Alternative and Sustainable Energy Scenarios for Hungary

Alternative and Sustainable Energy Scenarios for Hungary

Alternative and Sustainable Energy Scenarios for Hungary

Authors:

Authors from Wuppertal Institute for Climate, Environment and Energy:
Prof. Dr. Stefan Lechtenböhmer
Magdolna Prantner
Clemens Schneider

Authors from Energiaklub Climate Policy Institute and Applied Communications:
Orsolya Fülöp
Fanni Sáfián

With support of:
Dr. Karin Arnold
Benjamin Best
Mathis Buddeke
Frank Merten
Willington Ortiz
Ole Soukup

Managing Editor:
Benedek Jávor MEP

Publication of
Zöld Műhely Alapítvány
Villányi út 89., 1118 Budapest, Hungary

Copy Editor:
Tracey Wheatley

Budapest, 2016

Table of Contents

1. Introduction

On December 12th 2015, 195 groups reached the Paris Agreement at COP 21, aiming to combat climate change. A key element of the agreement is the long-term goal of limiting global warming to "well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels". According to the Fifth Assessment Report of the IPCC, in order to have good prospects of meeting the 2 °C limit, global greenhouse gas (GHG) emissions would have to be about 50% to 60% lower than the 2010 levels and would need to be reduced to around zero by the end of the century (IPCC 2014). There is widespread agreement that industrialised countries, with their relatively high per capita GHG emissions, will need to reduce their emissions faster than the global average.

The EU has set itself ambitious targets with regards to a significant reduction of its greenhouse gas emissions by 40% by 2030 and by 80% to 95% by 2050, relative to 1990 emissions levels and has presented roadmaps depicting an overall decarbonisation of its economy by the middle of the century (European Commission 2011).

Climate change is, however, not the only factor that will drive the change of European energy systems. Among other critical issues driving energy transformation in Europe are: the increasingly threatened supply of energy, intensifying integration of European markets, the efforts to improve energy efficiency of the European economies in order to reduce energy costs and raise business competitiveness, as well as release poorer parts of the population from overly high energy costs.

Given this background the individual member states of Europe need to gain a better understanding of precisely how the energy system will change in their country, to be better prepared for the future changes and to identify which options they have to figure out and pursue national energy policy priorities and to achieve the overall targets agreed in the EU. However, contrary to the situation in some other EU member states, for Hungary only a small number of energy scenarios describing the potential drivers of change and their possible consequences as well as policy options does exist so far. Also the framework conditions for the existing Hungarian energy strategy, approved in 2011, (with a strong fossil fuel and nuclear focus) have changed substantially e.g. by the suspended South Stream project and the EU raising concerns around the planned extension of Paks nuclear plant, making a fresh look at the situation necessary.

Therefore The Greens / European Free Alliance Group of the European Parliament contracted Wuppertal Institute for Climate, Energy and Environment together with Energiaklub to develop scientifically sound, comprehensive, alternative, and sustainable long term energy scenarios for Hungary, with a time horizon of 2030 and 2050. The scenarios developed for this report shall deliver information about the costs and long-term effects of different energy choices for Hungary as well as credible information on the potential benefits of greening the energy mix. By this the study aims to provide policy makers with better evidence for making informed, prudent and forward-looking decisions in this field.

The authors hope that the project and its results will be instrumental in initiating a public debate in Hungary, helping to build a sense of ownership among different stakeholders and citizens and at the same time enable national decision-makers to reflect the changing geopolitical and policy context and to reshape national energy policy with a long-term, sustainable, strategic mind set.

Furthermore, in the context of the Energy Union package, the project aims to be a very first step to explore the long-term possibilities of a mutually beneficial regional cooperation for a sustainable energy system between Hungary and its neighbouring countries.

In order to explore possible future developments of the Hungarian energy system in a European context four different scenarios were developed:

The 'NUCLEAR' scenario aims to describe a development of the energy system under a "business as usual" philosophy with a continuity of the current energy policy. This primarily focuses on the expansion of nuclear operations at the Paks power plant as the main strategy for dealing with the challenges of the future energy system. Technically the scenario is based on the most recent EU energy reference scenario for Hungary (European Commission 2013) with some changes regarding future nuclear activity.

In contrast to this the 'GREEN' scenario envisages a strong energy policy focus on energy efficiency and the expansion of renewable energy generation in Hungary. It shares the same basic data as well as the assumptions on population as well as GDP development as the other scenarios. Its strategy is based on a deep sector-by-sector analysis of the existing potentials for improving energy efficiency and the potentials to sustainably expand renewable energy generation. This includes an analysis of the future integration of the regional and European electricity systems in order to balance variations in production and demand.

To explore further alternative options of the future development of the Hungarian energy system two 'INTER' scenarios were developed which both assume that neither Paks2 nor any other new nuclear reactors will be built in Hungary. Besides this the scenario INTER-A follows the lines of the current trends and current policy for the energy demand side. Instead of new nuclear power plants renewable electricity generation is expanded to supply the electricity demand in the scenario. Scenario INTER-B adds to this an active policy for energy efficiency and energy savings – although this is less ambitious than the respective policy in the GREEN scenario.

All four scenarios have been modelled in a way to be comparable and compatible with the European Reference Scenarios published by the European Commission. All of them, however, score differently with regards to the core sustainability criteria for the Hungarian energy system. These are the amount of GHG emissions from the energy system, the amount of nuclear energy used and of nuclear waste produced, the import and use of fossil energy carriers, and the costs of the energy system that have to be borne by Hungarian businesses and households.

In the following summary report we first briefly introduce the methodology used to generate the scenarios and then discuss key assumptions as well as results for all four scenarios. Finally we compare the scenarios and provide policy recommendations. More details on the methodology and the results can be found in the full report available in Hungarian.

2. Modelling future energy systems

The scenarios have been modelled using a combination of two proven models. The WISEE-Model has been developed by Wuppertal Institute (WI) and was used to simulate final energy demand and the potentials for increasing energy efficiency. The EnergyPLAN model has been developed by Aalborg University and was used in this study to simulate electricity and heat supply as well as demand on an hourly basis to analyse the functioning of future high RES electricity systems. The models have been calibrated to be comparable and compatible to the most recent European Reference Scenarios published by the European Commission (2013).

Modelling is a technique used to create quantitative scenarios. In the Alternative and Sustainable Energy Scenarios for Hungary (ASES) project modelling was used to create consistent scenarios on energy use and energy supply. Energy system analysis provides a reference energy system as a framework to analyse the system and to reproduce it in a model. The model allows for a consideration of interlinkages between demand, supply, technical limitations and physical constraints (like limited biomass potentials, weather dependent technologies for electricity production). Sectoral, geographical and temporal resolution of the model can vary according to the respective research questions.

In the ASES project scenarios were derived by a combination of two model types. The energy system simulation model (WISEE ESM) calculates the demand of energy services and final energy demand. Primary energy use, CHP-heat, electricity supply as well as demand side management (DSM) and dispatch of storage capacities are modelled with EnergyPLAN. Both models have a national resolution, i.e. the Hungarian territory is reproduced as one entity in the models. That means that spatial distribution of heat and electricity grids are not regarded in the models. Questions on possible bottlenecks in transfer capacity or the demand of future grid extension (or even deconstruction in the case of heat grids) cannot be examined with the versions of the models used here.

Sectoral resolution of the energy system simulation model is high. Sector modules of WI's existing and extensively used WISEE ESM were applied and adapted to the Hungarian case and data availability. WISEE ESM's strength is a comprehensive reproduction of sectoral energy demand, i.e. energy demand is calculated bottom-up using detailed information on the existing stock of energy consuming appliances and their utilization in Hungary.

Whereas the energy system simulation model has a yearly resolution, the electricity supply side model has an hourly resolution. This reflects the rising need of energy science to get information on a seasonal / monthly / daily or even hourly balance of electricity demand and supply because of fluctuating renewable electricity generation.

To operate both models in a consistent way in order to generate integrated scenario analyses, yearly electricity and district heat demand data were translated into hourly resolved demand curves.

The state of the art method for transforming yearly data to a higher temporal resolution in energy system modelling is the use of (historical) normalized sectoral load curves for heat and electricity respectively. The electricity demand curve was prepared on the basis of data from the Hungarian TSO (MAVIR 2014), while the heat demand curve is based on the data of a power plant in Budapest from 2011 (FŐTÁV 2014).

2.1 WISEE energy system simulation model

The basis for the overall energy demand modelling are the respective sectoral modules of WI's WISEE ESM. Following Herbst et al. (2012) the WISEE ESM can be classified as a bottom-up simulation model, with a very detailed representation of energy system technologies and a low degree of 'endogenization', i.e., many parameters are externally fixed which allows national particularities to be taken into account and provides for optimum transparency of these data. The model's focus is on unveiling existing energy efficiency and GHG mitigation potentials and describing consistent pathways to exploit them rather than pure economic optimization of the whole system (Connolly et al. 2010; Hourcade et al. 2006).

In the current project the following variables were set exogenously using national statistics, policy plans and the EU reference scenarios:

- population,
- economic activity,
- market shares of technology when investing in a given year,
- available technologies in a given year and their respective specific energy demand.

Based on these data the model determines respective stocks of technologies in given years as well as their (mean) specific energy consumption endogenously.[1] Four energy demand sectors are represented in WISEE ESM: industry, services & agriculture, households and transport.

Within the ASES project the industry module, the service module and the household appliances tool were used and adapted to the Hungarian system. Residential buildings and transport were modelled with adapted sub-models which have been used and validated in Energiaklub`s earlier research on the Hungarian energy system.

Hungarian energy intensive industry has been modelled bottom-up, i.e. site and process specific. Existing literature (and statistical) information on typical (age specific) energy needs of production stock has been used. Energy demand of existing industry was derived for the base year (2010) by regarding the utilization of production stock, which can be derived by matching capacities with production. Production data are at least partly available in the form of production statistics. Whereas steel industry and refineries provide very detailed production statistics, this is not the case in the chemical industry. EU's PRODCOM does not provide all production data due to confidentiality (there is only a little number of producers in Hungary). Energy use and respective (direct) GHG emissions were validated with energy statistics and site/appliance specific GHG emission data of the EU ETS.

Future production was derived on the basis of the EU reference scenarios (European Commission 2013) which give at least GVA values for the industry sectors. In the case of steel industry, comparing energy consumption data in the scenarios validated this derivation further.

The time series of energy intensities for production processes were determined for every sector-specific technology (e.g., electric arc furnace, blast oxygen furnace, steam cracking) and for crosscutting technologies (e.g. motors, lighting) in the respective modules. To do this, vintage stock models for all major plants in the steel industries, the refinery and petrochemical sector as well as fertilizer production (ammonia and nitric acid) were used. The vintage stock models account for all major production stocks individually with their specific age, capacity and efficiency using data from Hungary's industry reporting to the European Trading Scheme (ETS). For the paper mills and clinker ovens, such detailed data on single stock not available, therefore a simplified model was used.

A technology matrix provided base assumptions for the specifications of new investments or replacements (lifetime, efficiency, energy carriers) and their availability dates.

Assumptions about lifetimes were derived from Fraunhofer-ISI et al. (2011) and stakeholder inputs (from previous projects). All technical assumptions have been validated thoroughly during the participation process that was led by the Wuppertal Institute in order to formulate the Climate Protection Plan of the German federal state NRW. WISEE was used there to calculate scenarios in a participatory way with stakeholders. A comprehensive documentation of this process and the resulting assumptions is given in Lechtenböhmer et al. (2015a, 2015b).

The choice of technology is scenario specific. So in the "maximum scenario" electrification is the focal point to get beyond "best-available technology" and to achieve a deep decarbonisation.

2.2 EnergyPLAN

The EnergyPlan model has been developed (and continuously improved) since 1999 by Aalborg University, Denmark. The software allows the hour by hour simulation of the operation of a country's or a region's whole energy system including all sectors, primary energy use, electricity, heat supply and numerous other fuel conversions and storage technologies. The main goal of the model is to find the way to integrate intermittent renewable energy sources in an optimal way (EnergyPLAN 2015). For that aim the model offers diverse tools for analysing key energy parameters (e.g. electricity and heat production, primary energy supply, etc.) as well as environmental (e.g. CO_2 emissions) and economic parameters (e.g. electricity production costs, fuel costs).

1 To handle uncertainties and to cope with the lack of statistical data for Hungary, a simplified procedure was used in the service and transport sector.

