1	93.7
Self discharge	% per day	0.1	0.1	0.1	0.1
Energy installation costs	USD/kWh	420	339	244	176
Power installation costs	USD/kW	-	-	-	-

Table 3. Forecasted reduction cost for lithium-ion batteries (NMC/LMO) technology.

2.2.3 Lithium-Ion Batteries (LFP)

	Unit	2016	2020	2025	2030
Cycle life	-	2000	2046	3031	3819
Calendar Life	Years	12	13.6	15.8	18.4
Round Trip efficiency	%	92.0	92.5	93.1	93.7
Self discharge	% per day	0.1	0.1	0.1	0.1
Energy installation costs	USD/kWh	420	339	244	176
Power installation costs	USD/kW	-	-	-	-

Table 4. Forecasted reduction cost for lithium-ion batteries (LFP) technolog.

2.2.4 Lithium-Ion Batteries (Titanate)

	Unit	2016	2020	2025	2030
Cycle life	-	10k	12k	15k	19k
Calendar Life	Years	15	16.9	19.7	23
Round Trip efficiency	%	96	96.5	97.1	97.8
Self discharge	% per day	0.1	0.1	0.1	0.1
Energy installation costs	USD/kWh	1050	880	665	502
Power installation costs	USD/kW	-	-	-	-

Table 5. Forecasted reduction cost for lithium-ion batteries (titanate) technology.

2.2.5 Lithium-Ion Batteries (NCA)

	Unit	2016	2020	2025	2030
Cycle life	-	1000	1203	1516	1910
Calendar Life	Years	12	13.6	15.8	18.4
Round Trip efficiency	%	92	92.5	93.1	93.7
Self discharge	% per day	0.2	0.2	0.2	0.2
Energy installation costs	USD/kWh	352	284	204	147
Power installation costs	USD/kW	-	-	-	-

Table 6. Forecasted reduction cost for lithium-ion batteries (NCA) technology.

2.2.6 High Temperature Batteries (ZEBRA)

	Unit	2016	2020	2025	2030
Cycle life	-	3000	3377	3914	4538
Calendar Life	Years	15	16.9	19.6	22.7
Round Trip efficiency	%	84	85	86	87
Self discharge	% per day	5	5	5	5
Energy installation costs	USD/kWh	399	323	234	169
Power installation costs	USD/kW	-	-	-	-

Table 7. Forecasted reduction cost for high temperature batteries (ZEBRA) technology.

2.2.7 High Temperature Batteries (NaS)

	Unit	2016	2020	2025	2030
Cycle life	-	5000	5614	6489	7500
Calendar Life	Years	17	18.8	21.4	24.3
Round Trip efficiency	%	80	81.4	83.2	85
Self discharge	% per day	7	7	7	7
Energy installation costs	USD/kWh	525	436	326	243
Power installation costs	USD/kW	-	-	-	-

Table 8. Forecasted reduction cost for high temperature batteries (NaS) technology.

2.2.8 Redox Flow Batteries (Vanadium)

	Unit	2016	2020	2025	2030
Cycle life	-	13k	13k	13k	13k
Calendar Life	Years	12	13.7	16.2	19.2
Round Trip efficiency	%	70	72.2	75.1	78.1
Self discharge	% per day	0.2	0.2	0.2	0.2
Energy installation costs	USD/kWh	347	268	183	125
Power installation costs	USD/kW	1312	1063	818	661

Table 9. Forecasted reduction cost for redox flow batteries (Vanadium) technology.

2.2.9 Redox Flow Batteries (ZnBr)

	Unit	2016	2020	2025	2030
Cycle life	-	10k	10k	10k	10k
Calendar Life	Years	10	11.4	13.5	16
Round Trip efficiency	%	70	72.2	75.1	78.1
Self discharge	% per day	15	15	15	15
Energy installation costs	USD/kWh	900	696	475	324
Power installation costs	USD/kW	-	-	-	-

Table 10. Forecasted reduction cost for redox flow batteries (ZnBr) technology.

2.2.10 Battery Inverters (>30kW)

It is forecasted to have relevant improvements in calendar life of battery inverters and a strong reduction in installation costs thanks to synergies with PV inverters and traction converters for electric mobility. This progress will be pushed by new concepts for improved capacitors and innovative topologies (such as feed-forward controls).

	Unit	2016	2020	2025	2030
Calendar Life	Years	15	16.8	19.3	22.3
Round Trip efficiency	%	98	98	98	98
Energy installation costs	USD/kWh	-	-	-	-
Power installation costs	USD/kW	105	89.5	68.9	53.1

Table 11. Forecasted reduction cost for battery inverters (>30kW).

