ISSN 2052-0018 (print) // ISSN 2053-3667 (online)
Geographical Locality Studies 2016 Volume 4, Number 1. pp. 788–819

Modelling and Analysing the Effects of a New Nuclear Power Plant. Is there Room for Renewables in Hungary by 2030?

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Abstract

As a solution for capacity deficiency expected in the following decades, building a new nuclear power plant has been decided in Hungary. According to a hypothesis, this unit will overbalance the energy system and hinder renewable technologies from spreading; therefore, it will not provide a sustainable solution. In this research, the effects of the new nuclear units and a possible alternative scenario are investigated and compared. Three energy models were created with EnergyPLAN software for the year of 2030: an Official one, based on the Transmission System Operator's projections; an Alternative one, based on Energiaklub's energy vision, outlined in this research; and a Hybrid one, which blends these two.

The results show that, even by a conservative development, more than 27% of the renewable electricity production is possible in Hungary by 2030, while it is only 10% in the Official scenario, where 75% of electricity production is nuclear, coming from one physical site. Critical Excess Electricity Production (CEEP) analysis showed, that significant excess electricity production will arise due oversized nuclear capacity for six years when altogether 4,400 MW nuclear capacity will co-work. This results not only in hindering renewables, but also in endangering normal working conditions of combined (CHP) and condensational power plants, which may cause hazards and shut downs of these units.

Key words

Energy system modelling; EnergyPLAN; Hungary; nuclear power; renewable energy; critical excess electricity production

1. Introduction

Hungary has a population of 9.9 million inhabitants (CIA, 2016). Its *Total Primary Energy Supply* (TPES) was 962 PJ in 2014 and its electricity demand was 42.7 TWh in 2014 (KSH, 2015). Due to decreasing international electricity prices, the electricity import has increased in the last years up to 31.4% in supply (KSH, 2015). The country had 8,558 MW_e total capacity in 2015 (MAVIR, 2015), from which only 4–5,000 MW will have been remained by 2030 (MAVIR, 2014a), due to the closing old power plant capacities. Therefore, according to the *Hungarian Transmission System Operator* (TSO), *MAVIR*'s calculations from 2014, 6–7,000 MW of new power plant capacities has to be built (or extended) in *Hungary* by 2030 (MAVIR, 2014a). The official *Hungarian Energy Strategy* of 2011 planned to have 11,300 MW capacity by 2030, from which 4,000 would be nuclear capacity: 2,000 MW of the existing *Paks nuclear power plant* and a new 2,000 MW nuclear power plant. However, this energy strategy should have been reconsidered every two years, which has not occurred.

In January 2014, the Hungarian *Minister for National Development* and the head of the Russian *Rosatom*, signed a contract about a new nuclear power plant construction in *Hungary*, in *Paks*, which was announced to the surprised Hungarian population by the media (FÜLÖP, O. 2015). The new power plant of 2,400 MW (two VVER-1200 reactors) will be built by *Rosatom* which was decided without a tender (FÜLÖP, O. 2015). The construction of the power plant (excluding supplementary investments, like grid improvements) will cost around 12.5 billion Euros, from which 10 billion Euros will be provided by Russian loan for *Hungary* for 21 years (FÜLÖP, O. 2015). However, independent financial feasibility studies show that a return of the investment is unlikely and a significant state aid will be needed (ROMHÁNYI, B. 2014; FELSMANN, B. 2015) Much of the background studies, data and contracts are classified for 30 years by the Parliament

(Szentkirályi, B. 2015), which results in difficulties or no possibility to gather information, even for future analysis, and increases risk of corruption (Fazekas, M. *et al*. 2014).

There will be a critical period in the Hungarian energy system for approximately six years, expected between 2026 and 2032. During this period, the existing four reactors *Paks Nuclear Power Plant* (2,000 MW) will run next to the *Paks II power plant* (2,400 MW). Not only building a new nuclear power plant, but also this large amount of nuclear electricity production—which will be more than half of the Hungarian electricity production—can have lasting effects on the electricity system in the following six years. Therefore, the year 2030 has been chosen to be investigated in this research and because most of the energy strategies and forecasts are calculated to that year.

1.1. Scope of the article

The aim of this research was to model and analyse the effects of a new nuclear power plant in *Hungary*, especially in the critical six years, focusing on the future possibility of spreading of energy generation from renewable resources and to create an alternative scenario to see the possibility of substituting the needed capacities with energy efficiency and renewable development. Therefore, three different, hourly based models of the Hungarian energy system were created with the *EnergyPLAN software*.

1) *Official:* is based on the *Hungarian Energy Strategy* from 2011 (Ministry of National Development, 2012) and the *Hungarian Transmission System Operator*, *MAVIR*'s projection of future power plant capacities from 2014, including the new nuclear power plant (MAVIR, 2014a).
2) *Alternative:* an energy vision of *Hungary* by 2030 was created through a six-month process to build this scenario, hosted and professionally supported by *Energiaklub Policy Institute and Applied Communications*. Only an informative summary was available until now about this vision (Sáfián, F. 2015); therefore, the detailed methodology will be presented in this paper. This sce-

nario includes increased renewable capacity and energy efficiency improvement, without nuclear power plant construction.

3) *Hybrid:* includes the new nuclear capacity and spreading renewable production as well, based on the two previous visions.

The results of the analyses with *EnergyPLAN* of the different scenarios and their comparison can help answer the above questions and draw consequences of different directions of energy planning and policy in *Hungary*.