Energiaklub has already applied EnergyPLAN to analyse different strategies for the national energy system in Hungary (Sáfián 2015). For the purpose of our study EnergyPLAN was used to analyse the performance of the energy supply systems that emerged out of the (bottom-up) WISEE simulations. Thus WISEE provided the key parameters of the technology matrix that would match the storylines developed for each scenario, in the target years 2030 and 2050. Based on those parameters the corresponding energy systems were modelled in EnergyPlan with a focus on the electricity supply, and their hourly operation was simulated.

Hourly distribution curves from 2011 for heat demand, solar radiation, wind power production, electricity production and electricity import-export flows in Hungary were used to set up the models. The simulation followed a strategy which maximized the use of fluctuating renewable energy sources (besides biomass and biogas), while the allocation of the other plants (biomass, biogas, natural gas, oil, coal, etc.) was carried out according to a technological optimization strategy.

3. Scenarios

In order to explore possible future developments of the Hungarian energy system in a European context four different scenarios were developed, of which the first scenario basically follows current policy while the other three describe more or less ambitious alternatives.

All four scenarios, however, score differently with regards to the core sustainability criteria for the Hungarian energy system. These are the amount of GHG emissions from the energy system, the amount of nuclear energy used and of nuclear waste produced, the import and use of fossil energy carriers, and the costs of the energy system, which have to be borne by Hungarian businesses and households.

3.1 Assumptions of the NUCLEAR scenario

The 'NUCLEAR' scenario aims to describe a development of the energy system under a "business as usual" philosophy with a continuation of the current energy policy which focuses primarily on the expansion of nuclear operations at the Paks power plant as the main strategy for dealing with the challenges of the future energy system. Technically the scenario is based on the most recent EU energy reference scenario for Hungary (European Commission 2013[2]) with some changes regarding future nuclear activity.

During the preparation of the NUCLEAR scenario, we decided to make some amendments to the PRIMES / EC (2013) data. In the case of the extension of the Paks nuclear power plant we used the data of the official national strategy. While PRIMES data contains a possibility of further nuclear power plants going online after 2030, the official Hungarian energy scenario (Nuclear-Coal-Green) does not. Therefore we did not assume any further extension of nuclear power plants after 2030. The NUCLEAR scenario assumes following nuclear capacities:

- 4400 MW in 2030 (instead of 4035 MW in PRIMES / EC 2013),
- 2400 MW in 2050 (instead of 3200 MW in PRIMES / EC 2013).

Therefore the NUCLEAR scenario assumes higher natural gas consumption than in PRIMES. There are several reasons for this: sometimes incoherent and ambiguous PRIMES data, lower nuclear capacities in 2050, and natural gas consumption is considered by the model as the variable fuel tuned to balance the system. The consequence is a slightly smaller RES percentage in the NUCLEAR scenario.

3.2 Assumptions of the GREEN scenario

In contrast with this the 'GREEN' scenario envisages a strong energy policy focus on energy efficiency and the expansion of renewable energy generation in Hungary. It shares the same basic data as well as the assumptions on population and GDP development as the other scenarios. Its strategy is based on a deep sector-by-sector analysis of the existing potentials for improving energy efficiency and the potential to sustainably expand renewable energy generation. This includes an analysis of the future integration of the regional and European electricity systems in order to balance variations in production and demand.

The GREEN scenario assumes a radical cut in final energy demand. The decrease of energy need is based on various factors:

- Increased energy efficiency in every sector;
- Hydrogen-strategy in industrial and transport sectors;
- Electric mobility;
- Increased retrofitting of the building sector;
- Increased renewable energy in order to cover the remaining energy need;
- Analysis of existing national and international literature to determine the technical potential of renewable energy sources in Hungary.

2 The scenario follows largely the PRIMES reference scenario for Hungary as published in EC 2013. PRIMES is a partial equilibrium model for the EU energy markets that is used for forecasting, scenario construction and policy impact analysis. It is mainly used for energy and environmental policy analysis, impacts of carbon emission trading, renewable and energy efficiency policies on energy markets (E3Mlab/ICCS, n.d.)

The available electricity scenario studies contain inconsistencies in both renewable capacity and generation data, which are probably due to data gaps. Therefore we based our own assumptions for long-term technical potentials for renewable energy on current international literature (see chapter 4 for more details). The basis of the critical analysis was the research of ELTE University, Budapest (Munkácsy 2011, 2014). According to the assumptions of the GREEN scenario, in the period up to 2050 wind and solar will be the most dominant renewable energy sources, followed by biomass and biogas. Based on the estimation of technical renewable energy potentials we made severe reductions in order to take into consideration serious potential sustainability constraints, such as the soil nutrition needs in the case of biomass.

In order to integrate the increasing renewable electricity supply, we assumed active demand side management (2 TWh) and an increasing electricity exchange following the grid expansions planned in the context of the Energy Union. Our assumptions on the development of the international transmission network take into account the current "Ten Year network development plan" (ENTSO-E 2015).

3.3 Assumptions of the INTER scenarios

To explore further alternative options of the future development of the Hungarian energy system two 'INTER' scenarios were developed which both assume that neither Paks2 nor any other new nuclear reactors will be built in Hungary.

Scenario INTER-A follows the lines of the current trends and current policy for the energy demand side. Instead of new nuclear power plants renewable electricity generation is expanded to meet the electricity demand in the scenario. The final energy demand remains as in NUCLEAR scenario. The increased use of various renewable energy power plants will close the gap between demand and supply.

Scenario INTER-B adds an active policy for energy efficiency and energy savings to this – although this is less ambitious than in the respective policy in the GREEN scenario. Similarly to INTER-A scenario, the gap between energy demand and supply will be closed by the increased use of renewables.

4. Available technical RES potentials until 2050

Scenarios from different studies depict possible future developments of renewable energy sources used to generate electricity (RES-E) in Hungary up to the year 2030 or 2050 respectively. The range of installed capacities and the electricity generation from renewables assumed in these scenarios is displayed in Figure 1 and Figure 2.

Both capacity and generation estimates show several inconsistencies which are probably due to data gaps. Ignoring these inconsistencies and focusing on the general trends of the scenarios analysed, it becomes obvious that they depict a wide range of possible future deployment of renewables.

These deviations may be caused by different underlying assumptions concerning RES-E potentials, considering different technical, social, economic or environmental restrictions. Unfortunately, these assumptions are not available to the public for most of the existing studies on future RES deployment. Furthermore, the timeliness of the analysis and the applied data may strongly influence the result of a RES-E scenario analysis. Some of the studies were published a few years ago – and therefore rely on a technological status that dates even further back. The applied data may therefore already be partly out-dated due to rapid developments in technology and the cost of renewables. For these reasons our own estimates on sustainable potentials for renewable energy generation are presented in the following sections.

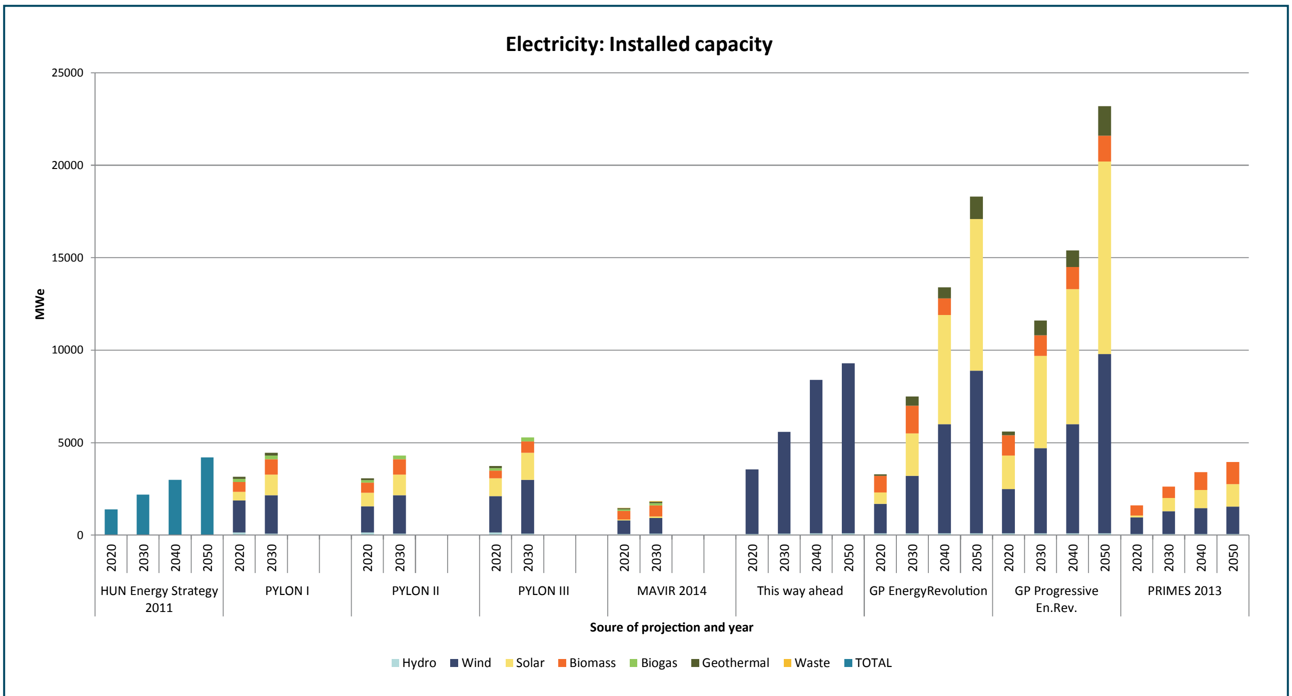


Figure 1. Installed renewable electricity generation capacity in Hungary 2020-2050 according to different studies and scenarios (Sources: NFM 2011; PYLON 2010; MAVIR 2014; Munkácsy 2014; Greenpeace et al. 2015; European Commission 2013)

4.1 Wind

Although further restrictions may apply to land availability for wind power, it can be stated that wind power potential in Hungary is well above the assumed long-term generation of 26 TWh stated in Munkácsy (2014) and other studies mentioned previously.

We assume a technical potential of 72,610 MW (152 TWh) and a realizable potential of 25,000 MW (50 TWh/a). These results are based on the following central assumptions:

- 14,522 km² (15.6 % of the country) would be available for wind power in principle (based on Eurostat 2014; Fraunhofer ISI 2014). Of this roughly 1/3 could be expected to be realized after thorough site analysis (by analogy with UBA 2014).
- A capacity density of 5 MW/km² can be assumed as realistic (Hoefnagels et al. 2011).
- Average long-term full load hours of 2,100 h/a can be achieved with the expected future power plant provision (own calculations based on (Fraunhofer IWES 2016; UBA 2010, 2014; Lütkehus 2013).

The deviation from existing scenarios for Hungary is due to the following reasons:

- Higher land use potentials for wind power based on current studies (e.g. (Fraunhofer ISI 2014)).
- Higher capacity density on suitable area (wide range of assumptions in existing literature from 5 to more than 20 MW/km² (Hoefnagels et al. 2011; UBA 2014)) – related to increasing capacities of individual plants.
- High full load hours even on weak-wind sites due to technical improvements.

