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2017 **Michaela Koščová**

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The merit order effect of photovoltaic generation in Slovakia

Bachelor thesis

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Abstract

Photovoltaics in Slovakia have been experiencing a fast development in the last years, benefiting from a large support in various forms – be it generous subsidies and guaranteed feed-in tariff or legal preferential treatment. Due to very low – close to zero marginal costs it may appear that the green energy generated by solar power plants is "free" thus we expect a decrease in the wholesale electricity price. Indeed, in several countries the so-called merit order effect has been proven and the spot price of electricity declines thanks to the generation from the photovoltaics and/or other renewable sources.

This thesis evaluates the impact of the solar energy penetration into energy mix on spot prices, seeks evidence of the merit order effect in the Slovak electricity market and quantifies it thanks to publicly available data. The multivariate regression analysis takes into consideration the full years 2011-2016. The merit order effect estimated by an OLS time series model is negative, however, the spot price reduction attributable to the photovoltaics is not sufficient for resulting savings to outweigh the costs of the support scheme borne by end users what implies a consumer loss.

Keywords

renewable energy sources, photovoltaics, merit order effect, energy subsidies, feed-in tariff

Abstrakt

Fotovoltaika na Slovensku sa v posledných rokoch rýchlo rozvíjala hlavne vďaka štátnej podpore vo forme štedrých dotácií, garantovanej výkupnej ceny a prednostného výkupu. Kvôli nízkym – takmer nulovým marginálnym nákladom sa zdá, že “zelená energia” pochádzajúca zo solárnych elektrární je bezplatná, preto očakávame zníženie veľkoobchodnej ceny. Tento efekt sa skutočne potvrdil v mnohých krajinách. Spotová cena klesá vďaka výrobe z fotovoltaiky a/alebo iných obnoviteľných zdrojov.

Táto práca hodnotí dopad výroby solárnej energie na spotovú cenu elektriny – dokazuje a kvantifikuje efekt poradia záslužnosti na slovenskom trhu s elektrinou. Regresná analýza berie do úvahy dáta za roky 2011-2016. Ekonometrický model potvrdzuje záporný efekt, teda zníženie spotovej ceny v dôsledku zvýšenej výroby zo solárnych zdrojov. Vyplývajúce úspory však nie sú dostačujúce na preváženie nákladov na podporu týchto zdrojov, ktoré sú hradené koncovými odberateľmi a tí sa tak ocitajú v strate.

Kľúčové slová

obnoviteľné zdroje energie, fotovoltaika, efekt poradia záslužnosti, dotácie v energetike, výkupná cena

Declaration of Authorship

I hereby proclaim that I wrote my bachelor thesis on my own under the leadership of my supervisor and that the references include all resources and literature I have used.

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Prague, 19 May 2017

Signature

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The Bachelor's Thesis Proposal

Author: Michaela Koščová

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Topic: The merit order effect of photovoltaic generation in Slovakia

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Description

Renewable energy is generally defined as coming from natural sources that are continually and sustainably replenished. Photovoltaics are classified as renewable energy source since the principle rests on converting solar radiation into direct current electricity. It is a way how to create cost-effective and pollution free energy without using fossil fuels, producing greenhouse gases or radioactive or toxic waste.

The issue of renewable sources of energy becomes more and more important due to the commitment of European Union to increase the share of renewable energy in gross final energy consumption. The target desired to reach until 2020 is set at 14% for Slovakia whereas for the European Union the percentage is set at 20%.

Use of solar energy for producing electricity in Slovakia was at a low level after the entry into the European Union because of high investment costs of building photovoltaic plants. After the decision of the Regulatory Office for Network Industries from the year 2008 concerning the support of electricity production in photovoltaic plants and establishing a guaranteed fixed feed-in tariff the interest in solar energy raised. Thanks to the increased demand for renewable energy sources, the construction of photovoltaic cells and arrays has advanced significantly and costs have decreased.

Prices of electricity on the spot market have dropped notably due to greater employment of the photovoltaics which is described as the merit order effect. The purpose of this bachelor thesis is to assess this phenomenon, i.e. to evaluate the impact of the solar penetration to energy mix on spot prices. The merit order effect will be estimated through an OLS model using available time series data and approximate savings calculated. Furthermore, the author aims to study the evolution of guaranteed feed-in tariff and the overall generous governmental support of renewable energy sources.

To conclude, the author would like to comment on whether the costs of such support of the renewables are offset by the savings caused by the merit order effect and on the final consumer benefit or loss.

Outline

1. Introduction
2. Photovoltaics in Slovakia
3. Merit Order Effect
4. Literature Review
5. Data and Methodology
6. Results
7. Conclusion

Core bibliography

1. Stefano Clo, Alessandra Cataldi, and Pietro Zoppoli. The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. Energy Policy, 77:79-88, 2015.

2. Johanna Cludius, Hauke Hermann, Felix Matthes, and Verena Graichen. The merit order effect of wind and photovoltaic electricity generation in Germany 2008-2016: Estimation and distributional implications. Energy Economics, 44:302-313, 2014b

3. Amy O'Mahoney and Eleanor Denny. The Merit Order Effect of Wind Generation on the Irish Electricity Market. Munich Personal RePEc Archive, 2011.