1.2. Official energy planning and policy in Hungary

The official *National Energy Strategy of Hungary* of 2011 (MINISTRY OF NATIONAL DEVELOPMENT, 2012) plans until 2030. It addresses structural changes in the energy system with increasing capacities of low CO_2 emission intensity, like renewable-based ones; spreading heat production from renewable resources; and increasing share of low emission transportation modes. From the three future energy demand scenarios, the middle one (called 'Joint effort') was selected by strategy authors for further calculations. This scenario includes slightly growing TPES reaching 1,147 PJ by 2030, and annually 1.5% increase in electricity consumption. Regarding power generation, three crucial efforts are stated: "the long-term preservation of nuclear energy in the energy mix; the maintenance of the current level of coal-based energy generation", and increase of renewable energy production "depending on the capacity of the economy, system controllability and technological development" (MINISTRY OF NATIONAL DEVELOPMENT, 2012). From six different energy mixes, the 'Nuclear–Coal–Green' was selected as favourable target, projecting 4,000 MW nuclear, 4,900 MW natural gas, 400 MW coal (lignite) and 2,200 MW renewable capacity by 2030.

However, this strategy should have been monitored and updated every second year which lags behind. MAVIR creates and updates projection of energy needs and capacities every year (MAVIR, 2014a). According to MAVIR's up-to-date projection, electricity needs will grow only 1.0–1.3% annually (in previous years, MAVIR also forecasted a 1.5% growth.). Depending on the market conditions, capacities are projected to increase from 8,600 MW (with 11.2 TWh import; delayed investments scenario) to 13,600 MW (with 8.0 TWh export; intensive capacity growth scenario) by 2030, from which 3,200–4,400 MW will be nuclear, 2,400–6,500 MW natural gas, around 100 MW coal, and 1,850 MW renewable, irrespectively of the scenario. These, more current projections of MAVIR are the basis of the *Official scenario* created in this research, detailed in *Chapter 2.2.2*.

Official Hungarian energy planning, while acknowledges energy efficiency and conservation efforts and aims of the European Union, concentrates mostly on building new power plants, claiming GDP growth will raise energy demand. Nuclear and coal-based power plant constructions are highlighted due to their strong and influential lobby groups. However, while energy efficiency, renewable energy sources and smart energy solutions appear in the *Energy Scenario* and official plans, in reality and in the media, they get only peripheral role (MOLNÁR, Cs. 2014). Since 2006, no wind capacity tenders were announced; therefore, no new turbines have been installed since 2011 (O'BRIAN, H. 2012); the long-promised new renewable energy feed-in tariff system, called METÁR (which would be highly necessary to reach the EU targets), has still not been introduced since 2011 (ROTHFUCHS, H. 2011); and new tax on photovoltaic solar panels were put in force from 2015 (DAILY NEWS, 2015).

1.3. Alternative energy vision

The long-term goal of *Energiaklub* is to phase out fossil and nuclear energy in *Hungary* to be able to realise a sustainable energy system in the next decades. Improving environmental awareness, energy sufficiency, efficiency and diverse range of renewable-based technologies will be the most important factors to outline a flexible, decentralised energy system. Besides energy safety and economics, social and environmental aspects are also important ones in energy planning decisions. For example, the 4th generation district heating systems, based on local energy sources, providing jobs nationwide will be important elements of the energy system.

The year 2030 can be seen as an intermediate station along the way to the long-term aims where new trends are getting stronger, but the fundaments of the energy system are still traditional. The reason for that is that the modelled scenario is not a normative, best-case scenario. While defining exact numbers and characteristics of the future alternative energy system of *Energiaklub*, desirable and, at the same time, realistic and easily achievable targets were defined as a first, basic alternative scenario. In the next *Chapter*, the details of outlining and modelling this scenario by 2030 will be introduced, along with the two other models based on official energy planning.

2. Methodology

This paper can be seen as a continuation of a research that started in 2011, creating and validating the first energy model for *Hungary* with the *EnergyPLAN software*, published in *Energy* (SÁFIÁN, F. 2014). The main characteristics of the Hungarian energy system, the status and results of alternative energy planning in *Hungary* were described there, as well as the *EnergyPLAN software*, which will briefly be presented in this chapter.

2.1. EnergyPLAN software

EnergyPLAN is an energy system analysis tool, which have been developed at *Aalborg University* (AAU), *Denmark*, since 1999. This software enables to build and analyse full energy systems (including all sectors, also transportation) of a year, hour by hour. It is working as a deterministic input-output model, optimising the energy system from technical or market-economic aspects. The main input demand of the model is yearly aggregated electricity, heat and fuel demands, renewable and nuclear energy production quantities and capacities, hourly distribution of electricity, heat demands and production curves. Costs and numerous options of regulation strategies can be also defined. The outputs are energy balance, annual energy production, fuel consumption, electricity import or export, and total costs. Serial analyses can also be made by a built-in application, where changes in CO_2 emissions, total fuel usage or critical excess electricity production (CEEP) can be investigated depending on variable capacities of certain renewable technologies. In this research, *EnergyPLAN* version 12.1 was used[1].

2.2. Model building

Based on the above presented visions, plans, and projections, exact input data had to be defined to model building in *EnergyPLAN* software. The model of *Energiaklub* for 2030 was used as the basis for the two other models; therefore, it will be presented in more details. In the Official and Hybrid models, where not indicated, all parameters are equivalent to the Alternative model. Some of the main inputs like electricity needs remained the same to ensure comparability between the models. *Chapter 2.2.2.* presents the parameters of the Official and Hybrid model, according to the official plans and projections. *Chapter 3.3.* summarises the main input data of the models.

2.2.1. Alternative model based on *Energiaklub*'s energy vision 2030

In the followings, the calculation and sources of the main inputs will be detailed, from which the model (and partly the other two models) were built.

2.2.1.1. Electricity demand

Since each electricity demand projection has been overestimated in the last decades, a new estimation was carried out. Based on the Hungarian sectoral electricity consumption data of Eurostat between 1990 and 2012, and European average figures of 2012 (EUROSTAT, 2016), sectoral-, and total electricity demand were conducted with trendlines, international comparisons and assumptions based on recent processes in economy and consumption *(Table 1)*.