4.2 Solar photovoltaic

Our assessment results in higher PV potentials compared to the results of the existing analyses mentioned above: we calculate a realizable capacity of 63,578 MW and a generation potential of 67.7 TWh. These results are based on the following central assumptions:

- 89 km² of roof area (9 m²/cap), 32 km² of façade area (3.25 m²/cap) available for building-integrated PV (Hoefnagels et al. 2011; UBA 2010, 2014) and 946 km² (1 % of the country) available for ground-mounted PV after consideration of competing uses (own assumptions based on (Eurostat 2014; Fraunhofer ISI 2014, 2015))
- Space demand of 5.88 m²/kWp for building-integrated (UBA 2014) and 22 m²/kWp for ground-mounted PV (BMVI 2015)
- 1,100 full load hours for rooftop and ground-mounted PV (optimally inclined), 700 full load hours for façade-integrated plants (vertically inclined) (Hoefnagels et al. 2011)

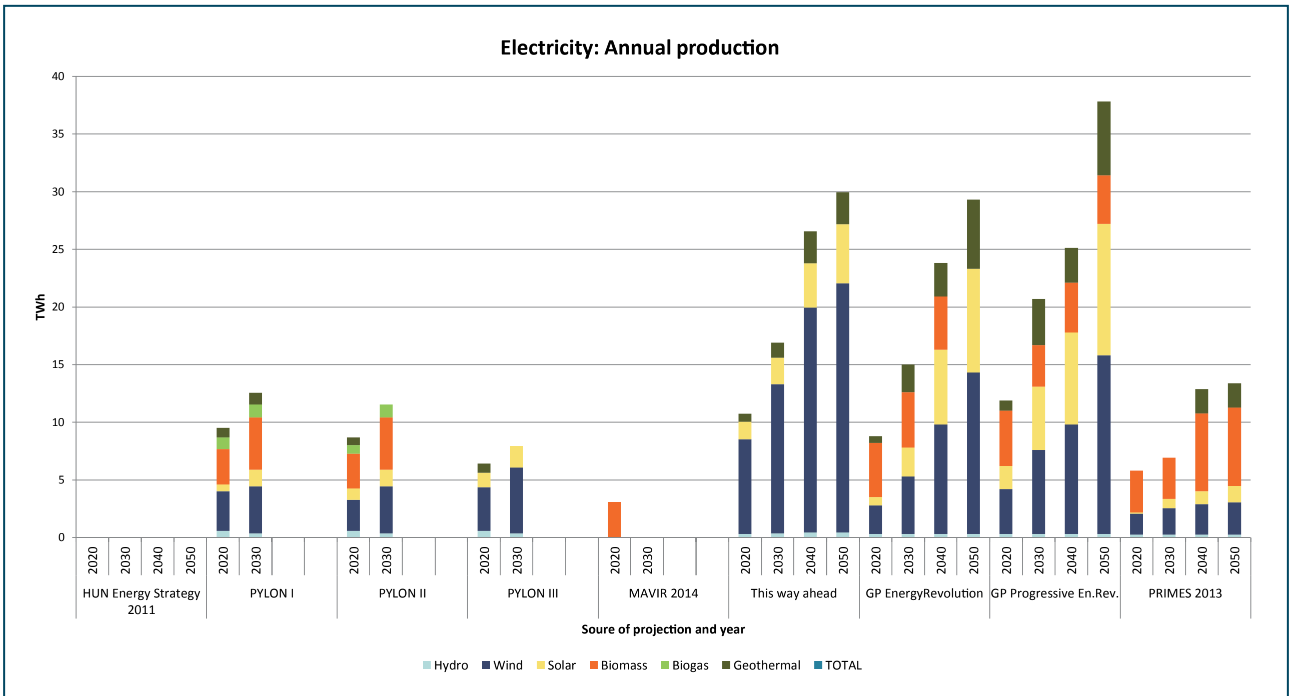


Figure 2. Renewable electricity production in Hungary 2020-2050 according to different studies and scenarios (Sources: NFM 2011; PYLON 2010; MAVIR 2014; Munkácsy 2014; Greenpeace et al. 2015; European Commission 2013)

Compared to Munkácsy (2014), this increase in potential is mainly due to the consideration of façade-integrated and especially ground-mounted plants, the latter constituting the most relevant share of the calculated potentials. However, in contrast to building-integrated PV, the exploitation of ground-mounted PV potentials is linked to an additional space demand.

4.3 Biomass

We assume an overall (technical) long-term potential for biomass of about 445 PJ. Bio-liquids, biogas and bio waste cannot be validated due to incomplete information and are therefore adopted from Munkácsy (2014) (195 PJ). In addition to this, for biomass from energy crops, our own result (about 250 PJ) significantly exceeds the potential stated by Munkácsy (2014).

Our calculation of biomass potentials from energy crops is based on the following central assumptions:

- 2 Mio ha of arable land available for energy crops (Zeddies et al. 2012)
- Yield of energy crops of 6 t/ha (Thrän et al. 2005; Kovács 2010)

Compared to Munkácsy (2014) we assume higher overall biomass potentials due to:

- Assumption that exploitation of potentials remains at maximum level for all sources of bioenergy, once reached for the first time.
- Concerning energy crops: 2 Mio ha (according to Zeddies et al. 2012) instead of 0.5 Mio ha in Munkácsy (2014). (Optimistic assumptions in other studies even exceed 3.5 Mio ha. (Thrän et al. 2005)).

5. Comparison of the scenarios

All four scenarios have been modelled in a way to be comparable and compatible with the European Reference Scenarios published by the European Commission (2013).

The broad range of outcomes from the differing choices considered in each of the scenarios is well illustrated by Figure 3, which shows the evolution of total primary energy supply (TPES) of the Hungarian energy system in the four considered scenarios. Two facts very well illustrate the broad range of choices considered by the four scenarios as well as the radical different outcomes that result from those choices.

First important difference is the strong reductions of TPES that are obtained in the scenarios GREEN and INTER-A, which already illustrates the energy efficiency potentials available for the future development of the Hungarian energy systems.

The second large difference is the sharp reduction in the dependency on fossil and nuclear energy carriers achieved in the GREEN scenario: from circa 80% of the TPES in 2010 to less that 30% by 2050. In the following sections these and other results are discussed in more detail.

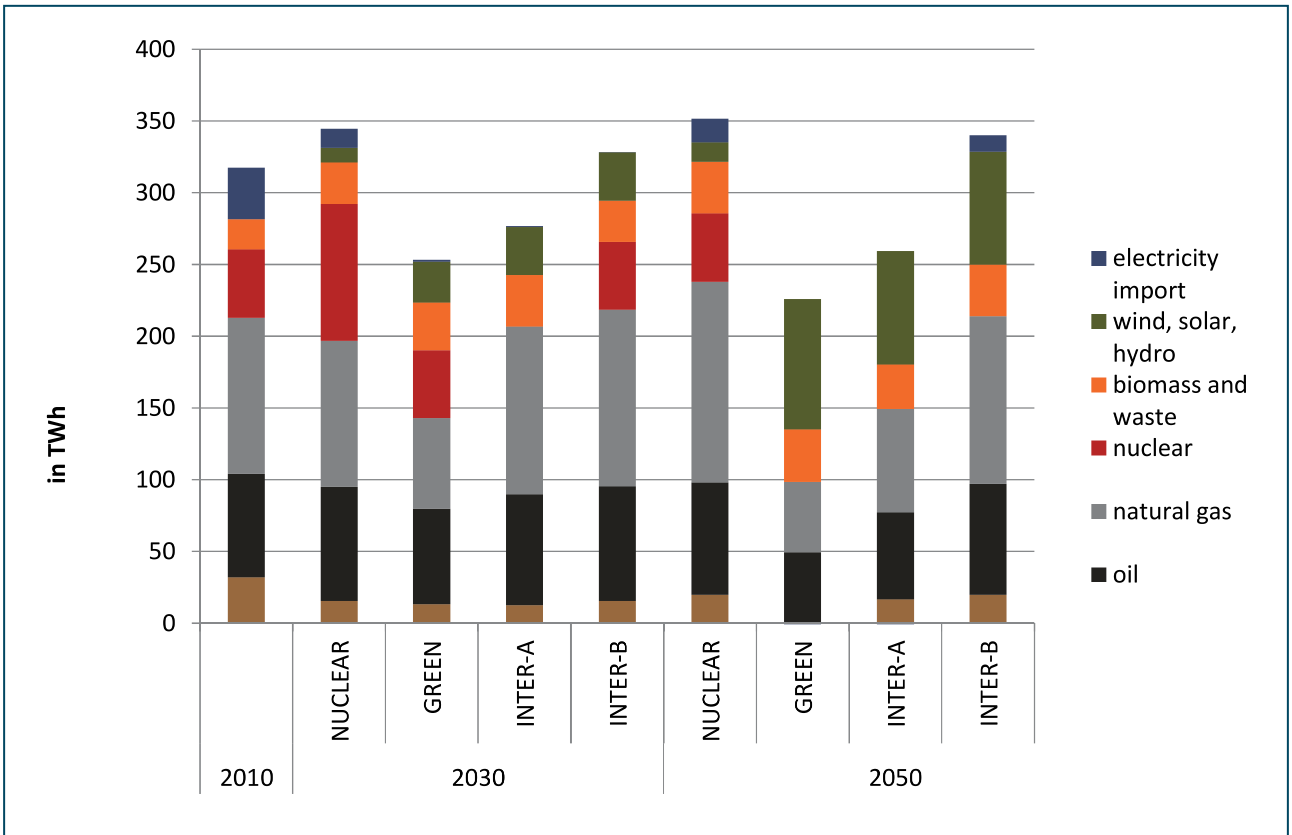


Figure 3. Total primary energy supply by energy carriers

5.1 Power generation

The power generation systems that develop under each of the considered scenarios are illustrated by Figure 4. The progressive phase-out of nuclear power implicit in the scenarios GREEN and INTER-A and INTER-B is compensated by a higher level of investment in renewable energy generation capacities. This also translates into a larger level of total installed capacities in those three alternative scenarios. While the total installed capacity under scenario NUCLEAR rises to 11,4 TW by 2050 (beginning at around 9 TW by 2010), all alternative scenarios lead to installed capacities of around 25 TW in the same period. This is due to the operational nature of wind and solar technologies, which have lower full load hours than fossil and nuclear generation capacities.

Besides the differing total levels of installed capacity, the distribution among the generation technologies also shows interesting contrasts. Under the NUCLEAR scenario the power plant stock remains dominated by fossil and nuclear capacities (around 64% of the total installed capacity by 2050). This also implies that the renovation of Hungary`s already aged power plant stock would be undertaken by investments in nuclear (the extension of Paks) and new gas and coal fired power plants (particularly between 2030 and 2050). This sequential dynamic in the NUCLEAR scenario (first strong investment focus on nuclear and then on fossil plants) is more explicitly illustrated in the development of the share of fossil energy carriers in electricity generation as shown in Figure 5. Fossil power production is expected to be almost cut by half between 2010 and 2030 (from circa 19 TWh to circa 9 TWh) and subsequently to increase well beyond the initial level by 2050 (to around 28 TWh). Here too the contrast to the GREEN scenario is prominent, where the aged power plant stock (fossil and nuclear based) is progressively replaced, mainly by renewable energy capacities, and to some extent through new additions of natural gas plants.

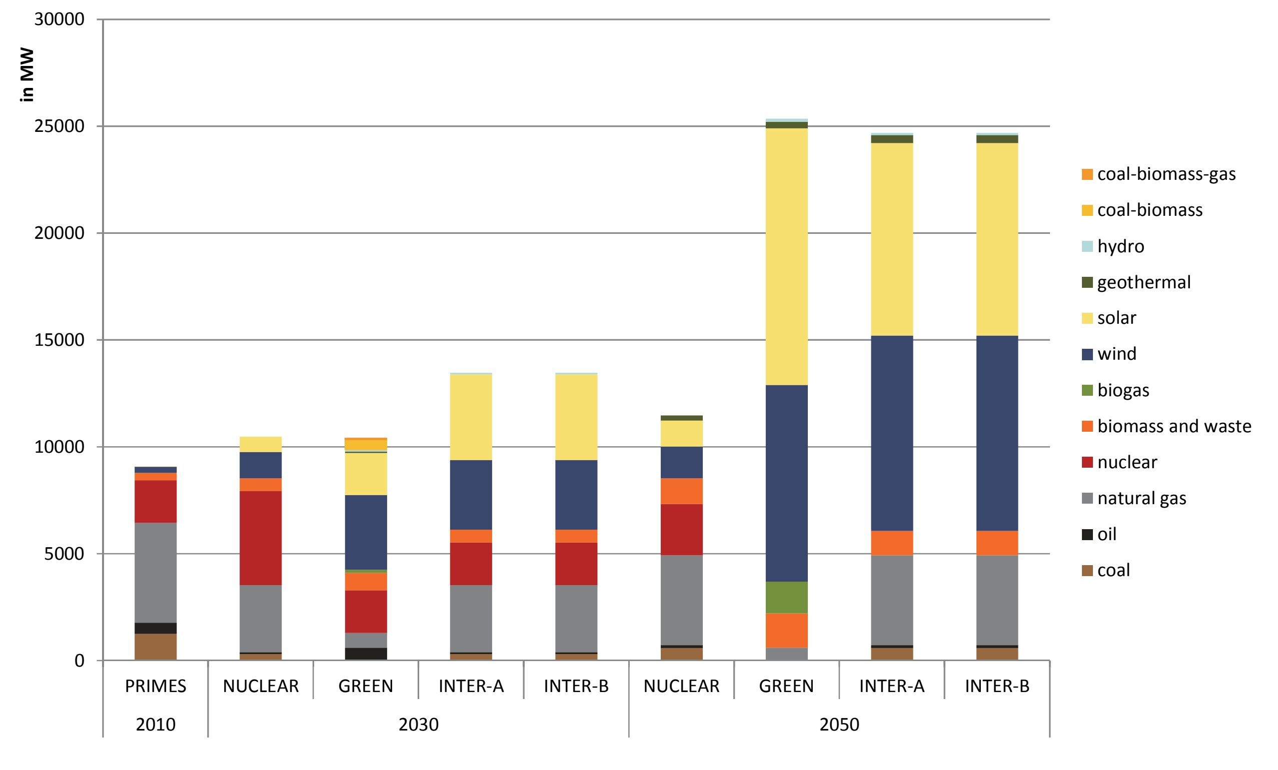


Figure 4. Power generation capacities by energy carrier

5.2 Energy efficiency

In the GREEN and INTER-B scenarios ambitious energy efficiency measures are introduced (compared to the NUCLEAR scenario that is based on PRIMES / EC Reference scenario, 2013). Sectors with the highest rates of savings in the GREEN scenario are residential and commercial as well as public buildings. Here large energy saving potentials do exist (Fülöp 2011, 2013). Also a significant share of them can be realized by targeted policy mixes for insulating existing buildings and by introducing low energy and passive house concepts in new developments.