4. Liliana Gelabert, Xavier Labandeira, and Pedro Linares. An ex-post analysis of the effect of renewables and cogeneration on Spanish electricity prices. Energy Economics, 33:S59-S65, 2011.
5. RONI. Porovnanie podpory OZE a vykupnych cien elektriny vyrobenej z OZE v okolitych krajinach. Technical report, Regulatory Office for Network Industries Slovakia, 2014.
6. Klaas Wurzburg, Xavier Labandeira, and Pedro Linares. Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. Energy Economics, 40:S159-S171, 2013.

Contents

Acronyms

MOE	[merit order effect]
RES	[renewable energy sources]
PV	[photovoltaic(s)]
TSO	[tariff for system operation]
FIT	[feed-in tariff]
OLS	[ordinary least squares]
IHS	[inverse hyperbolic sine]
N	[number of observations]
log	[logarithm]
GWh	[giga-watt-hour]
MWh	[mega-watt-hour]
kW	[kilo-watt]
MW	[mega-watt]
€/MWh	[euro per mega-watt]
VAT	[value added tax]
NPP	[nuclear power plant]
RONI	[Regulatory Office for Network Industries]
SEPS	[Slovak electricity transmission network]
OKTE	[Organizer of short-term electricity market]
SSE	[Stredoslovenska energetika, a.s.]
SE	[Slovenske elektrarne, a.s.]
EU	[European Union]
EC	[European Commission]

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1 Introduction

Photovoltaic energy is classified as renewable energy since the underlying principle rests on converting solar radiation from the Sun into direct current electricity. It is an efficient way to create sustainable, cost-effective and pollution free energy without using fossil fuels, producing greenhouse gases or radioactive and toxic waste. This young technology only started to develop from scratch in 1950s and first entered the U.S. market. Germany and Japan followed and initiated subsidy programs in order to spur its adoption.

Today, numerous countries on all five inhabited continents produce electricity from solar power plants. The European Union endeavors to promote not only the photovoltaic generation, but renewable energy sources in general. For this purpose, the Europe 2020 Strategy was implemented in 2009. The Renewable Energy Directive 2009/28/EC sets a goal of 20% of final national energy consumption to be produced from renewable sources. This legislation is binding for all EU countries, yet their own specific targets differ and range from 10% to 49%. Slovakia is supposed to reach 14% by 2020 (EC, 2010).

The EU countries have also agreed on the following steps already. The new 2030 Framework for climate and energy includes targets and policy objectives for 2020-2030 in order to achieve a more competitive, secure and sustainable energy system. It is based on the revision of Renewable Energy Directive from November 2016. One of the three main goals is related to RES and requires at least a 27% share of renewable energy consumption EU-wide. The individual figures for the member countries have not been announced yet.

Compared to other European countries, the Slovak Republic belongs to a relatively sunny region (especially its southern part), which implies a good potential for solar generation (Suri et al., 2007). Since the 2020 Strategy implementation, the photovoltaics in Slovakia have been largely supported by the government in different forms either through generous subsidies and guaranteed feed-in tariffs or legal preferential treatment (RONI, 2016a). The support scheme and subsequent fast development of photovoltaics have had a tremendous impact on many aspects of life in the society.

From the environmental as well as the political point of view, such incentive appears desirable. Production from renewable sources diminishes greenhouse gas emissions and improves the quality of air, and thus has a positive effect on health. It also helps promote green growth and employment and lowers energy dependence on limited reserves of fossil fuels.

However, the economic standpoint strives to identify whether or not the advantages outweigh the inconvenience. Said differently, it may appear that the green energy coming from solar power plants is "free" due to very low – close to zero – marginal costs therefore we expect the price of electricity to decline. Indeed, in several countries (Australia, Texas, Israel, Spain, Italy, Ireland, Germany, Czech Republic and more - see section 3) the so-called merit order effect has been proven, and the wholesale electricity price decreases thanks to generation from photovoltaics and/or other renewable sources. Yet the costs of support schemes are borne by final consumers – in the Slovak case they fall within the tariff for system operation that is incorporated in the retail price and has been pushing the electricity price upwards. Therefore the crucial questions to answer are: Is the merit order effect present in the Slovak electricity market? If so, what is its size? Do the savings attributable to the merit order effect offset the costs of the related support scheme? Does such an event result in a consumer benefit, or would the end consumers be economically better off had there been no photovoltaic generation? Although numerous studies exist concerning the above-mentioned phenomenon, to date nobody has assessed the merit order effect in the Slovak electricity market.

The objective of this thesis is an evaluation of the penetration impact of renewable energies to the energy mix on spot prices over the full years 2011-2016. Building on approaches described in the existing literature we construct a model and run an OLS regression on available time series data, the outcomes of which quantify the merit order effect and determine savings arising from a larger supply of electricity resulting from photovoltaics. We further calculate the costs and compare the obtained results in order to conclude whether or not the savings outweigh the expenses and thus create a consumer surplus or, vice versa, a consumer loss.