3 PV PENETRATION IN ELECTRICAL GRIDS

The integration of a significant share of variable renewables into power grids requires a substantial transformation of the existing networks in order to:

1. allow for a bi-directional flow of energy; that is top-down (from generators to users) and bottom-up (with end-users contributing the electricity supply) aimed at ensuring grid stability when installing distributed generation;
2. establish an efficient electricity-demand and grid management mechanisms aimed at reducing peak loads, improving grid flexibility, responsiveness and security of supply in order to deal with increased systemic variability;
3. improve the interconnection of grids at the regional, national and international level, aimed at increasing grid balancing capabilities, reliability and stability;
4. introduce technologies and procedures to ensure proper grid operation stability and control (e.g. frequency, voltage, power balance) in the presence of a significant share of variable renewables;
5. introduce energy storage capacity to store electricity from variable renewable sources when power supply exceeds demand and aimed at increasing system flexibility and security of supply.

To guarantee that all these scenarios can be introduced in the next energy grid, it is important to predict the amount of intermittent renewables in the future European grids, for this purpose [02] is considered as a reference scenario; in *Table 12* results are summarized for EU countries.

For Switzerland, we considered a trend similar to surrounding countries; unfortunately, the scenarios described during 2011 in [04] were too pessimistic, considering that today the installed solar power is already higher than the forecast for 2035.

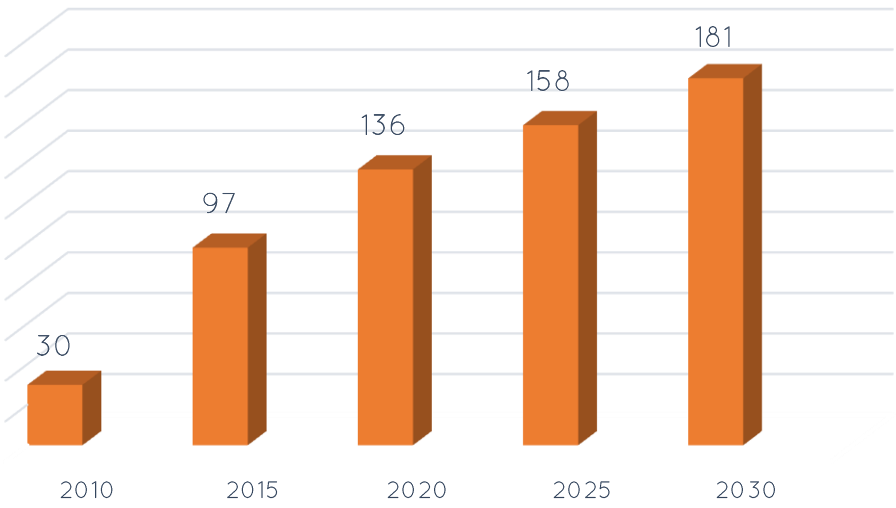

Figure 1. Actual and forecast data of global installed PV in Europe in GWp.

	2010	2015	2020	2025	2030
Austria	154	876	1090	2692	2821
Belgium	904	3212	3818	3818	3818
Bulgaria	25	1052	1069	1541	2572
Croatia	0	55	55	581	686
Cyprus	7	135	338	382	529
Czech Republic	1727	2266	2328	2365	2391
Denmark	7	837	838	838	838
Estonia	0	1	1	1	1
Finland	7	12	9	9	19
France	1030	6100	20535	24532	25382
Germany	17554	39757	52803	55901	63959
Greece	202	2605	3147	4766	5616
Hungary	2	45	106	106	106
Ireland	0	1	19	19	19
Italy	3113	18905	20057	23015	24562
Latvia	0	1	2	2	2
Lithuania	0	74	74	74	74
Luxembourg	29	120	131	131	131
Malta	2	60	185	185	198
Nederland	88	1238	5586	5586	5586
Poland	0	35	79	79	99
Portugal	134	467	531	1017	2172
Romania	0	1792	1824	1824	2223
Slovakia	19	608	620	620	680
Slovenia	12	262	352	569	779
Spain	4653	7126	9275	16027	24564
Sweden	11	81	88	88	88
United Kingdom	94	9721	11043	11043	11043
Switzerland	35	1660	2252	2567	3418

Table 12. Forecasted penetration of PV in electrical grids expressed in MWp.

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