In contrast with this energy efficiency potentials are more difficult to realise in transport and energy intensive industries. Savings in the GREEN scenario by 2050 vs. 2010 amount to 30% in transport and 13% in industry, albeit in the case of business as usual, these sectors also show the highest increases in final energy demand.

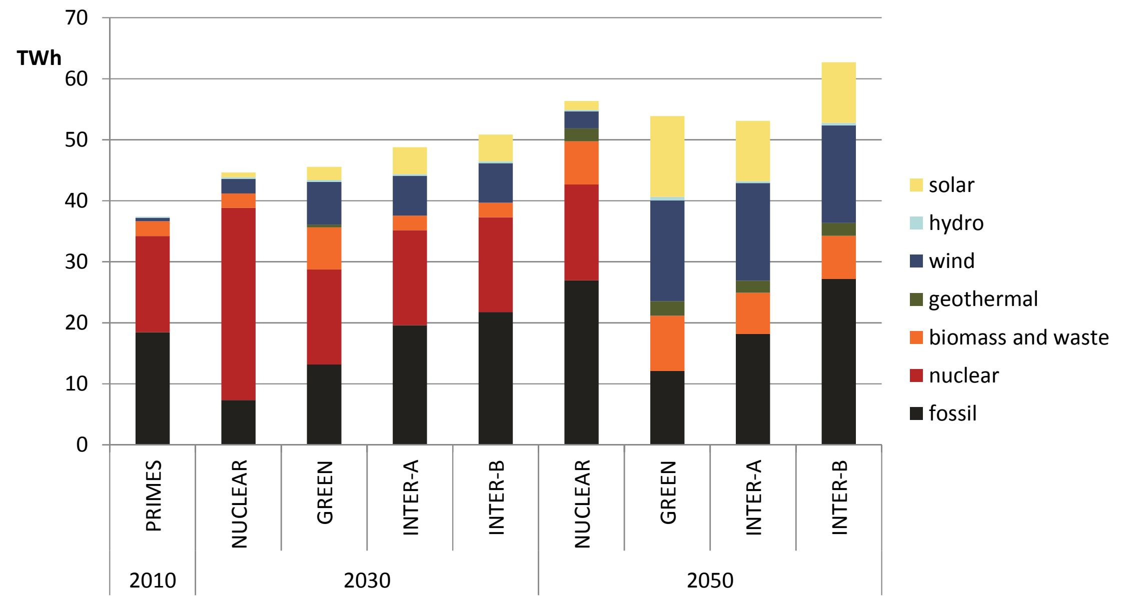


Figure 5. Annual electricity generation by energy carrier

Increasing energy efficiency leads to a reduction of coal use in final energy in the GREEN scenario by almost 98% and of oil by more than 50% vs. 2010. Due to the high savings as well as the expansion of renewable heating systems and electrical heat pumps in buildings, the demand for natural gas for final energy purposes decreases by over 70% by 2050.

Due to the growth in use of electric appliances such as in the heating segment and in transport, electricity demand remains more or less stable in the GREEN scenario, which means that the share of electricity will increase from 18 to 34% from 2010 to 2050. However, compared to the expected 45 % increase in electricity demand in the business as usual case the GREEN scenario will need 12 TWh or 25% less electricity in 2050, due to high efficiency improvements in electric appliances, which compensate the additional consumption from the expansion of electricity uses.

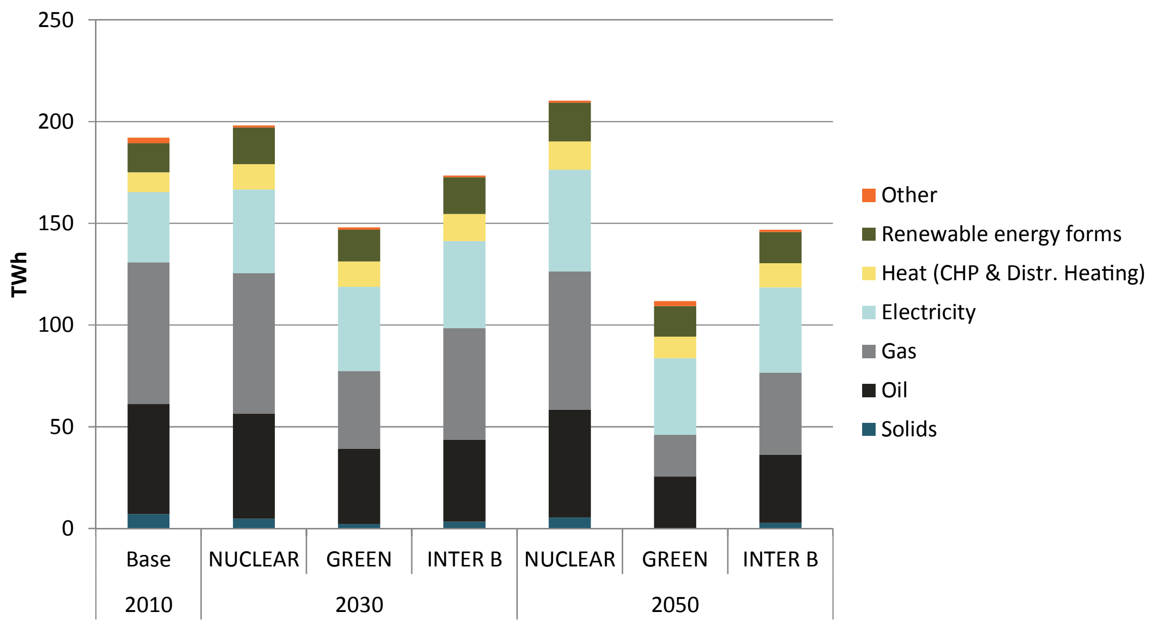


Figure 6. Annual final energy demand by energy carrier/technology applied[3]

3 *Final energy demand in the INTER-A scenario are equal to those in the NUCLEAR scenario, therefore not displayed in the graphic*

The INTER-B scenario contains only moderate energy efficiency measures compared to the GREEN scenario:

- Less insulation in the building sector;
- A large part but not all of the household appliances are modernized;
- In the transport sector less electric cars and no hydrogen-strategy;
- Industry & Service sectors: no hydrogen-strategy, only part of the available efficiency potential will be utilized;
- Lower investment into energy efficiency measures as compared to the GREEN scenario;
- Still significant reduction in the final energy use.

5.3 Renewable energy

Following energy efficiency renewable energy generation is the second most significant option to increase the sustainability of the Hungarian energy system. To be sustainable renewable energies, however, need to respect the multiple demands for limited space and agricultural land in Hungary (EEA 2006). In recent years development of photovoltaic as well as wind energy technology (particularly for low wind sites) has been impressive and significantly reduced costs as well as efficiency of the technology.

Taking this into consideration, a review of existing studies on renewable energy potentials for Hungary was carried out. This review took into account Hungarian studies, European studies with a country wise resolution and German studies, which were extrapolated. All in all, this comparison showed that the existing potentials of solar, wind and bioenergy as well as geothermal are significant – even if the use of agricultural lands is strictly limited (see above Chapter 4).

5.3.1 Shares in TPES and electricity generation

In total wind and PV would each technically be sufficient to supply the complete Hungarian electricity demand by the year 2050 even in the BAU case. The sustainably available potential of biomass would be sufficient to supply twice the non-electric final energy demand in the GREEN scenario in 2050 and almost 80% of the respective demand in the NUCLEAR scenario.

In the GREEN as well as INTER scenarios only between 10 and 20% of the identified renewable electricity generation potentials will be de facto used until 2050 – to generate between 62 % (INTER) and 78 % (GREEN) of Hungarian electricity and to supply between 26 and 50% of total primary energy, as shown in Figure 7.

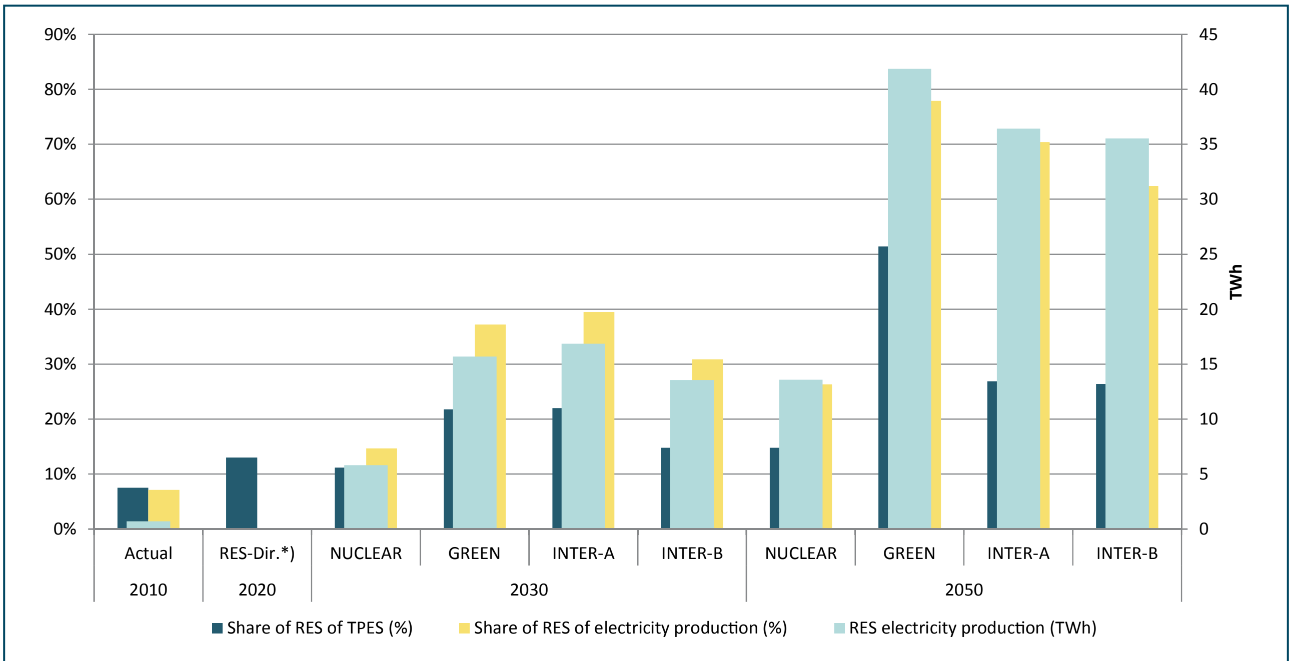


Figure 7. Share of renewable energy sources in the total primary energy supply
*) RES Directive, national target: 13% of gross final energy demand (equals roughly TPES)

In the NUCLEAR scenario renewable electricity will only account for 26% of electricity generation and some 15% of primary energy supply by 2050, which means only a marginal additional improvement on the national target of 14,65% of gross final energy demand which was set in the RES-directive for 2020.

Instead of a steady expansion of RES electricity the NUCLEAR scenario assumes two new nuclear power plant blocks will be completed before 2030 at Paks. They will mainly replace old coal and natural gas fired power plants. By 2035, however, the currently existing nuclear power plants will have to be decommissioned. In order to replace them, after 2030 new gas fired power plants will have to be built.

5.3.2 Electricity export – import balance

The increasing integration of European electricity markets and the consequent expansion of transnational interconnections are of particular relevance under scenarios with a high share of renewable energy power generation. Figure 8 illustrates this issue through the projection of seasonal exports and imports of power by 2050 under the GREEN scenario. The high availability of solar radiation between March and August leads to a strong increase in electricity production from PV capacities during that period of the year. Assuming the appropriate regulations and infrastructure for transnational coordination of power transfers are in place, these seasonal fluctuations can be compensated for as power exchange under an integrated regional market. Particularly the exchange of electricity with neighbouring countries possessing high hydroelectric capacities like Austria and Romania, and to some extent Slovakia, Croatia and Slovenia play an important role to balance electricity generation and demand in the long term future.