There are several reasons why we are particularly interested in the Slovak photovoltaics: the first is the negligibility of wind generation in the Slovak Republic and the nature of biomass and hydro power production which discourage us from an overall assessment of the renewables. The second is, as described above, favorable geographic conditions such as the amount of solar radiation or the number of sunny days. Thanks to this the photovoltaics have the capacity for developing and contributing to reaching the European 2020 Strategy goals concerning the RES production. Furthermore, the related support scheme is genuinely generous and photovoltaics have consumed a large volume of money since the legislative changes were adopted which started off a solar boom upon setting guaranteed feed-in tariffs. These reasons make photovoltaics a really important issue whose economic aspect we are interested in.

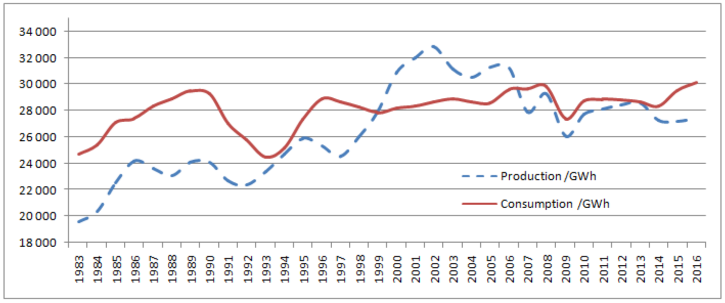
The rest of this thesis is structured as follows: the chapter on the Slovak energy market (2) offers an exhaustive theoretical background describing the Slovak production and consumption patterns, agents and interactions between them, principles governing the electricity market and energy mix composition. It also explains the merit order effect theory. Literature review (3) summarizes findings of other authors in order to enhance understanding of the problematic and is followed by Data (4) and Methodology (5) on datasets' features and the econometric approach employed. Next, Results (6) reports the outcomes of our analysis and Conclusion (7) comments on the contribution and terminates the thesis.

2 Slovak energy market

2.1 Production, consumption and interconnections

Although the period of our interest encompasses the years 2011-2016, we look into the past to gain a better insight into the Slovak electricity production and consumption history – the time period from 1983 to 2016 is represented by Figure 1. Whereas the consumption remains relatively steady throughout the last twenty years, ranging from 27 386 to 30 103 GWh (the sudden drop in 2009 was due to the global crisis), the generation is far more volatile. It sharply increased in 1997 and shifted the Slovak Republic to the position of exporter for the period of 1999-2006, thanks to the nuclear power units in Mochovce newly connected to the grid. The historical Slovak production maximum of 32 830 GWh was reached during that period, in 2002.

Figure 1: Slovak electricity production and consumption in 1983-2016



Source: Slovak electricity transmission system

As indicated, nuclear power plants do indeed play an important role in the Slovak electricity generation. After the permanent shutdown of the first nuclear power block Bohunice V1 in 2006, production fell under the level of consumption and Slovakia became a moderate importer of electricity. Note also the drop in the production in 2008 after the shutdown of the second block of Bohunice V1, which deepened in 2009 due to the financial crisis.

In 2016, the size of the measured flow of export and import was 10 598 GWh and 13 249 GWh respectively, according to the National Control Centre of Slovakia. The interchanges naturally fluctuate within a year and Slovakia might become an exporter at some point, fulfilling the needs of the Slovak energy grid and the grid of the neighbor countries (SEPS).

Focusing on the most recent years we observe a widening gap between the Slovak electricity consumption and the production. The significance of the imports have increased since 2013. The power system is, however, able to balance the difference thanks to the connections with neighbor markets – mainly the Czech Republic and Hungary, the former being the biggest exporter to Slovakia, the latter the biggest importer from Slovakia. There is also some less significant amount of electricity exchanged with Poland and Ukraine, see Figure 10 in Appendix. The transmission systems of Slovakia and Austria are not connected at all. The calculations and analyses of the Slovak electricity transmission system (SEPS) provide no evidence of need for a cross-border interconnection. The volume of the electricity exported and imported is summarized in Table 1.

Table 1: Export and import in 2009-2016 (GWh)

Year	Export	Import	Balance
2009	7 682	8 994	1 312
2010	6 293	7 334	1 041
2011	10 500	11 227	727
2012	13 079	13 472	393
2013	10 628	10 719	91
2014	11 862	12 963	1 101
2015	12 611	14 968	2 357
2016	10 598	13 249	2 651

Source: Slovak electricity transmission system

In order to facilitate the aforementioned exchanges, Slovakia became part of the 4M Market Coupling involving the Czech Republic, Hungary and Romania in November 2014 (RONI, 2016b). The market coupling refers to integration of two or more electricity markets through an implicit cross-border allocation mechanism (ACER, 2013). It is perceived as a first step towards a fully integrated market allowing short and long term trading of energy, balancing services and security of supply across borders. This approach also contributes to higher market liquidity and optimal price volatility.

Nonetheless, in the case of Slovakia, the bidding zone (defined as an area without internal business congestion) remains identical with the political area of the country. It means that electricity can be transferred without requirement of transmission capacity allocation and a transaction can only be completed between any two points within the Slovak Republic (Bems et al., 2016).

2.2 Stakeholders

The flow of energy from a production source to final consumers – comprising generation, transmission and distribution – requires different players with specified roles in the market. The Slovak Energetics Act (2012) defines the following stakeholders: the electricity provider, the electricity transmission operator, the distribution system operator, the supplier, the consumer and the short-term electricity market operator.