[1] EnergyPLAN software, version 12.1. Aalborg University (www.energyplan.eu)

Table 1 – Electricity demand by sectors in 2012 and estimation by 2030

*Source: based on EUROSTAT (2016) data. (*of total electricity consumption)*

	2012 data (GWh)	2030 projection (GWh)	change (%)	trend or estimation method
Consumption in energy sector	3,719	3,809	+2.4	11.3%* in *Hungary*, 6–7%* in EU-28 in 2012; estimation of 9.5%* in 2030
Distribution losses	3,684	3,207	–12.9	11.2%* in *Hungary*, 7%* in EU-28 in 2012; estimation of 8%* in 2030
Industry	8,910	9,856	+10.6	exponential trendline from 1993 (end of industrial structural change)
Transportation	983	2,903	+195.4	custom calculations
Residential	10,620	11,682	+10.0	10% increase between 2012 and 2030
Agriculture, Forestry, Fishing	782	800	+2.3	remains on the same level with slight increase
Services	11,517	14,849	+28.9	polynomial trendline based on 1990–2012 (R^2 = 0,96; equals to 29% growth in 18 years)
Total	**40,215**	**47,107**	**+17.1**	**(equals to 0,88% growth annually)**

Hungary has significant energy saving potential due to high distribution losses and high level of the energy system's own consumption, compared to the EU-28 average *(Table 2)*. The economic growth of industrial sector will also indicate lower increase in electricity consumption due to improving energy efficient technologies. Transportation demand was calculated with a detailed calculator of *András Futó* (more details is presented in *Chapter 2.2.1.5.*), including 570,000 hybrid electric vehicles (HEV), 220,000 plug-in hybrid electric vehicles (PHEV), 40,000 pure electric vehicles (EV) with 25% share of smart charge—these numbers can be seen as conservative projections. During modal shift, 30% of freight road traffic (t/km) changes to freight train. These changes cause a huge increase in electricity consumption in electric transportation.

Table 2 – List of large and small fossil fuel-based power plants according to Energiaklub's vision of 2030. *Groups (according to EnergyPLAN): 1: heat producers; 2: small combined heat and power (CHP) plants; 3: large CHP (can run also in condensation mode); 4: condensation PP; 5: peak PP.*
Source: MAVIR (2014b)

Group	Power Plant	Capacity (MWe)	Efficiency (%) – Electric	Efficiency (%) – Heat	Efficiency (%) – Total	Production (TWh) – Electricity	Production (TWh) – Heat	Used primary energy (TWh) – Coal	Used primary energy (TWh) – Oil	Used primary energy (TWh) – Nat. gas	Used primary energy (TWh) – Other	Used primary energy (TWh) – Total
	Paks Nuclear	2,000	31.3	0.1	31.4	15.7	*0.1*				46.4	46.4
4	Dunamenti	408	54.0	0.0	54.0	1.2				2.3		2.3
4	Mátrai	500	35.3	0.3	35.6	3.2	0.0	8.1	0.0	0.2	0.8	9.1
4	Gönyűi	433	54.7	0.0	54.7	1.4				2.4		2.4
4	Csepeli	410	44.3	7.7	52.0	1.6	0.3		0.0	3.6		3.6
3	Budapesti	396	42.6	41.2	83.8	1.2	1.1		0.0	2.7		2.7
3	Pannon	85	29.0	15.0	44.0	0.0	0.1			0.0	0.4	0.4
3	Debreceni	95	34.5	41.7	76.2	0.2	0.3			0.7		0.7
2	Gas engines	600	34.2	43.8	78.0	2.6	3.3			7.6		7.6
2	Gas turbines	340	29.3	46.6	75.9	1.7	2.6			5.7		5.7
2	Steam turbines	50	28.0	35.0	63.0	0.2	0.4		0.2	1.0		1.2
5	New OCGT units	500	30.9	0.0	30.9	0.0			0.0			0.0
1	Ajkai	102	10.7	50.7	61.5	*0.0*	0.1	0.1		0.0	0.1	0.2
1	ISD Power	65	7.5	50.0	57.5	*0.1*	0.9		0.0	1.7		1.7

Regarding households, population degrowth, efficiency improvements, and new electronic instruments will shape the future needs, generating a 10% increase during the total period. The most significant electricity demand growth will happen in services sector where the strong trend of intensive growth will continue in the next decades as well, due to more air conditioners caused of climate change and wider services. By summing up the above, total electricity consumption will be 47.1 TWh by 2030.

2.2.1.2. Heat demand

Based on the previous researches of *Energiaklub*, investigating energy saving potentials in residential (FÜLÖP, O. 2011; FÜLÖP, O. – VARGA, K. 2013), public educational and office buildings (FÜLÖP, O. 2013) cost-optimality studies of energy efficiency investments (SEVERNYÁK, K. – FÜLÖP, O. 2013) and the *National Building Energy Strategy* (CSOKNYAI, T. *et al.* 2013), heat saving potentials were defined by 2030. Due to building refurbishments, heating system improvements, complex building renewals and new, efficient buildings, 23 TWh primer energy demand could be saved by 2030, compared to 2011. The total fuel demand for heat production is calculated to be 184 PJ (51.1 TWh) by 2030. Most savings can be realised regarding natural gas (–35%), residential coal (–55%) and firewood (–70%) consumption. The level of district heating supply will remain on the same level; however, it will include new, small, local, biomass- or geothermal-based district heating systems next to the existing ones, which will supply less heat caused by higher energy efficiency of buildings.