The annual balance for 2050 shows imports as well as exports of electricity are well below 1 TWh in all months of the year, with export surplus in summer and import surplus in winter. In total, however, Hungary exports 2.5 TWh and imports 1.5 TWh of electricity, which means a slight surplus of exports. Compared to the current situation with net imports of about 12 TWh and the NUCLEAR scenario in which by 2050 about 5 TWh will still be net imported, this means that Hungary will significantly increase its share of self-supply of electricity.

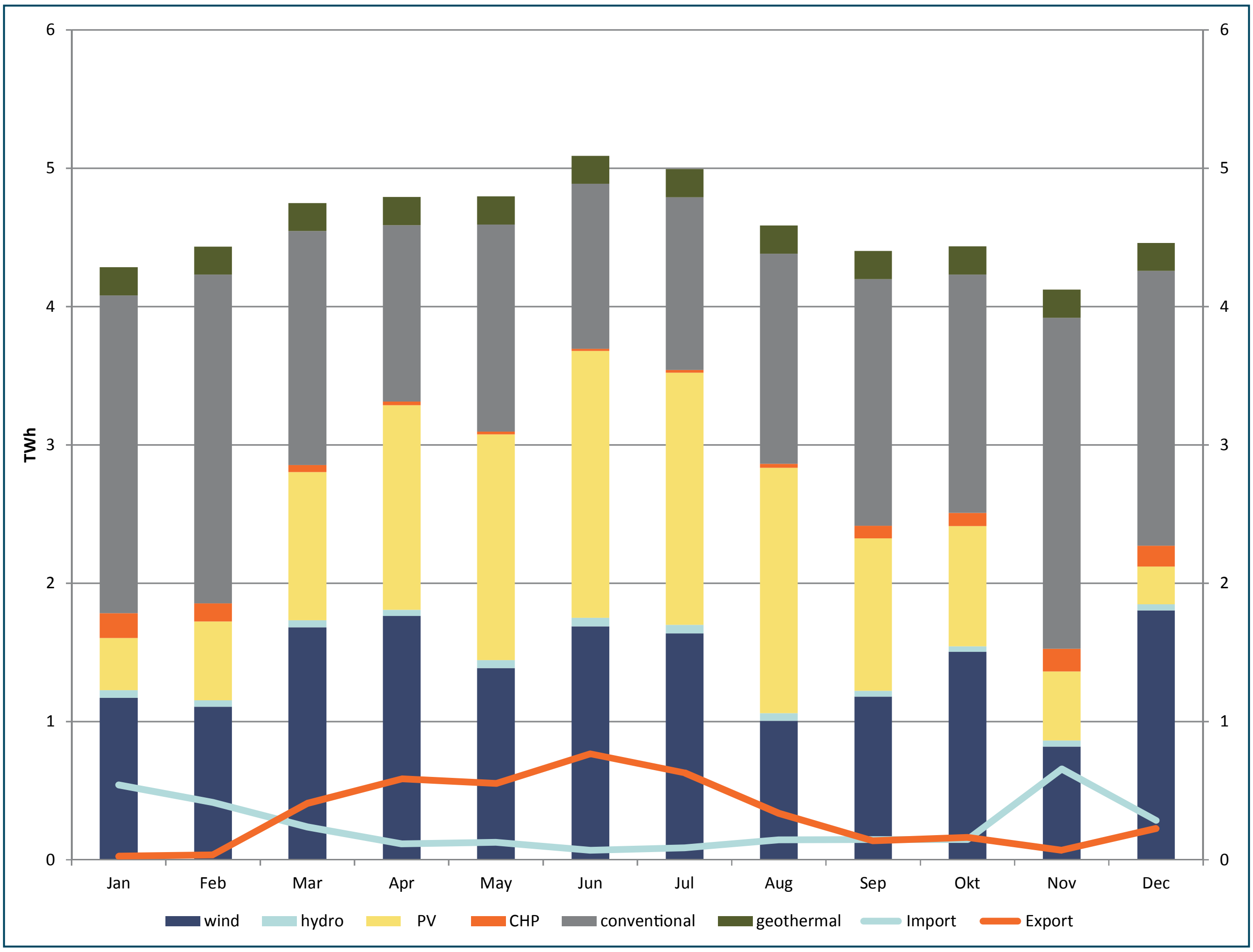
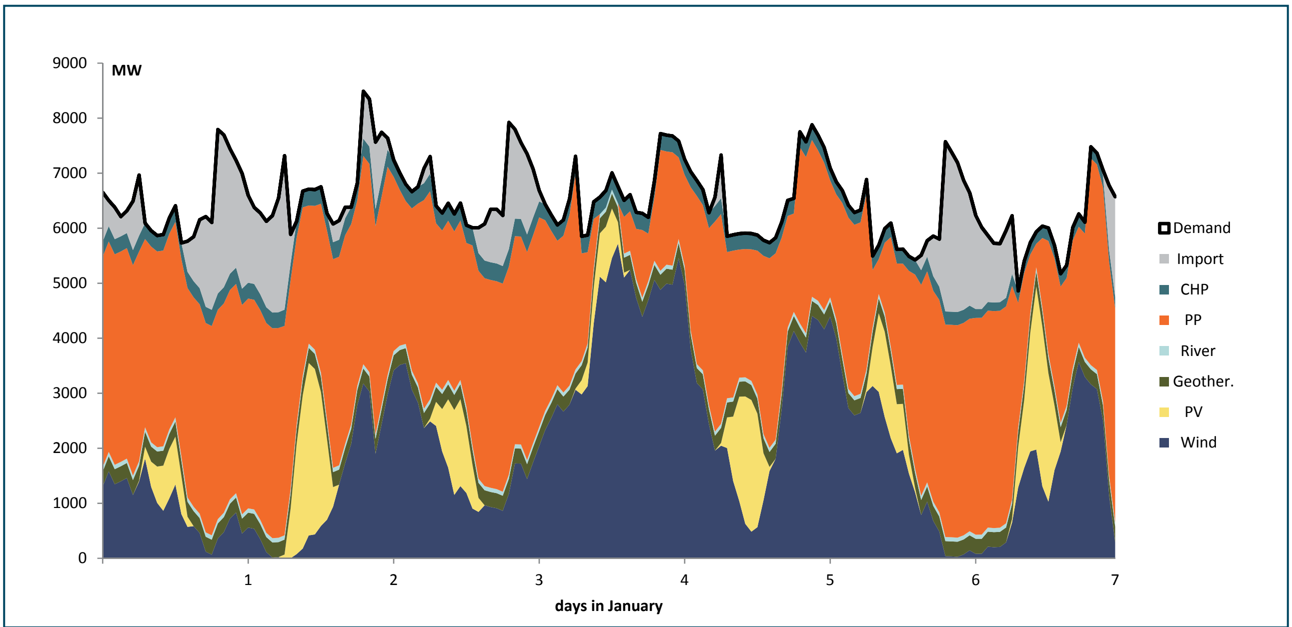


Figure 8. Seasonality of electric power generation in 2050 under the GREEN scenario

However, for the electricity system to function, short term fluctuations as well as available capacities to increase or decrease demand, storage capacities and grid capacities are all of crucial importance. In the GREEN scenario only flexible electricity options were simulated (up to 600 MW for a 2-days-long interval), while we did not integrate storage options other than hydrogen production. Figure 9 shows the respective electricity balance for the Hungarian grid for two extreme weeks of the year 2050, which have been simulated with EnergyPLAN. The top graph shows the electricity generation when electricity demand is the highest in the year of 2050, according to the GREEN scenario. This date is calculated to be in the first week of January, which also shows moderate wind electricity generation and low PV generation. Therefore a high share of fossil (gas fired) generation is needed and in periods with almost no wind (in the nights of day 1 and day 6) electric power of up to 3,500 MW has to be imported. This amount is most probably feasible with current international transmission line capacities.

However, more critical from a grid perspective, would be a week in the second half of May (Figure 9 bottom), where the electricity demand is the lowest in the summer period. In this period high PV generation plus high wind generation in days 4 and 5 leads to significant overcapacities in the grid of up to 7,000 MW in the second half of the week. This amount has to be compared to the current expansion plans of international grid connections. Currently the ENTSO-E plans to increase these connections to Hungary to 6,500 MW by 2030.

Studies for the EU have estimated that by 2050 international exchange capacities between Hungary and its neighbouring EU member states would be increased up to 20,000 MW, mainly to the North (Slovakia) and the West (Austria) (Fraunhofer ISI 2014). Further, potential pumped storage hydro capacities in neighbouring countries are estimated to be between 23,800 MW and 28.400 MW (Romania: 8,100 MW to 9,600 MW, Slovakia, Slovenia, Croatian: 5,300 MW to 6,400 MW, Austria: 10,400 MW to 12,400 MW; NTC study for 2050 EREC for 2050), which is three to four times more than maximum export simulated for Hungary for 2050.



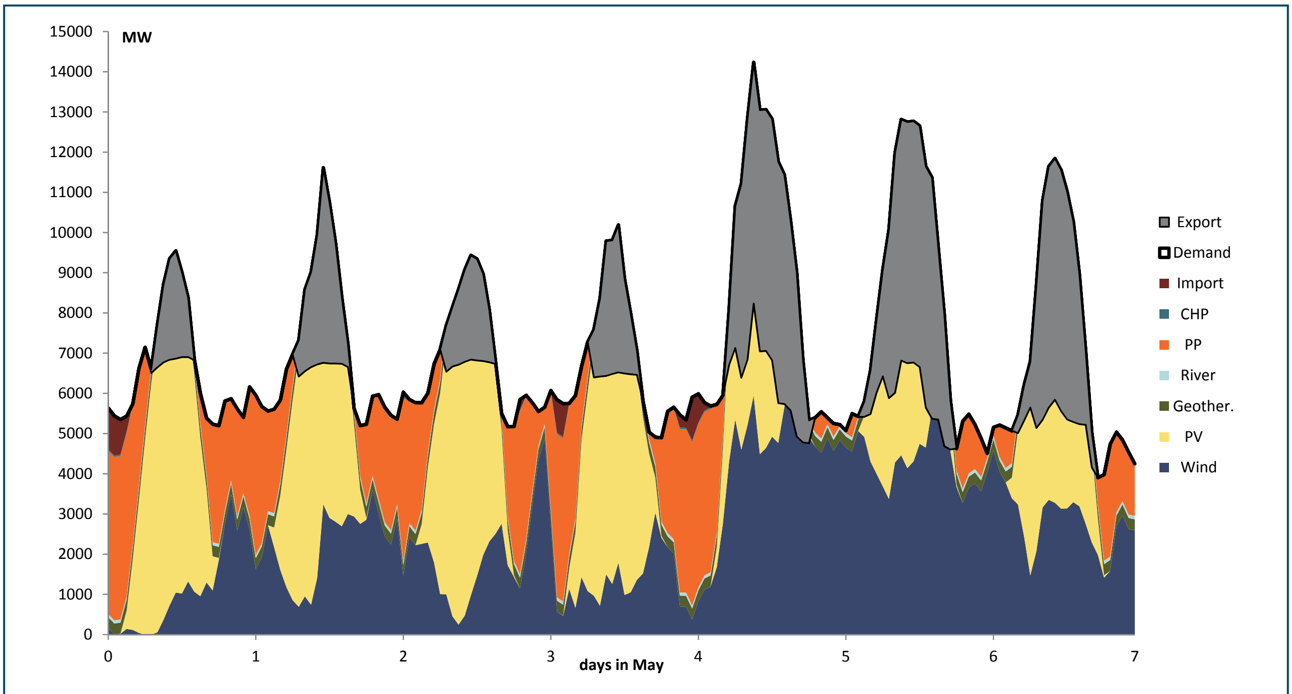


Figure 9. Hourly electricity balance for Hungary for two extreme weeks in 2050; GREEN scenario