The biggest electricity provider in Slovakia is Slovenske elektrarne, a.s. (SE), which covers 69.1% of the country's generation as of 2016. The Slovak Republic owns 34% of the company and the shareholders' rights are executed by its Ministry of Economy. Energeticky a prumyslovy holding, a.s. (EPH) – a leading Central European energy group – and Enel, S.p.A. – one of the world's largest energy companies – hold 33% each. The ownership structure might, however, change soon. The option concerning the Enel's share sale to EPH is expected to get exercised in the first half of 2019. EPH would then own 66% share in Slovenske elektrarne, a.s.

The sole holder of the national electricity transmission permit is Slovak electricity transmission system, PLC (SEPS), a company 100% owned by the state. As the only transmission network operator it is responsible for the electricity transmission from power plants to the distribution network in the whole territory of Slovakia. Furthermore, SEPS ensures maintenance, renewal and development of the transmission system. Its wholly owned subsidiary, the Short-term electricity market operator, PLC (OKTE) organizes and evaluates the short-term cross-border electricity market as well as provides the clearing of imbalances in Slovakia since January 2011.

The distribution grid incorporates three regional distribution system operators (DSOs): Stredoslovenska energetika – Distribucia, a.s., Vychodoslovenska distribucna, a.s. and Zapadoslovenska distribucna, a.s., the fully owned subsidiaries of three traditional electricity suppliers: Stredoslovenska energetika, a.s. (SSE), Vychodoslovenska energetika, a.s. (VSE) and Zapadoslovenska energetika, a.s. (ZSE) respectively. The DSOs were created in 2007 within the unbundling process under the EU energy packages and retain a natural monopoly in their respective territories.

The ownership and operation of the national electricity system is split – the so-called transmission includes the energy flow from power plants to the distribution network and operates at the level of 400kV and 220kV, the lines and devices being owned by SEPS. The distribution network itself – a system for transferring the electricity to end consumers is owned and operated by the DSOs, at the level of 110kV, 22kV and 0,4kV.

The aforesaid suppliers: SSE, VSE and ZSE are partially privatized. Fifty-one percent of each of these companies is held by the Slovak Republic, the remaining 49% is owned by EPH, innogy SE and E.ON energy groups respectively. Around twenty more suppliers such as SPP, Slovakia Energy, CEZ Slovensko, Magna E.A., SE Predaj etc. operate in the Slovak energy market, most of which also supply gas. They follow different market strategies and some of them focus on only selected customer segments. Another important body is the Regulatory Office for Network Industries (RONI), a state authority ensuring balance between the investors' and consumers' interests.

2.3 Market mechanism

Since the vertical unbundling implemented in 2007, competition has arisen among suppliers of electricity and consumers are free in their choice (Meszaros et al., 2014). Electricity is traded as a commodity on an over-the-counter market or an exchange – specifically in Slovakia it is the Power

Exchange Central Europe (PXE). Products are usually monthly, quarterly and yearly packages, either traded on a forward (the delivery will be executed the next year) or on a spot market which functions on a day-ahead basis (Meszaros et al., 2014). Prices on these two markets reflect the overall condition of the economy and the energy industry.

As storage of electricity is not feasible, it must be delivered in real time. Yet the products on the market do not cover real consumption. Due to the nature of the day-ahead market, suppliers predict and purchase the amount of electricity they expect consumers to utilize, however, their predictions are not 100% accurate (RONI, 2016b). Thus there is always more or less electricity on the grid than necessary. The difference (evaluated every 15 minutes) must be cleared by the regulatory electricity. The so-called imbalance costs are then determined by OKTE, split among and paid by the electricity suppliers. The Slovak power system approach to dealing with assessment and settlement of imbalances is therefore classified as “net pool”. Kiesel and Paraschiv (2017) provide a more comprehensive analysis of balancing out forecasting errors in production based on 15-minute intervals.

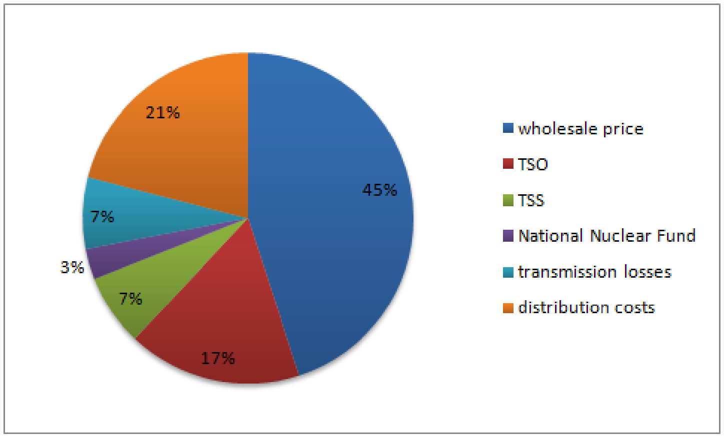
2.4 Price structure

The price of electricity is solely determined by market forces – interactions between demand and supply – without any form of regulation at the wholesale level. The retail price for end consumers, however, consists of several components, see Figure 2.