2.2.1.3. Large power plants and fossil-based small power plants

The power plants and their parameters were taken from MAVIR's most recent projections (MAVIR, 2014a), regarding large and small, fossil-fuelled power plants, creating a reasonable mix of the higher and lower rate power plant building scenarios. The list of power plants *(Table 2)* contains the existing nuclear power plant in *Paks*, while excludes *Paks II* and numerous power plants which are working today, but will be closed by 2030. *Mátrai coal-fired power plant* is not in the capacity list of MAVIR, but it is planned since years to build on the field of the existing *Mátrai coal-fired power plant* (VALASKA, J. 2011); therefore, it is also included in the model.

The power plants are grouped according to the *EnergyPLAN* grouping system (see first column and explanation of *Table 2*); the total capacity and average parameters (efficiencies, heat storages, etc.) are put in the model by these groups. Nuclear power plants and renewable power plants (except large power plants co-burning biomass) are presented in a different section. Heat production of *Paks nuclear power* plant (0.1 TWh) could not be indicated in the model. Furthermore, electricity production (<0.1 TWh) of *Ajkai* and *ISD Power plants* are neglected due to low efficiencies; these power plants were attached to Group 1 consisting of heat only producers.

2.2.1.4. Renewables

Renewable energy capacities and production were defined based on a wide research of related literature including researches of Hungarian sustainable energy potentials and future scenarios (ÁMON, A. *et al*. 2006; FISCHER, A. *et al*. 2009; SZAJKÓ, G. 2009; KPMG, 2010; MUNKÁCSY, B. 2011; BÜKI, G. – LOVAS, R. 2010; GREENPEACE, 2011; BARTHOLY, J. *et al*. 2013; HARMAT, Á. 2013; TÓTH, P. – CSÓK, L. 2014), Hungarian official strategies (MINISTRY OF NATIONAL DEVELOPMENT, 2012) action plans (NFM, 2011) and their background studies (REKK, 2011; PYLON, 2010) and international development curves (EUROBSERV'ER, 2010; EWEA, 2011; EUROBSERV'ER, 2014a & 2014b). Based on these, the first version of the model was outlined, with the aim of defining rather conservative, but easily achievable capacity targets by 2030. This version was published in January 2015, where the figures were affirmed or corrected by Hungarian renewable energy associations. The following list in *Table 3* presents the altered and validated list, used in this research.

Wind capacities will be 8.5 times more in 2030 than in 2014, according to the conservative calculations. Currently 330 MW are in operation, and during the last wind capacity announcement for 410 MW,

Table 3 – Renewable energy capacities and electricity production in Energiaklub's energy vision by 2030

Source: ENERGIAKLUB

Energy source	Capacity in 2030 (MW)	Power production (TWh)
Wind	2,800	5.40
Solar	1,400	1.82
Solid biomass	825	2.24
Biogas	750	1.62
Geothermal	67	0.47
Hydro	66	0.24
Total	**5,908**	**11.79**

during one year, 1,117.75 MW application was rejected due to cancelling the tender (B. HORVÁTH, L. 2013). Besides favourable solar potential, on-roof photovoltaic capacities of households started to almost double every year since 2009, growing from 0.46 MW to 68.13 MW by the end of 2014 (MEKH, 2016). The estimation of 1,400 MW by 2030 was confirmed by *Hungarian Solar Energy Association*. Solid biomass is already the most important renewable energy source in *Hungary*, but used primarily in large power plants. However, the new capacities of 825 MW will be small, local, perhaps community-owned combined heat and power (CHP) units. The first estimation of biogas capacity (350 MW) was more than doubled according to the *Hungarian Biogas Association*'s recommendation. *Hungary* has significant geothermal potential, but has severe technical barriers to utilise it; therefore, only pilot geothermal power plants will run by 2030. Without new, large-scale hydro power plants, only small units can be added to the existing energy system; therefore, hydro capacities will slightly grow by 2030.

2.2.1.5. Transportation

A detailed calculator of *András Futó* was used to define transportation demands based on trends between 2000–2010 of specific fuel demands, running volumes, vehicle stocks, etc. Regarding electricity, several targets were defined, from which most important are modal shift from road freight traffic to train traffic. Finally, 4.27 million private vehicles are calculated to run by 2030, from which 2.3 million petrol, 1.1 million gasoline-based (80% of private fleet), while next to 0.67 million hybrid and electric vehicles (PHEV, HEV), 0.2 million LPG/CNG cars will be on the roads. Average fuel consumption will decrease to 6.9 (petrol) and 6.1 (gasoline) litres/100 km, where the biofuel content will raise to 7%. Train usage will raise by 30% both regarding personal and freight transportation. Total fuel demand of transportation will be 34.0 TWh gasoline, 15.5 TWh petrol, 2.9 TWh natural gas and 0.5 TWh LPG, while in 3.1 TWh transportation electricity consumption 0.54 TWh accounts for hybrid and electric cars' consumption.

2.2.1.6. Distribution curves

Hourly detailed production and demand distribution curves play important roles in the models: besides the volume of energy production based on them, they indicate weather conditions (solar, wind production curves, heat demands), user behaviour (heat and electricity demand), and enable a particular analysis of the energy system. Therefore, coherent distribution curves are needed for one common year, with 8,784 data points for 366 days. In this case, 2011 was selected to this occasion, as for this year almost all the needed data series were available from measurements in *Hungary*; all data series listed in the followings are indicating that year.

Electricity demand and wind power production curves were downloaded from MAVIR (2015). This means, that no changes were made to indicate alterations in future electricity (or any other) consumption behaviour. District heating production measurements from a CHP unit of FŐTÁV (Budapest's district heating company) were used, also for individual heat and hot water demand (FŐTÁV, 2014). Solar production curves were generated from global radiation curves measured by *Hungarian Meteorological Service* (OMSZ) and *University of Debrecen* in *Debrecen Agrometeorological Observatory* (NAGY, Z. *et al*. 2008; 2010; OMSZ, 2014). Hydro production is simulated with a German river hydro distribution curve built in *EnergyPLAN*, since it provided better results on the validation (SÁFIÁN, F. 2014) than any own-created distribution curves, while production data were not available. For nuclear power production, distribution curve was generated manually based on the known maintenance periods of *Paks power plant*. Waste, geothermal energy and biomass production were considered as constant.