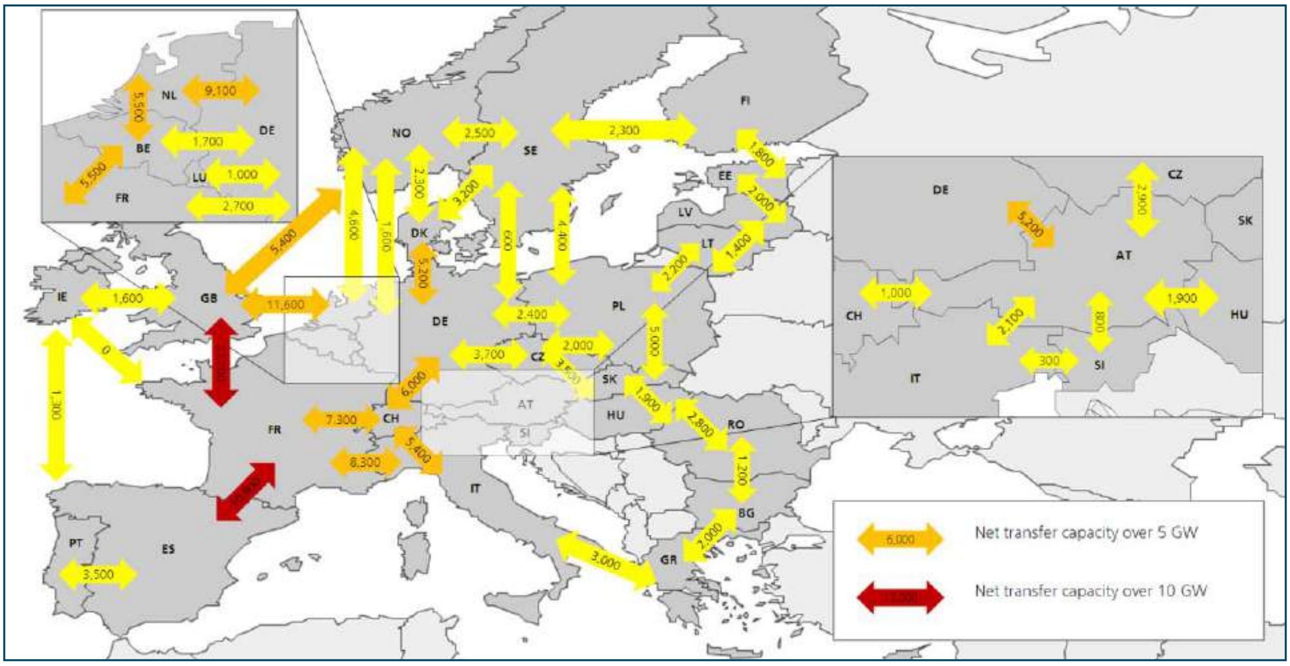


Figure 10. Annual net power transfer capacities among national state borders in Europe by 2050 (Fraunhofer ISI 2014)

5.4 Energy related CO_2 emissions

All scenarios lead to reductions in energy related CO_2 emissions, however the level of reductions that can be reached varies significantly, as illustrated in Figure 11. Under the NUCLEAR scenario important emission reductions are reached by 2030. However, CO_2 emissions increase again between 2030 and 2050. As already noted in section 5.1, this is due to the sequential dynamic of investments inherent in in the NUCLEAR scenario, where renovations and addition of power capacity are firstly addressed through the expansion of Paks, while the subsequent increase in electricity demand is mainly covered through investment in conventional power plants between 2030 and 2050. In this respect the pathway indicated by the NUCLEAR scenario is clearly in contradiction with the political developments in the international agenda for tackling climate change as well as with the European commitments and ambitions in the field of climate mitigation and energy, which aim at largely decarbonising European economies by mid century.

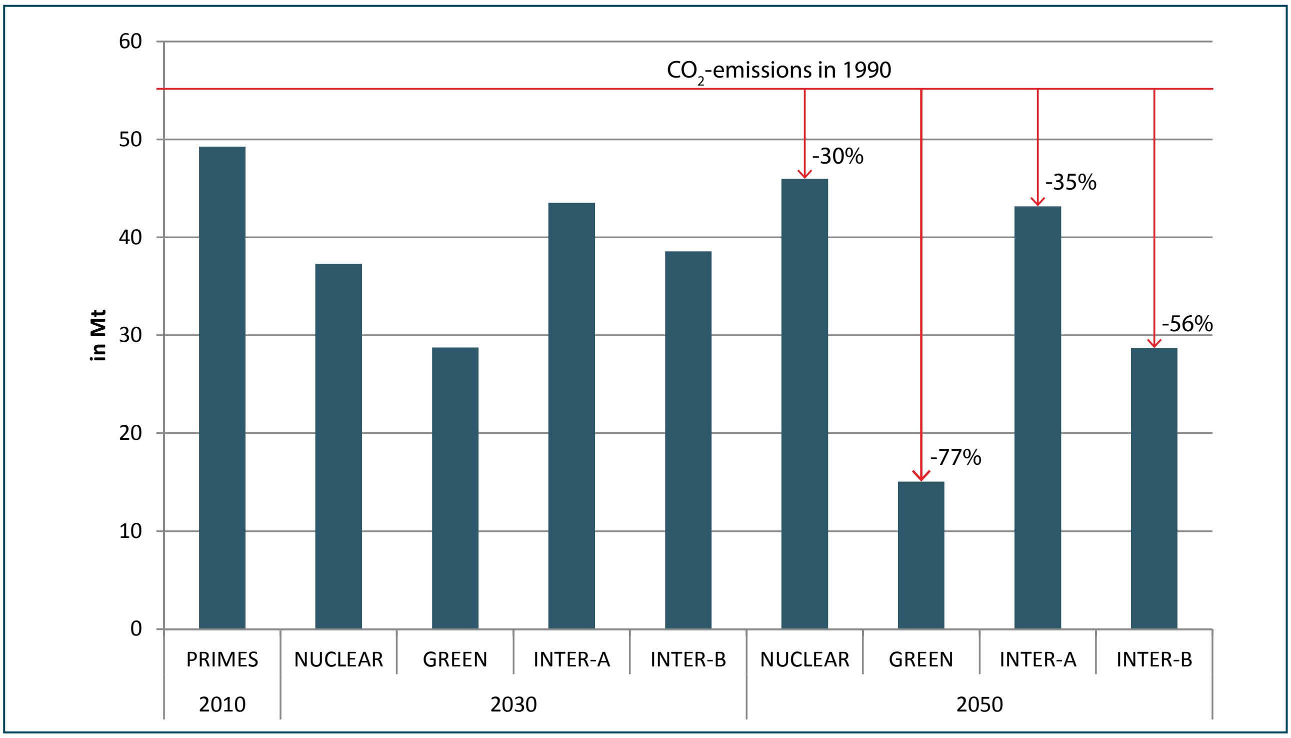


Figure 11. Reductions of energy related CO_2 annual emissions compared to the emission level by 1990

The deepest reduction of CO_2 emissions will be achieved under the GREEN scenario, i.e. 77% reduction compared to the level in 1990. This is reached by the combination of the two main strategies comprised in this scenario: i) strong reductions of energy consumption through the application of existing standards and proven energy efficiency measures in all relevant sectors, i.e. the industry, service sector, buildings and transport (see section 5.2). ii). The progressive replacement of aged power plant stock primarily through increasing investment in renewable energy capacities (see section 5.1). The pathway described by the GREEN scenario is well in line with the current international climate policy ambitions set in Paris in 2015 as well as with energy and climate policy at European level.

Reductions in annual CO_2 emissions under the INTER-A scenario are only slightly deeper than under the NUCLEAR scenario, reaching only a 35% reduction compared to the level of CO_2 emissions of 1990. Here the phase-out of nuclear energy during the period up to 2030 leads to the highest CO_2 emissions among all the scenarios within this period. In the period 2030-2050 the investment into renewables takes off, but to a lesser extent than in the other alternative scenarios. Under scenario INTER-B significant emission reductions are reached by 2050 (56% related to the level in 1990). Particularly important for this outcome is the use of 'low hanging fruits' in energy efficiency improvements, particularly the less complex and costly measures in building insulation, industrial sector and electrical appliances.

5.5 Cost effects of the electricity production in various scenarios

Estimating the energy sector`s future costs hold many uncertainties and is subject to broad academic discussion. In establishing assumptions on the evolution of costs up to 2050, we revert to those studies that we deem most relevant and which include detailed information regarding technology-specific costs. This study focused on estimations of investment in power plants and electricity grid, O&M, fuel and CO_2 costs. Moreover, in order to explore the sensitivity to prices changes of the different paths described by the scenarios, two set of assumptions were constructed. The first set of assumptions (referred to as 'low') considers very conservative assumptions related to the development of fuel and CO_2 prices in the whole period of study. The second set (referred to as 'high') considers plausible increases of both fuels and CO_2 costs, which range in the middle of recent energy price projections, whereas the low projection marks the lower end (see comparison by AEE 2015).

The estimation of O&M and fuel costs were based on statistics of international and (when available) European price levels according to International Energy Agency (IEA 2015). Gas prices of 25.2 €/MWh (low) and 32.4 €/MWh (high) for 2030 and 21.6 / 39.6 €/MWh for 2050 have been used, according to the price range by IEA (2015). Coal price is either stable at 7.2 €/MWh or increases to 10.8 €/MWh (2030) and 12.6 €/MWh (2050). For nuclear fuels constant prices of 5.0 or 7.1 €/MWh have been assumed.

Estimations of the CO_2 price were based on analysis by the German Agency for Renewable Energies (AEE 2013). We investigated the effect of two different plausible developments in the CO_2 prices. First a very conservative assumption was set which considers an average CO_2 price of 19,3 EUR/t for the period until 2030 which increases up to 33,4 EUR/t by 2050. A second set of estimations were made on the assumption that CO_2 prices achieve levels which are double that of the first assumptions. This is a plausible development for advancing the goals set during the last UNFCC conference of parties in Paris in 2015.

As investment costs, only "overnight" costs, which include construction costs of a power plant but exclude all interest incurred during the construction phase – which can last from weeks for PV installations to several years for nuclear power plants – have been used (WEIO 2014). This means that neither financing costs nor sources of capital or costs for infrastructure connections are taken into account here. Assumptions have been based on a recent meta study DIW (2013). For gas fired power plants overnight investment has been estimated at 862 €/kW and for nuclear a range from 5.000 to 6.000 €/kW has been assumed. Wind power costs are assumed to either slowly decrease down to 1183 €/kW by 2050 or to reach this level already by 2030 and decrease further to 1075 €/kW by 2050. For PV 600 vs. 950 €/kW are assumed for 2030 and 425 vs. 600 €/kW for 2050.

Estimations on the costs of electricity grid development are prepared separately based on the results of recent EU-wide research projects. Cost of dismantling power plants are not included in the cost estimate and it is argued that the residual value of the plant covers deconstruction cost (DIW 2013). Similarly, in order to keep a rather conservative approach, costs of dismantling nuclear reactors were not considered.

In order to estimate the cost of transmission lines the results of the "E-Highway" project were considered (E-Highway 2015). On the long term the acceptance of new DC corridors and overhead lines is crucial. The cost of distribution grid expansion is estimated based on the results of the "ImpRES" project (Fraunhofer ISI 2014b). This means the cost assumptions given for the state of Saxony-Anhalt were used, particularly as the population density is very similar to that of Hungary.