Besides the wholesale electricity price that represents about 45%, the final invoice accounts for the tariff for losses in the transmission via electricity transmission system and the tariff for system services. Furthermore, the distribution fees are used to cover costs incurred by the distribution system operators and the fee for the levy to the National Nuclear Fund is included. Its size is set by the respective Slovak Government Regulation.

Four our analysis, the most important is the tariff for system operation (TSO). Its purpose is to contribute to the financing of electricity produced

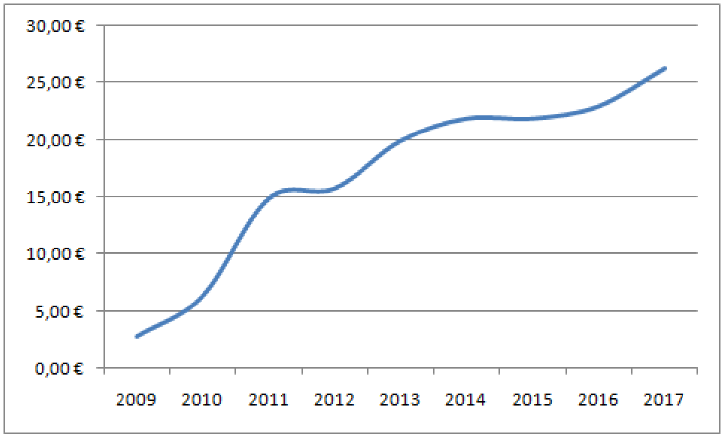
Figure 2: Final price structure in 2016



Source: National Control Center of Slovakia

from domestic coal, electricity produced from renewable energy sources, electricity produced from high-efficiency combined production and activities of the Organizer of the short-term electricity market (Vlachynsky, 2015). These four elements, however, do not have the same weight in TSO. The RES item respresents 67% as of 2017 and can be subdivided. According to calculations of SSE, photovoltaics stand for about 50% of the RES component. This figure is crucial for our further computations of PV support scheme costs. As solar generation increases, so does the volume of the related support needed which results in pushing the final price upwards through rising TSO. Figure 3 summarizes the size of the tariff over the years 2009-2017 (RONI).

Figure 3: Size of the tariff for system operation in 2009-2017



Source: Regulatory Office for Network Industries

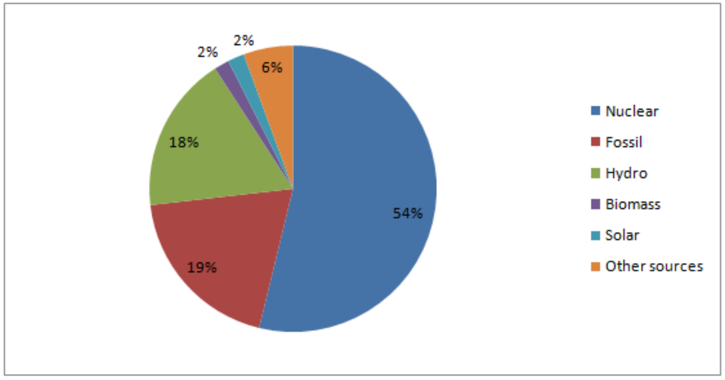
Transmission and distribution related fees, as well as system fees are set by a decision of the Regulatory Office for Network Industries. In addition to these, end customers other than households, which are exempted, are charged an excise duty. They are also subject to the value added tax (VAT) pursuant to applicable laws.

The price cap method applies in the electricity market. The retail price for households and small businesses is regulated by setting the maximum price, tracking the trends in the market.

2.5 Energy mix

In order to meet a country's energy needs, the sources are used in different proportions and represent the so-called energy mix. It depends on the availability of usable resources in the territory or the possibility of importing them and policy choices determined by historical, economic, social, demographic, environmental and geopolitical factors. The composition of the Slovak energy mix has not changed dramatically throughout the last years. The shares of individual sources in 2016 can be seen in Figure 4.

Figure 4: Slovak energy mix in 2016



Source: Slovak electricity transmission system

The electricity production in Slovakia is heavily focused on nuclear generation that currently represents 54.1% of the energy mix according to the International Atomic Energy Agency (IAEA). All the nuclear energy in Slovakia comes from two power plants (NPP) operated by Slovenske elektrarne, a.s., situated in Bohunice and Mochovce, in the southwestern part of the country. Three out of five Bohunice NPP's units were shut down in the years 1979, 2006 and 2008. The remaining two, as well as Mochovce NPP's units 1 and 2, have recently undergone a modernization process and their installed capacity has increased significantly. The Mochovce units no.3 and 4 are currently under construction. They are expected to be finalized and connected to the grid by 2019 (SE). Consequently, the nuclear generation that has been steady over the observed period (see the volume generated in Table 2) will increase sharply. A yearly production from the two new blocks will save 7 billion tons of CO_2 emissions and cover 26% of the national electricity consumption. Therefore Slovakia should be self-sufficient in the energy production (SE, 2016). This construction is considered the largest investment in the private sector in the Slovak Republic and will strengthen the country's role in a prominent nuclear region involving the Czech Republic, Hungary and Ukraine (Bems et al., 2015).