2.2.1.7. Balance and regulation

In *EnergyPLAN* model, technical simulation was selected (and not market-economic) as simulation strategy, where both heat and electricity demands were balanced (strategy No. 2). There are 10–10 GWh heat storage in total next to the group 2 and 3, including small and large CHP units. There is 4,000 MW of transmission capacity available for electricity import and export—however, during the analyses of *Chapter 4*, this is set to zero. Minimum grid stabilisation production share is 30%, small CHP stabilisation share is 50%. There is no regulation for CEEP or minimum running capacity of power plants.

2.2.1.8. Official and Hybrid models 2030

In order to have comparable models, only the most necessary changes were made when building the Official and Hybrid models: mainly power plant capacities. However, this way it is neglected, that Official (and Hybrid) scenarios are likely to be regulated in a different way from the renewable energy-focused Alternative model of *Energiaklub*; furthermore, user behaviour may vary as well. It is also very likely that in the official version, focusing on power plant building as a solution for growing energy needs (and not efficiency or energy saving improvements), energy needs can be expected to raise at a higher rate. However, electricity needs are the same in all models.

Regarding the *Official scenario*, power plant capacities are based on MAVIR's projections (MAVIR, 2014a), which means, that almost all fossil fuel-based capacities are the same with the Alternative scenario. The main differences are: 4,400 MW nuclear capacity; more peak power plant capacity (1,200 MW—have to be equal to the largest block of the country); and significantly less renewable capacities. In Hybrid scenario, wind and solar capacities calculated by *Energiaklub* are added to the power plants of Official energy model, therefore including 4,400 MW nuclear capacity as well. This way this scenario could show how significant nuclear power capacities can work together with significant renewable capacities. In these scenarios, a new nuclear power production distribution was generated, since in *Paks II power plant* (2,400 MW) 2 x 1,200 MW block will work, where a maintenance stop will cause only 50% power production compared to *Paks I*, where 4 blocks of 500 MW are working (75% production during maintenance).

2.3. Summary of main inputs of the three models

The models are the same regarding energy demands, distribution curves, regulation strategies, etc. Also, electricity demand will be the same: 47.1 TWh in all three models in this comparison. The main differences are in capacities, which can be compared in *Table 4*.

Table 4 – Power plant capacities by models (indicating groups according to the EnergyPLAN software; large CHP plants can work in CHP or condensing PP mode)

Source: Calculated by SÁFIÁN, F. (2016) with EnergyPLAN software

	OFFICIAL (MW)	ALTERNATIVE (MW)	HYBRID (MW)
Nuclear power plant	4,400	2,000	4,400
Condensing power plants (Gr. 4)	1,751	1,751	1,751
Large CHP plants (Gr. 3/4)	576	576	576
Peak power plants (Gr. 5)	1,200	500	1,200
Small natural gas CHP (Gr. 2)	830	990	830
Small biomass CHP (Gr. 2)	600	825	600
Small biogas CHP (Gr. 2)	120	750	120
Wind	850	2,800	2,800
Solar	90	1,400	1,400
Hydro	75	66	75
Geothermal	65	67	65
Total capacity	**10,557**	**11,725**	**13,817**

The Alternative model has almost 6,900 MW of decentralised, small power plants, from which more than 5,900 MW is renewable, approximately the same as the fossil-based capacities (including nuclear). In case of the Official scenario, there is only 2,630 MW decentralised capacity, from which 1,800 MW is renewable; the majority is still large (7,900 MW), centralised, fossil-fuelled (8,750 MW) power plant. Regarding Hybrid scenario, the capacities are more balanced with around 5,900 MW small and 7,900 MW centralised capacities, meaning around 8,750 MW fossil and 5,060 MW renewable power plants.

3. Results

The three models were run in *EnergyPLAN software*, simulating one-year run of the different models by 2030, but with weather and consumption circumstances from 2011. *Table 5* summarises the most important indicators from the results.

Table 5 – Most important results of model simulations in EnergyPLAN software

Source: Calculated by SÁFIÁN, F. (2016) with EnergyPLAN software

	OFFICIAL (TWh)	ALTERNATIVE (TWh)	HYBRID (TWh)
TPES	272.9	252.2	268.7
RES TPES share	6.9	13.4	8.6
RES electricity share	10.3	27.1	22.2
Import electricity	0.0	0.5	0.0
Export electricity	0.5	0.1	2.4
CO2 emissions. corr. (Mt)	35.2	40.8	31.7

The *Alternative model* has the lowest total primary energy source consumption, highest renewable share, and renewable supply is 27% of electricity production. However, it needs 0.5 TWh import electricity, and it has the highest CO_2 emissions of energy sector. This is due to the large utilisation of condensing power plants running on natural gas or coal (12.4 TWh production compared to 4.0 TWh in *Official scenario*)—as 2030 can be viewed as a transitional year of the transformation process. The *Official and Hybrid scenarios* have larger fuel consumption (even with the same renewable capacities) due to high nuclear production. *Official scenario* has half renewable energy production compared to the Alternative scenario, and renewable electricity generation is less than half of that; the figures are little higher in *Hybrid scenario*. The two latter models have low CO_2 emissions and needs no electricity import. On the contrary, there is a significant electricity export in Hybrid scenario.

4. Analyses

The aims of this research were to create an alternative energy scenario, which was presented above; and to analyse the effects of a new nuclear power plant on the future Hungarian energy system, focusing on renewable energy production. Therefore, three analyses were carried out for each scenario with *EnergyPLAN* software to investigate this issue:

1. A CEEP analysis. CEEP is a used indicator in energy system analyses to describe the integration scale of renewable energy sources into the electricity system (LUND, H. 2003).
2. 24-hours analysis of the highest CEEP production periods – what are the main reasons for CEEP production?
3. Analyses of production shares of different type of power plants – is it reasonable, realistic and sustainable, considering the energy system?