Figure 12 summarises the estimates of annual cost of electric power production for all the scenarios considered. The graph presents the average annual costs during the period considered by the study, i.e. 2016 to 2050. Overall the GREEN path

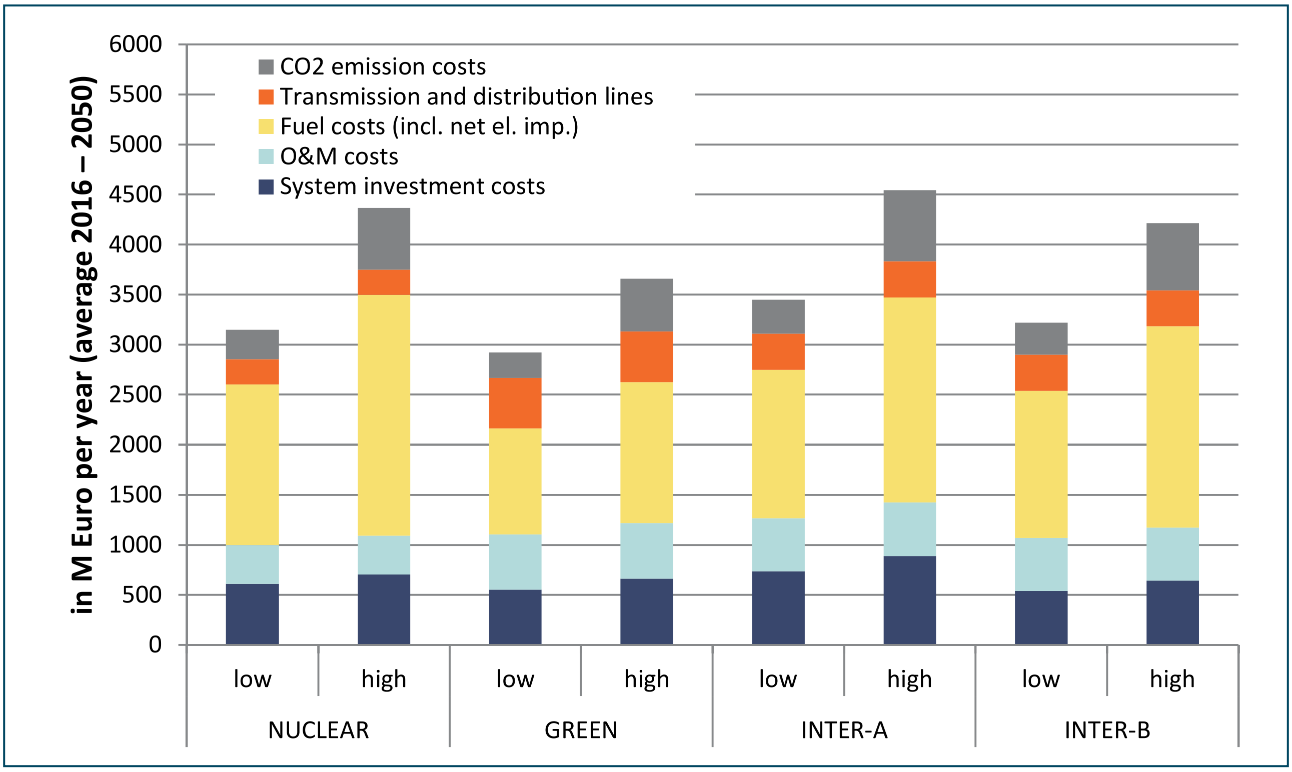


Figure 12. Projected electricity production costs of the Hungarian electricity system considering two different sets of assumptions: One set includes conservative ('low') assumptions in regard to the development of investment costs, fuel and CO_2 prices and the second set considers plausible developments of higher prices ('high').

leads to the lowest average annual costs of electricity production and distribution among the analysed scenarios, regardless the assumptions about investment, CO_2 and fuel prices. Under the most conservative set of assumptions ('low') the NUCLEAR scenario leads to electricity production costs, which are only slightly higher than the GREEN alternative. However, the contrast between the GREEN and the NUCLEAR paths increases sharply when higher cost levels are considered. The costs estimations in the INTER-B scenario are in general slightly higher than those in the NUCLEAR scenario. Thus, also the path described by INTER-B offers a competitive alternative to the NUCLEAR scenario, in terms of the costs of the electricity system.

Besides the differences between total level of costs of electricity production, an important contrast can also be seen in the distribution of those costs. The different outcomes of the pathways described by the NUCLEAR and the GREEN scenarios contrast strongly in respect of the share of expenses dedicated to cover fuel costs in the whole cost structure. While the NUCLEAR scenario demonstrates the lowest system investment costs among all scenarios, it also leads to the highest level of fuel costs. In contrast, the GREEN scenarios with the highest share of renewable power production exhibit the lowest level of fuel costs (around half that of the NUCLEAR scenario).

5.6 Final energy demand

The sector-by-sector technology oriented analysis of the future final energy demand in the residential, tertiary and industrial, as well as transport sector demonstrates significant potentials to increase energy efficiency and by this reduce absolute demand for final energy in Hungary. In the GREEN scenario a significant share of the existing potentials will be exploited, which will lead to final energy savings of about 42% by 2050 (vs. 2010) whereas final energy demand is expected to slightly increase by 9% under a business as usual policy (which is assumed for the NUCLEAR scenario).

The structure of the final energy demand remains more or less unchanged in the NUCLEAR scenario, as illustrated by Figure 13. Here increasing technical efficiencies are offset by growing demand for energy services due to growing income, GDP and transport volumes. In contrast to this in the GREEN scenario all sectors exhibit important energy saving potentials. Particularly crucial for reaching the deep reduction in energy demand are the residential, the service and the transport sectors. To that end the following energy measures are of relevance: broad implementation of high standards for buildings insulation, aggressive campaigns for replacement of electric household appliances with high energy efficient models, broad adoption of modal-split and increase in public transport.

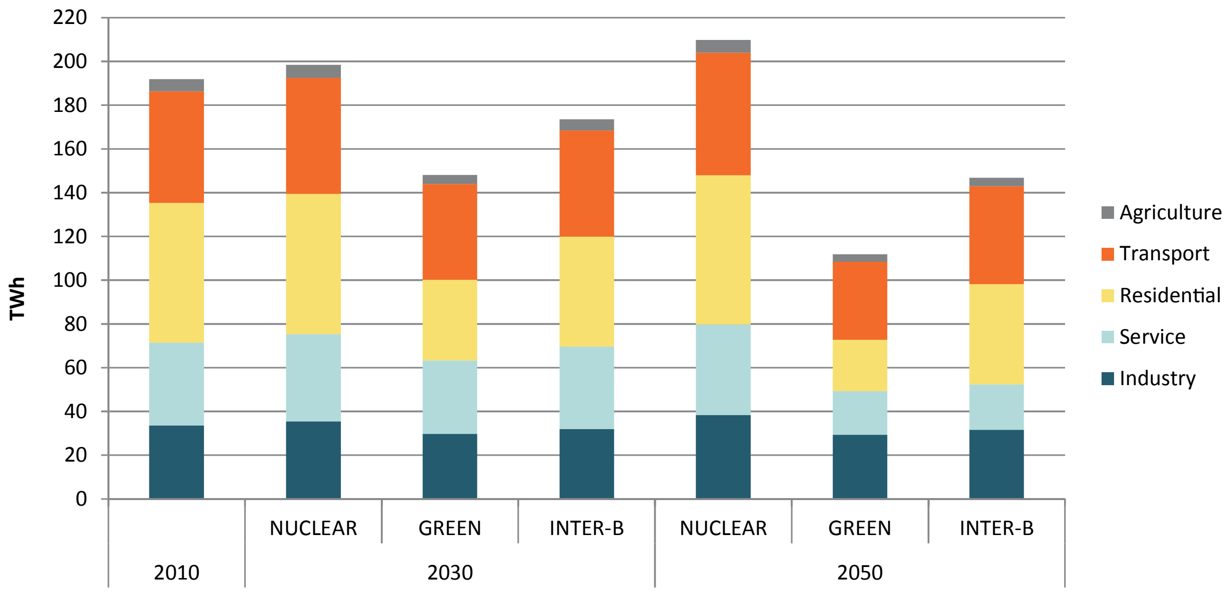


Figure 13. Structure of the final energy demand by sector*

*Energy demand structure in the INTER-A scenario is equal to those in the NUCLEAR scenario, therefore not displayed in the graphic

In industry, however, potentials are limited, mainly due to projected high growth in energy intensive basic materials industries such as steel and chemicals in the EC References scenario, which have been the basis for all scenarios made here. This means that sectoral shares of energy consumption will gradually change in the GREEN scenario. Shares of households and service sector will decline due to above average savings and industry and transport sectors will increase their share in final energy demand in spite of absolute savings vs. 2010.

The comparison of the annual average change in final energy demand in the NUCLEAR and the GREEN scenario with other decarbonisation scenarios from industrialised as well as emerging economies around the globe, which were compiled by the DDP project (DDPP 2015), shows that Hungary is somehow at a crossroads with regards to final energy demand (Figure 14).

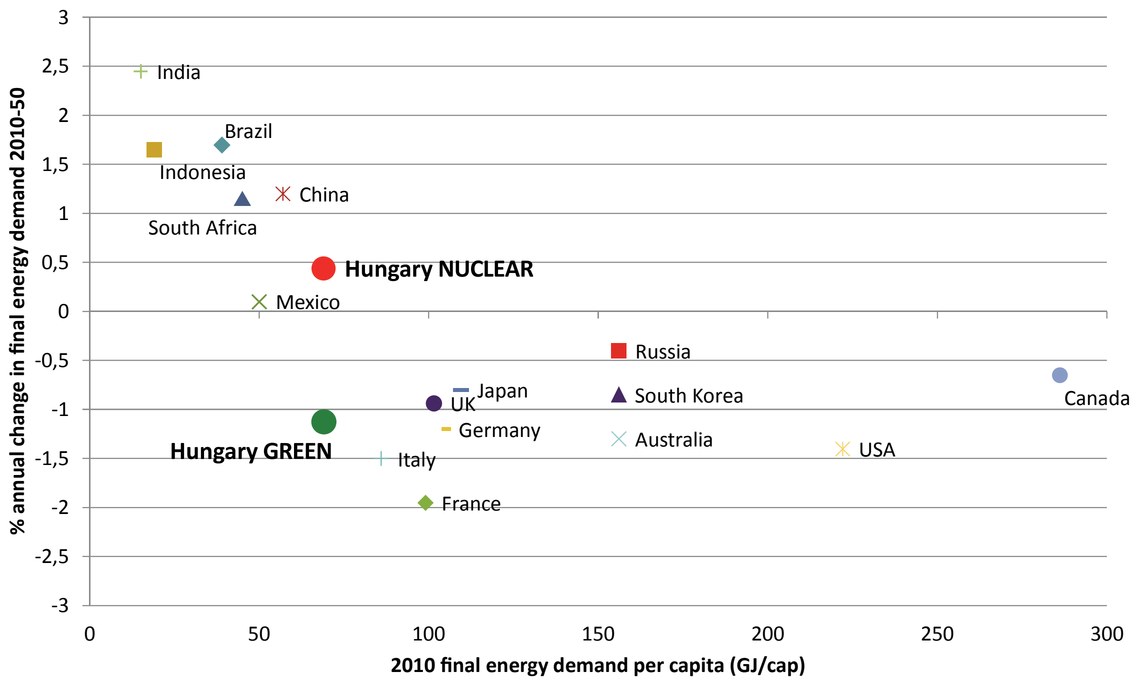


Figure 14. Results from the DDP project and the scenarios NUCLEAR and GREEN

The current energy use per capita of 70 GJ per capita is significantly lower than that of other EU countries such as France, Germany, the UK and even Italy. due to the climate and moderate living standards as well as low industrial activities and low transport intensity. Future trends, however, could go either up with an increase of final energy intensity of about 0.5% per year – which would be somewhere between Mexico and China, or go down at 0.9% per year – which would place Hungary in a group with Germany and the UK but with significantly slower improvements compared to Italy or France.

6. Policy recommendations

The analyses on energy efficiency and renewable energy potentials and on the resulting alternative and sustainable energy scenarios clearly result in two different future energy paths for Hungary. This holds particularly true for the electricity system.

Hungary therefore basically has to decide to either

A) heavily invest into a strong expansion of renewable energy generation and substantial improvements of energy efficiency together with a decentralization of electricity generation as depicted in the GREEN scenario or to
B) concentrate future investment in new nuclear as well as fossil power plants. This strategy would mean to concentrate future investment on a very small number of big power plants, which would lead to an increasingly centralized electricity production.

As the study shows, both solutions will need significant investments over the next decades as the current power plant stock in Hungary is already a significant age and needs substantial reinvestment over coming years. The two main scenarios, however, differ with regards to the timing of the investment needs: in the case of the NUCLEAR scenario high investment in the near future is needed as by 2030 new nuclear power plant capacities at Paks will have to be completed. In the case of the GREEN scenario the necessary investment will increase substantially as well but stepwise. The bulk of all investments will occur in the period 2030-2050 due to the fact that investment will be in incremental steps and also gradually increase over time as exploitation rates of the potentials will increase together with lower costs of the technology.

Overall, the results for the costs of the scenarios show that the GREEN scenario path comes approximately to a similar level of costs as the conventional path under rather conservative assumptions. If, however, higher (but still plausible) levels of natural gas prices and CO_2 costs are considered, the economic advantage (in terms of electricity production costs) of the GREEN scenario becomes even more significant.

What is more, the GREEN development path offers further co-benefits: as the investment into decentralised renewable power generation is much more widespread over the whole country it supports local development everywhere in the country instead of a few spots with big power plants and therefore supports also regional and particularly rural development. Regarding job creation in particular the increased energy efficiency in the GREEN scenario has strong positive effects. Moreover, RES expansion also has moderate positive domestic job effects over the time period until 2050 as compared to investment into a conventional power sector. Furthermore, these effects are better distributed around the whole country.

Regarding non economic benefits it can also be concluded that the GREEN path is more in line with the international as well as European climate policy goals as it achieves significant reductions in energy related CO_2 emissions of almost 70% vs. 2010 and almost 80% vs. the climate policy base year of 1990. The NUCLEAR scenario in contrast only leads to small additional emission reductions vs. 2010 and thus remains more or less stable at a level about one third below 1990.