In evaluating the relative position of Slovakia among other countries that operate nuclear power plants, we use data publicly available from the Power Reactor Information System (IAEA). In 2016, according to the share of nuclear energy in the country's electricity generation the Slovak Republic ranked second out of thirty countries producing nuclear energy worldwide, behind France with 72.3%, followed by Ukraine, Belgium and Hungary with 52.3%, 51.7% and 51.3% respectively. The full list of the countries and their ranking is available in Appendix (Figure 14). Although it is China who has the fastest growing nuclear program with 20 plants under construction – planned additional installed capacity of 20 622 MW is 23 times higher than the Slovak one reaching 880 MW – its share of nuclear generation of 3.6% is still much lower than in France, Slovakia etc.

The aforementioned enlargement of the Slovak power plants might shift the country to the world's first position in the share of nuclear generation by reaching approximately 80% and moving ahead of the current number one – France. These ranking projections, however, change unceasingly and depend upon the finalization of French and Ukrainian nuclear power plants currently under construction.

Nevertheless, this study focuses on the renewable energy sources – specifically the solar power as the wind generation in Slovakia is absolutely negligible (SEPS). We do not expect either the hydro power plants or the biomass to have any impact on the merit order effect because of the nature of generation from such sources. Their influence is rather overall and long-term. On this point see Gelabert et al. (2011) and Cludius et al. (2014b).

The available data are summarized in Table 2 to depict the production of Slovak power plants in the last years.

Table 2: Production of Slovak power plants in 2006-2016 (GWh)

Year	Nuclear	Fossil	Hydro	Biomass	Solar	Others	Total
2006	18 013	5 935	4 447	450	n.a.	2 382	31 227
2007	15 335	5 421	4 485	449	n.a.	2 217	27 907
2008	16 704	5 647	4 284	428	n.a.	2 246	29 309
2009	14 081	4 768	4 662	370	n.a.	2 193	26 074
2010	14 574	5 023	5 493	383	n.a.	2 247	27 720
2011	15 411	5 726	4 006	456	310	2 226	28 135
2012	15 495	5 218	4 344	434	561	2 341	28 393
2013	15 720	4 496	5 062	417	588	2 307	28 590
2014	15 499	3 479	4 572	409	476	2 819	27 254
2015	15 146	5 252	4 338	397	526	1 532	27 191
2016	14 774	5 319	4 844	461	514	1 540	27 452

Source: Slovak electricity transmission system

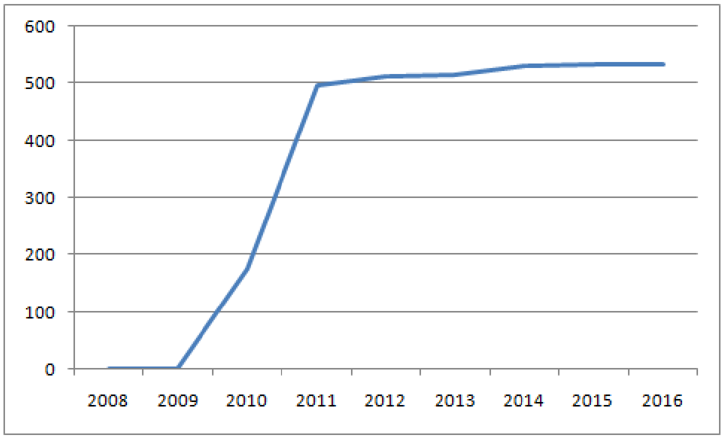
2.6 Development of photovoltaics in Slovakia and its support scheme

Utilization of the solar energy for electricity generation was at a very low level after Slovakia joined the European Union in May 2004. This was mainly caused by high investment costs and no support from the government. Photovoltaics were not included in the national energy policy, which left the country far behind the others in Europe. According to the Watt per capita ranking, only Latvia was doing worse at that time (SkREA, 2008).

The installed capacity up to 2007 represented 20kW. In 2008 it rose to

100kW, but Slovakia together with Bulgaria, Ukraine and Croatia still stayed at the very bottom of the list. By 2016 the total photovoltaics installed capacity increased to 533 MW which shifted the Slovak Republic to the 15th position in Europe. In the Watt per capita ranking Slovakia holds 15th position in Europe and 17th in the world (Japan is 4th and Australia 7th). These figures were gathered from the World Energy Council website (WEC). A summary of the total solar installed capacity in Slovakia is shown in Figure 5.

Figure 5: Solar installed capacity in 2008-2016 (MW)



Source: National Control Center of Slovakia

The beginning of such substantial progress in the Slovak PV situation dates back to 2009 – to the time of implementation of the Europe 2020 Strategy (EC, 2010). The national goal of reaching 14% of the gross final energy consumption produced from renewable sources represented a challenge for the energy policy. The solar generation had potential, yet required governmental support and implementation of inevitable legislative changes. For such purpose there are different mechanisms across Europe that reinforce the renewable energy production. They vary depending upon the country's location, the weather conditions and the energy policy. The support is usually executed through numerous channels – including guaranteed feed-in tariffs (FIT) for a fixed number of years, legal priority dispatch, quota obligations, tradable green certificates, fixed premium system, tax credits etc. The final support scheme design is determined by each country individually (RONI, 2014).