4.1. CEEP analysis

As electricity production of an intermittent energy source increases in an energy system, surplus, non-utilised electricity production grows. However, this growth is non-linear, renewable energy technology- and energy system-specific. The lower the excess electricity production is in a system with the same renewable electricity production, the better the integration and utilisation of renewable technologies are. This utilisation can be improved by regulated CHP plants, (smart-charged) electric cars, heat pumps, etc. (LUND, H. 2005)—however, these technologies are not significant in the author's models by 2030 yet.

For the analyses, all models were run in serial calculation mode, with the same changes applied in each model, following (LUND, H. 2003). Transmission capacity was set from 4,000 MW to zero, this way exportable excess electricity production (EEEP) will be appeared as CEEP as well. In normal regulation mode, CPH plants are taking part in grid stabilisation and ancillary services (stabilisation share of production is 25–30%), but in CEEP analyses this is set to zero as well. To ensure grid stability, the minimum of 350 MW running power plant capacities are available in every hour and at least 30% of electricity is produced by power plants able to supply ancillary services as well.

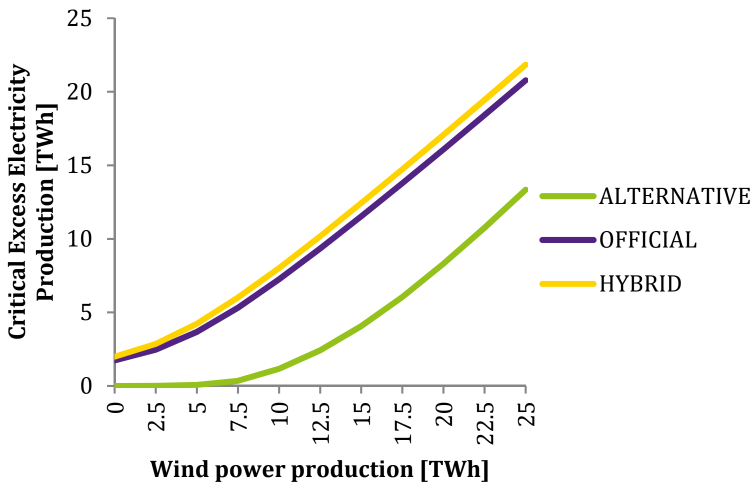


Figure 1 – Wind power and CEEP production in different models

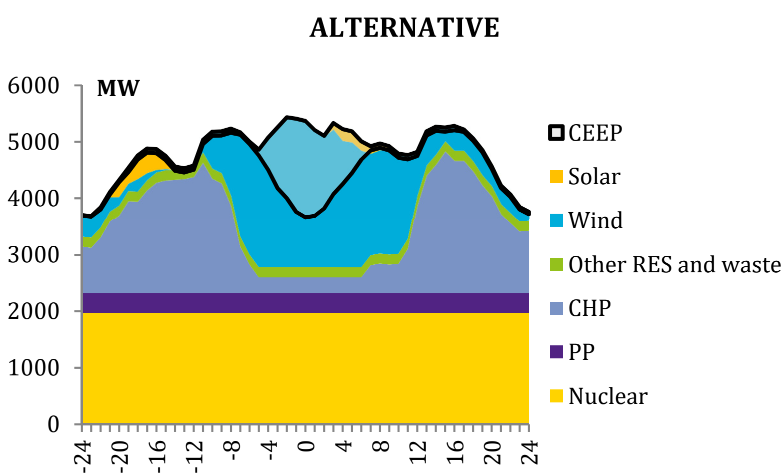
Designed by SÁFIÁN, F. (2016)

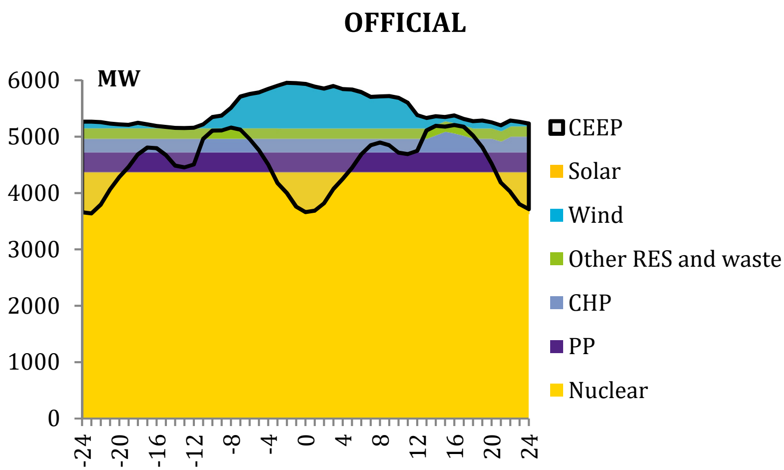
The results show *(Figure 1)* that the *Alternative model* can integrate wind energy production significantly better. Around the optimum point of 7.5 TWh wind energy production (equals to 3,885 MW wind capacity), CEEP is 4.7% of wind energy production in Alternative model, while 70.8% in the Official and 80.1% in the Hybrid scenarios. However, it is obvious, that in the latter two scenarios, excess electricity production is not solely coming from wind power, since there is 1.7 and 2.0 TWh CEEP at no wind power production as well.

4.2. Hourly analysis of CEEP production

To analyse the reason of CEEP production in the different models, the hour of highest CEEP value was selected, with 24-hour data before and after. This period was during the night of the 359–360th day of the year, in December. The following diagrams shown in *Figure 2* show the electricity generation of these two days by power plant groups (total production: top black curve), electricity demand (lower black curve), and with darker shadow, CEEP (area between the two lines).