The GREEN scenario, however, implies significant challenges with regards to the expansion of the distribution as well as transmission grids as they will have to accommodate high amounts of fluctuating renewable electricity. However, the bulk of these costs are independent of the chosen development path be it green or conventional/nuclear as a significant expansion of the grids has already been planned in the context of the integration of European electricity markets and further expansions of European grids are foreseen anyhow.

Policy Requirements of a GREEN Scenario

To go for a GREEN and sustainable energy scenario for Hungary it is not enough not to opt for nuclear expansion. In order to harvest the advantages of such an energy scenario a comprehensive energy policy has to be developed, which covers all sectors of the energy system and all consumer groups as well as the energy supply side. Some core requirements and policy actions to achieve the energy transition include:

- Clear political commitment to a comprehensive, sustainable energy transition, political endorsement of milestones as well as highly ambitious, and optimally legally binding, national energy efficiency and renewable energy goals and targets in order to create clear signals and long term reliable conditions for investors.
- Enable investment into distributed renewable electricity generation, particularly wind and PV. The investments needed can be financed by domestic but also international funds. To achieve such a broad portfolio as needed for a widespread RES development, wide groups of investors should receive incentives. This should particularly include citizens and cooperatives as they guarantee high local involvement and a flow back of revenue into the regions where the RES generation takes place. Feed in tariffs and other schemes are already well developed and explored. Together with the significant costs reductions of wind and PV in recent years such instruments could enable a steady increase in investment into new and renewable electricity generation, with due regard to long-term sustainability requirements.
- Such development, however, also needs the necessary planning regulations. This holds true even more for expansions of the electricity grid. Supporting provisions for these should be provided and regions as well as municipalities should participate and support local and regional developments.
- Efforts should be made to increase the capacity for heat and electricity production also in the area of geothermal energy, implying further research and development to overcome technical problems and minimise environmental impacts, with special attention to the issue of reinjection.
- In terms of energy efficiency, like in many other EU member states, policies could and should be improved. They range from regulation regarding minimum efficiency standards for buildings, cars, machines and appliances to clear economic incentives for energy efficiency, particularly in the building sector. These measures have to be tailored for every demand sector and application of energy as each of them has strong individual characteristics. Specific measures should be provided to deprived, energy-poor households. Cross-cutting policies such as energy or CO_2 taxes or an energy efficiency fund that runs awareness campaigns and funds respective measures can significantly improve the effectiveness of such policy mixes.
- Particularly important is also the transport sector. Based on the currently rather low energy use in Hungary taxation of cars with rebates for environmentally-friendly, energy-efficient cars together with fuel taxes and other instruments could be used to maintain low levels of transport energy consumption. This should be complemented by a strong support for public transport as well as a future introduction of alternative fuels and particularly electric vehicles.

7. References

AEE (2013): Agentur für Erneuerbare Energien: Studienvergleich: Entwicklung der Stromgroßhandels- und der CO_2 – Zertifikatspreise, http://www.forschungsradar.de/fileadmin/content/news_import/AEE_Dossier_Studienvergleich_Stromgrosshandelspreise_dez13_01.pdf

BMVI (2015): Räumlich differenzierte Flächenpotentiale für erneuerbare Energien in Deutschland. BMVI. http://www.bbsr.bund.de/BBSR/DE/Veroeffentlichungen/BMVI/BMVIOnline/2015/DL_BMVI_Online_08_15.pdf;jsessionid=883C887EE71A7EC6292C09BED9D532B1.live2051?__blob=publicationFile&v=2

Connolly, D. – Lund, H. – Mathiesen, B.V. – Leahy, M. (2010): A review of computer tools for analysing the integration of renewable energy into various energy systems. – In: Applied Energy, 87. (2010), pp. 1059–1082

Deep Decarbonization Pathways Project (2015). Pathways to deep decarbonization 2015 report, SDSN – IDDRI http://deepdecarbonization.org/wp-content/uploads/2016/03/DDPP_2015_REPORT.pdf p 21

DIW (2013): Current and Prospective Costs of Electricity Generation until 2050 available: https://www.diw.de/documents/publikationen/73/diw_01.c.424566.de/diw_datadoc_2013-068.pdf

E3Mlab/ICCS at National Technical University of Athens (n.d.): PRIMES MODEL 2013-2014 Detailed model description, http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The%20PRIMES%20MODEL%202013-2014.pdf, last access: December 21, 2015

E-Highway (2015): Modular plan over 2030-2050 for the European transmission system: a complete analysis of costs and benefits, available: http://www.e-highway2050.eu/fileadmin/documents/Results/D6.3_Modular_plan_over_2030-2050_for_the_European_transmission_system_a_complete_analysis_of_costs_and_benefits_20151202.pdf

EEA – European Environment Agency (2006): How much bioenergy can Europe produce without harming the environ-ment? Copenhagen.

EnergyPLAN (2015): Official website of EnergyPLAN. Department of Development and Planning, Aalborg University. http://www.energyplan.eu/

ENTSO-E (2015): Ten-year Netwrok Development Plan availabile: https://www.entsoe.eu/major-projects/ten-year-network-development-plan/ten%20year%20network%20development%20plan%202016/Pages/default.aspx

European Commission (2011): A Roadmap for moving to a competitive low carbon economy in 2050 /* COM/2011/0112 final */

European Commission (2013): EU energy, transport and GHG emission trends to 2050, Reference Scenario 2013

Eurostat (2014): Land cover and land use (LUCAS) statistics – Statistics Explained.
http://ec.europa.eu/eurostat/statistics-explained/index.php/Land_cover_and_land_use_(LUCAS)_statistics. Last access: 05 Februar 2016.Eurostat (2014): EUROSTAT 2014: Energy dependence.
http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tsdcc310&plugin=1

FŐTÁV (2014): A Budapest kelenföldi távhőrendszer 2011-es órás adatai. Sigmond György (MaTáSzSz) adatszolgáltatása a FŐTÁV Zrt. hozzájárulásával.

Fraunhofer ISI (2011): Tangible ways towards climate protection in the European Union (EU Long-term scenarios 2050) available: http://www.isi.fraunhofer.de/isi-wAssets/docs/x/de/publikationen/Final_Report_EU-Long-term-scenarios-2050_FINAL.pdf

Fraunhofer ISI (2014): Optimized pathways towards ambitious climate protection in the European electricity system (EU Long-term scenarios 2050 II). Final report. Karlsruhe: Fraunhofer Institute for Systems and Innovation Research ISI.

Fraunhofer ISI (2014b): Analyse der Netzausbaukosten und der Kostenverteilungswirkung, Untersuchung im Rahmen desProjekts "Wirkungen des Ausbaus erneuerbarer Energien (ImpRES)", gefördert Durch das Bundesministerium für Umwelt,Naturschutz und Reaktorsicherheit
http://www.impres-projekt.de/impres-wAssets/docs/2014_08_03_Netzausbaukosten-ImpRES_final.pdf

Fraunhofer ISE (2015): PHOTOVOLTAICS REPORT.
https://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf

Fraunhofer IWES (2016): Windmonitor.
http://www.windmonitor.de/. Last access: 05 Februar 2016.

Fülöp O. (2011): NEGAJOULE2020 – A magyar lakóépületekben rejlő energiahatékonysági potenciál, Energiaklub, Budapest

Fülöp O. (2013): Állami oktatási és irodaépületekben rejlő energiahatékonysági potenciál, Energiaklub, Budapest

Greenpeace et al (2015): Energy [r]evolution, A sustainable world energy outlook 2015, 100% renewable energy for all, report 5th edition 2015 world energy scenario,
http://www.greenpeace.org/international/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdf

Herbst, A.; Toro, F.A.; Reitze, F.; Jochem, E. Introduction to Energy Systems Modelling. Swiss J. Econ. Stat. 2012, 148,111-135.

Hoefnagels, E.; Junginger, H.; Panzer, C.; Resch, G.; Held, A. (2011): RE-Shaping. Shaping an Effecitve and Efficient European Renewable Energy Market. Long Term Potentials and Costs of RES-Part I: Potentials, Diffusion and Technological learning.
http://www.reshaping-res-policy.eu/downloads/D10_Long-term-potentials-and-cost-of-RES.pdfhttp://www.reshaping-res-policy.eu/downloads/D10_Long-term-potentials-and-cost-of-RES.pdf

Hourcade, J.C.; Jaccard, M.; Bataille, C.; Ghersi, F. Hybrid Modeling: New Answers to Old Challenges. Energy J. 2006, 2, 1-12.

IEA (2015): Energy Technology Perspectives 2015

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland

Kovács K. (2010): Biogáz helyzet Magyarországon.
http://geptame.hu/hkonf/Dr.%20Kovacs%20Kornel.pdf

Lechtenböhmer et al (2015a): Re-Industrialisation and Low-Carbon Economy – Can They Go Together? Results from Stakeholder-Based Scenarios for Energy-Intensive Industries in the German State of North Rhine Westphalia, in Energies, 2015 8(10), 11404-11429

Lechtenböhmer et al (2015b): Decarbonising the energy intensive basic materials industry through electrification – implications for future EU electricity demand, Proceedings of the 10th Conference on Sustainable Development of Energy, Water and Environment Systems, SDEWES2015.0694, 1-16 (2015)

Lütkehus, I.; Adlunger, K.; Salecker, H. (2013): Potenzial der Windenergie an Land: Studie zur Ermittlung des Bundesweit-en Flächen-und Leistungspotenzials der Windenergienutzung an Land. Dessau-Roßlau: Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/potenzial_der_windenergie.pdf

MAVIR (2014): A Magyar Villamosenergia-rendszer közép- és hosszú távú forrásoldali kapacitásfejlesztése 2014. Budapest, 2014.

Munkácsy B. (ed.)(2011): Erre van előre! Egy fenntartható energiarendszer keretei Magyarországon: Vision 2040 Hungary 1.0. – Környezeti Nevelési Hálózat Országos Egyesület, Szigetszentmiklós, 155 p.

Munkácsy B. (ed.)(2014): A fenntartható energiagazdálkodás felé vezető út: Erre van előre! Vision 2040 Hungary 2.0. – ELTE TTK Környezet- és Tájföldrajzi Tanszék, Budapest, pp. 143-152.

NFM (2011): Nemzeti Energiastratégia 2030. Nemzeti Fejlesztési Minisztérium.

PYLON (2010): Magyarország 2020-as megújuló energiahasznosítási kötelezettség vállalásának teljesítési ütemterv javaslata – Műszaki-gazdaságossági megújuló energiaforrás potenciál vizsgálata, a célkitűzés teljesítésére vonatkozó NCST bontása szerinti forgatókönyvek. „C" kötet. PYLON Kft., Budapest, 2010.

Sáfián F. (2015): Paks II nélkül a világ. Energiaklub, Budapest.

Thrän, D.; Weber, M.; Scheuermann, A.; Fröhlich, N.; Zeddies, J.; Henze, A.; et al. (2005): Nachhaltige Biomassenutzungsstrategien im europäischen Kontext: Analyse im Spannungsfeld nationaler Vorgaben und der Konkurrenz zwischen festen, flüssigen und gasförmigen Bioenergieträgern. Bericht im Auftrag des BMU. Leipzig: Institut für Energetik und Umwelt gGmbH; Universität Hohenheim; Bundesforschungsanstalt für Forst- und Holzwirtschaft; Öko-Institut e. V.

UBA (2010): Energieziel 2050: 100% Strom aus erneuerbaren Quellen. http://www.umweltdaten.de/publikationen/fpdf-l/3997.pdf. Last access: 16 April 2012.

UBA (2014): Treibhausgasneutrales Deutschland im Jahr 2050. Climate Change 07/2014. Dessau: Umweltbundesamt. www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/climate-change_07_2014_treibhausgasneutrales_deutschland_2050_0.pdf. Last access: 09 Februar 2015.

WEIO (2014): Power Generation Investment Assumptions http://www.worldenergyoutlook.org/media/weowebsite/2014/weio/WEIO2014PGAssumptions.xlsx

Zeddies, J.; Bahr, E.; Schönleber, N.; Gamer, W. (2012): Globale Analyse und Abschätzung des Biomasse-Flächennutzungspotentials. im Auftrag des BMELV No. FZK 22003911. Insitut für landwirtschaftliche Betrieblehre, Universität Hohenheim.

Wuppertal Institut

ENERGIAKLUB
CLIMATE POLICY INSTITUTE
APPLIED COMMUNICATIONS

The Greens | European Free Alliance
in the European Parliament

Zöld Műhely Alapítvány

www.fenntarthatoenergia.hu