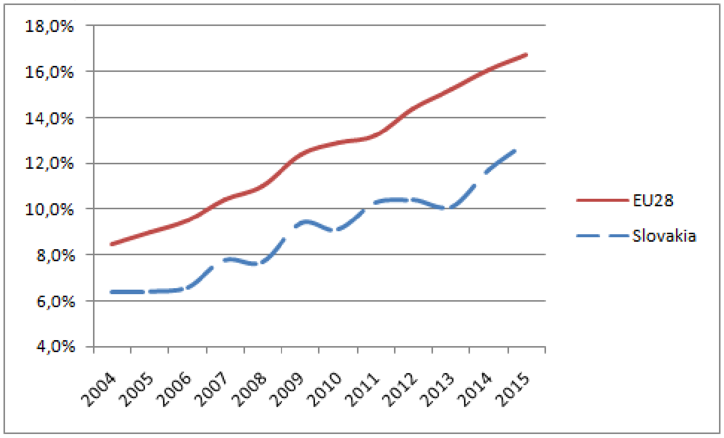
The future of photovoltaics in the Slovak Republic was shaped by the adjustments of legislation based on the Act 309/2009 which defines the ways to apply the national renewable energy generation support as follows: priority connection of renewable power plants to the grid; priority dispatch, transmission, distribution and supply of electricity; obligation of the regional DSO to purchase the whole volume of the electricity generated by renewables; the responsibility for imbalance assigned to the regional DSO and feed-in tariff. Tha final option represented an appealing tool to the investors, promising a high reward of 448.12 €per each MWh of the solar energy produced from a plant built in 2009. The obligation period for all eligible technologies was set at 15 years and started in the year in which the plant was put into operation or in the year of reconstruction or upgrade as given by the RES Act 309/2009. Moreover, operators of photovoltaic and wind power installations were eligible for subsidies under the Operational Programme Quality of Environment (OPKZP) financed by the European structural and investment fund.

This investmentattracting generous promotion – together with decreasing investment costs – caused the so-called solar boom in 2009. Since then, advancing through the first half of 2011, the number of brand new photovoltaic plants sharply increased as the result of the aforementioned incentives. The cumulative installed capacity is shown in Figure 5. But with a significant decrease in the feed-in tariff in the second half of 2011 and the legislative changes limiting the support eligibility, the pace of building new plants decreased as well, although the overall volume of the installed capacity kept on rising.

As of 2017, only roof-top or façade-integrated photovoltaic installations up to 30 kW are eligible for the feed-in tariff which amounts to 84.98€ per MWh according to the current RONI Decree (RONI). More information on eligibility and size of FIT over the period 2008-2017 is in Appendix – Table 8 and described by Culkova et al. (2015).

As the result of this energy policy, the Slovak share of renewable energy in the total consumption doubled, according to EuroSTAT – from 6.4% to 12.9% between 2004 and 2015, approaching the European Union's goal. The European Union made a similar journey over the same period, raising the share of renewables in total consumption from 8.5% to 16.7%, see Figure 6.

Figure 6: RES share on final consumption in 2004-2015



Source: EuroSTAT

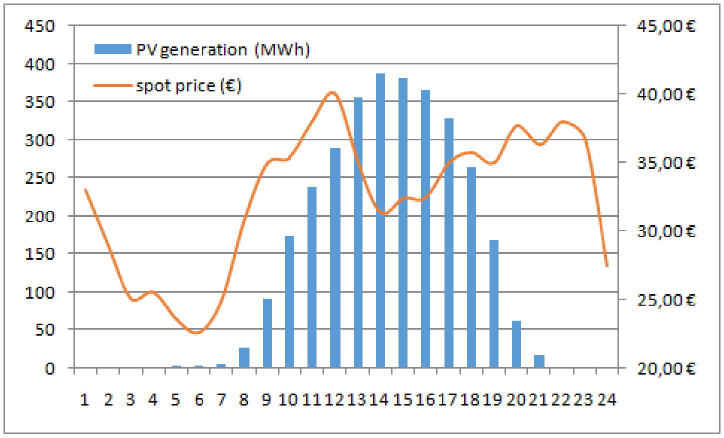
Although the Slovak current renewables' share is below the EU countries' average of 16.7%, Slovakia is not far behind Germany (14.6%), Czech Republic (15.1%) or France (15.2%). Taking into consideration that wind generation is of great importance in these countries and hence contributes heavily to the presented figures (especially in France and Germany), the position of Slovak photovoltaics turns out to be even stronger.

Because of the support scheme and favorable geographical conditions the solar potential is quite promising – according to the European Commission Photovoltaic Geographical Information System (PVGIS) and Suri et al. (2007). The average global horizontal irradiation is rather high, ranging between 1100-1150 kWh/m2/year, while in Germany it is only 1000 kWh/m2/year (average figure for the whole country – the sunny southern part is compensated for by the northern region of Germany). The Slovak photovoltaic potential also provides plenty of room for improvement and a good opportunity to achieve even more ambitious goals related to the renewable energy sources. The maps representing the solar irradiation in Slovakia, Germany and the Czech Republic are attached in Appendix as Figures 11, 12 and 13.