In the case of the *Alternative model*, the excess electricity production is caused by low electricity demand due to night hours, and a windy night. However, this is not the case regarding the Official model: nuclear electricity production is higher itself in some hours of the night, than electricity demand; next to it, wind energy production is not significant.





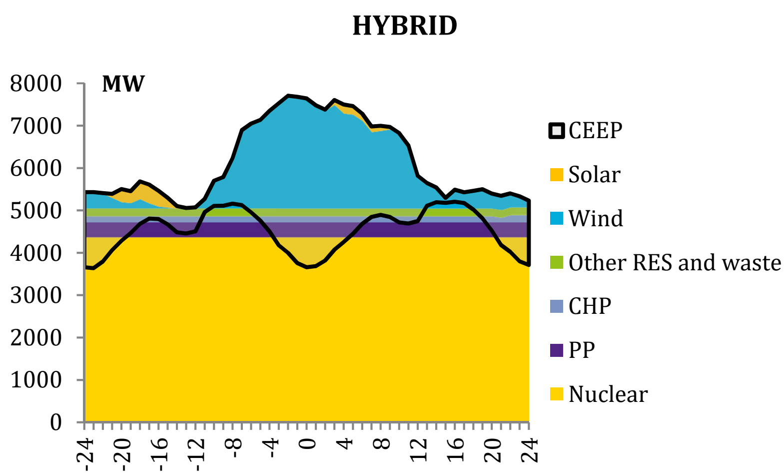


Figure 2 – electricity production, demand and CEEP in different models on the 359–360th day of the model

Designed by SÁFIÁN, F. (2016)

Based on correlation calculations between electricity demand and CEEP in Official model, it is clear, that the main cause of CEEP is not renewable energy production, but too high nuclear production compared to electricity needs, which mostly appears in winter months (corr. –0.64 on days with CEEP; corr. –0.87 on first 1000 hours of the year). Hybrid model sums up the two effects caused by wind power production and high nuclear power production.

4.3. Analysis of electricity production shares

It was already visible in the CEEP analysis in the *previous chapter* that the utilisation of different type of power plants alters significantly due to different nuclear and renewable capacities. However, in *Chapter 4.2.* the analysis was carried out with special regulation settings to be able to detect CEEP production. In this chapter, power plant production shares are presented in 'normal' circumstances as described in *Chapter 2.2.1*.

Figure 3 shows that electricity production of nuclear power plant(s) from only one physical site supplies almost three-quarter of electricity production in *Official and Hybrid models*, which arises security issues in itself. Intermittent renewable electricity share by 2030 is around 15% in *Alternative and Hybrid models* while only 3.7% in Official model by 2030. CHP (combined heat and power) and PP (power plant) production are in a critical situation next to large nuclear and renewable capacities – these power plant types are to be regulated (down) if needed. This can be seen on their production shares as well: they can produce almost half of total in Alternative scenario, only 20% together in Official and 11% in Hybrid. This would mean a positive transition of energy mix in another case; however, in *Hungary*, *Paks I* (2,000 MW) is expected to shut down step-by-step between 2032 and 2037. Therefore, PPs working in 2030 would be needed in the next decade as well, but low utilisation rates for the 6 critical years could result in PP shut downs during those years.

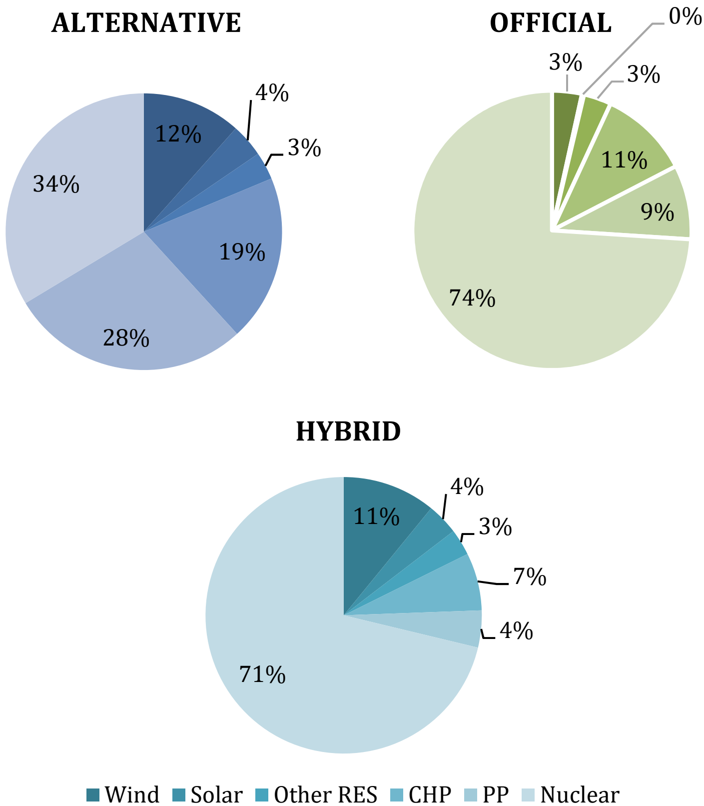


Figure 3 – Electricity production shares by power plant types in different models

Designed by SÁFIÁN, F. (2016)

As PP utilisation is more 'endangered' from this aspect, PP utilisation has to be highlighted. *Figure 4* shows the total capacity of PP (condensation power plants and CHP plants able to work in condensation mode), which is 2,327 MW, without peak power plants, and the utilisation of PPs by months.

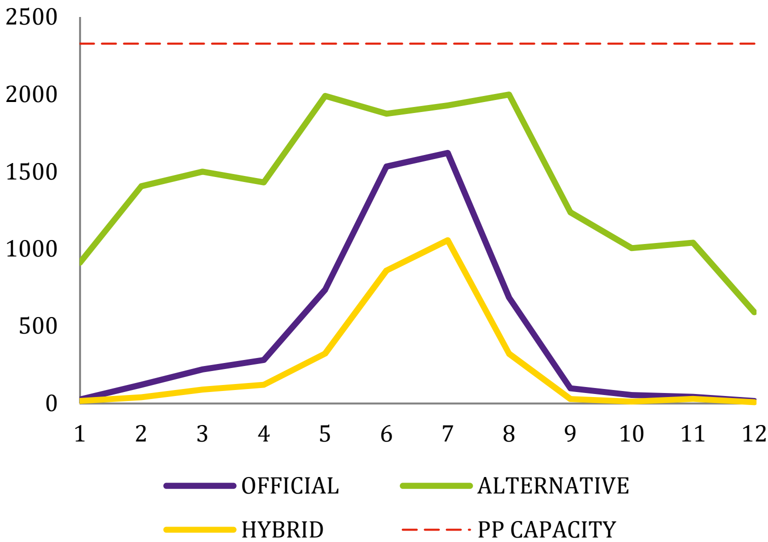


Figure 4 – Average monthly load capacity of condensational power plants in different models
Designed by SÁFIÁN, F. (2016)

The utilisation of PPs in *Official and Hybrid scenarios* is critically low, they slightly reach half of their capacity in a monthly average, while in the winter season, CHP plants are displacing them. The utilisation rate of PPs in Official scenario is 19.5%, which means only 1,710 hours, in Hybrid scenario 10.4% and 911 hours. These numbers raise the issue of uneconomic running conditions for power plants which could lead to shut downs. The *Alternative scenario* would utilise these power plants for 5,316 hours (60.5%), which could lead to normal running conditions based on average PP characteristics.

5. Conclusions

An alternative energy vision and model were outlined and calculated next to the official one. Simulation with *EnergyPLAN* software showed, that it is possible to run the energy system without a new nuclear power plan by 2030. Furthermore, according to the conservative renewable energy utilisation targets, 27% renewable electricity production share is reasonable by 2030, which is more than double compared to the Official scenario, where 2,400 MW new nuclear capacity is planned to be built instead of urging renewable-based improvements. This result implies, that *Hungary* has different viable options for energy system development, which have not been properly compared and discussed yet in public nor amongst experts; and that renewables would have more space in an alternative energy scenario than the official one.

CEEP and production share analyses showed, that excess production is significantly higher in Official and Hybrid scenarios. Hourly analyses showed, that not (solely) renewable energy production, but high nuclear power supply and low electricity demand are the main reasons of CEEP.

One can conclude, that nuclear power capacity will be oversized for 6 years of co-working of the two nuclear power plants, according to the Official scenario, which will be critical from the energy system's point of view. Nuclear capacity will be larger in itself in low demand hours than the expected electricity demand. The disproportionate nuclear power production and high baseload capacities arise serious issues regarding energy system regulation and renewable energy development, which can be expected as the followings:

- exporting electricity is the official solution for this issue, but the probability of CEEP due to large excess electricity production arises, especially during night, when export possibilities are unfavourable;
- between 2026–2032, due to the large nuclear electricity supply (and renewable production), other power plants will have to minimise their electricity production which is likely to cause uneconomic environment for CHPs and conventional power plants, while their existence would be essential after 2032–2037, when *Paks I* will be phased out;

- due to large nuclear electricity supply, preferred by TSO, will hinder other electricity production solutions for decades like 4th generation CHP district heating and renewable-based solutions;
- if TSO will not prefer nuclear electricity due to merit order effect or by preferring renewable or CHP production (and the nuclear power plant must be regulated down), financial return of the €12.5 billion investment by the state will be endangered. Therefore, there will be an interest against the development of other producers, like renewables;
- almost 75% of electricity production will come from one site, which arises security issues.

From looking upon a wider aspect, not only changes in the energy system, but also in the socio–economic framework will necessarily tend to hinder renewable solutions. For example, large amounts of research, development and investment costs will be channelled into nuclear industry, instead of diverse technologies. Furthermore, centralising the energy system on physical, but also on institutional level will hinder the development of renewable-based, decentralised local energy production.

Acknowledgements

This research was presented at the *International Conference on Smart Energy Systems and 4th Generation District Heating* in *Copenhagen, Denmark* on 25–26 August 2015, hosted by *4DH Research Centre*. I am grateful for the *ELTE Talent Management Council* and *Energiaklub Climate Policy Institute and Applied Communications* for supporting my participation at this conference.

The research was initiated, professionally and financially supported by *Energiaklub Climate Policy Institute and Applied Communications*, therefore I thank for all their help, faith in my work and enthusiastic attitude.

I thank *Tamás Weidinger* (ELTE Department of Meteorology), *Zoltán Nagy* (Hungarian Meteorological Service) and *György Sigmond* (MaTáSzSz) for supporting the model building by providing data.

I would like to express my gratitude to *András Futó* (BME), *Ádám Harmat* (ELTE), *Ádám Szolnoki* (MANAP), *Kornél L. Kovács* (Hungarian Biogas Association), *Orsolya Fülöp* (Energiaklub), *Zsófia Vetőné Mózner* (Corvinus University) and *Zsuzsanna Koritár* (Energiaklub) for their valuable inputs and comments.

I am thankful to my supervisor *Béla Munkácsy* (ELTE), *David Connolly* (AAU), *Henrik Lund* (AAU) and *Poul Alberg Østergaard* (AAU) for their initial advices and technical support regarding *EnergyPLAN software*.

Furthermore, I am obliged to my collegaues *Orsolya Fülöp* and *Zsuzsanna Koritár* who offered me a great help in proof reading and language editing.

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