2.7 Merit order effect

The merit order describes the way the individual energy sources are utilized for fulfilling the country's electricity needs. Based on marginal costs they are ranked from the cheapest to the most expensive as follows: intermittent renewables (photovoltaics and wind), hydropower, nuclear, coal, gas, oil. In order to provide consumers with the cheapest electricity possible, the sources must be employed according to the price of the last MWh generated. In addition, the priority of the renewable sources is strenghtened by the dispatch rule established by Act 309/2009 Coll. The suppliers are legally bound to purchase first all of the renewable energy produced, and only then move to hydro power as the second cheapest. Although their decision is not solely driven by the merit order, the situation would not be different without such legislation in rigour. One way or another, the renewables are the cheapeast source in terms of marginal costs hence the principle would remain the same.

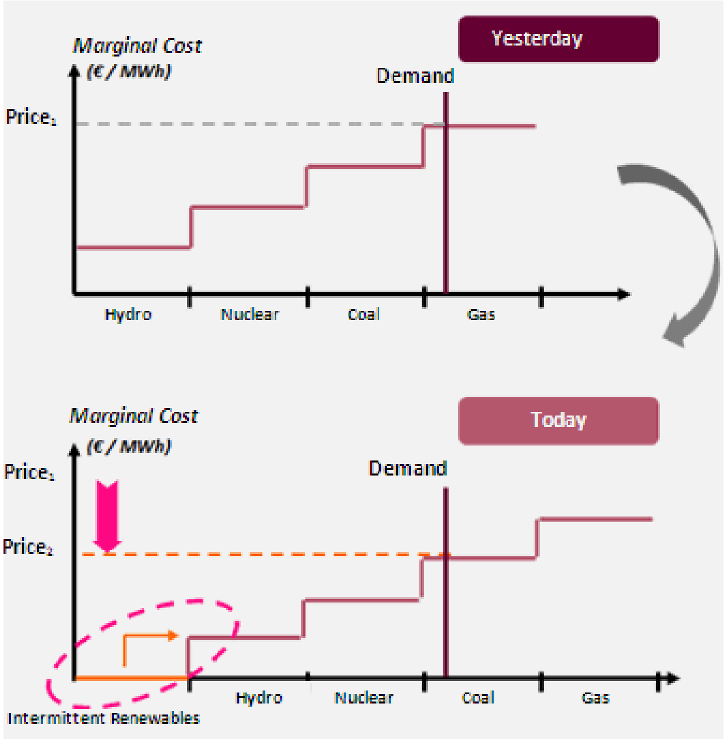
Figure 7: Daily profile 23/06/2016



Source: SEPS and OKTE

The so-called merit order effect is a phenomenon derived from the above-mentioned principle, examined in numerous countries – see section 3. The term denotes an analysis of correlation between the composition of the energy mix and the spot price of electricity. As depicted in Figure 7, the price increases with rising demand in the early hours and is diminished by the solar feed-in during the day. The underlying logic is that the electricity price is determined by the intersection of demand and supply at any moment. The demand is inelastic as the good in question is a necessity. The supply "curve" (the merit order curve) is actually in the form of "stairs" created by the merit order. The injection of intermittent energy onto the grid causes a rightward shift of the supply curve and a subsequent price decrease, in case the penetrated volume is sufficient to displace the actual source regulating the price, as shown in Figure 8.

Figure 8: Merit order effect

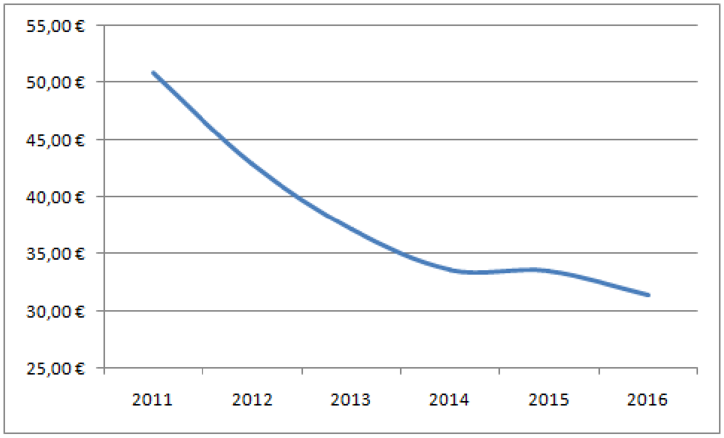


Source: illustrative scheme

The spot price has, indeed, dropped in Europe in recent years. Besides other reasons such as general decrease of commodities' price in the market; the decline of CO_2 price and near-collapse of the European emission trading scheme; lower electricity demand; and less expensive coal and natural gas; the largest factor contributing to the drop in wholesale prices was the expansion of renewable energy (Hirth, 2016).

Specifically in Slovakia, the yearly average spot price dropped by 38% over the observed time span, in line with general trend in Europe – see Figure 9. Such decrease may partially be attributed to the structural change the Slovak energy mix experienced with a larger deployment of the photovoltaics. The related MOE (if confirmed negative) explains how much the spot price diminishes due to additional solar feed-in. Nevertheless, we must also account for the financial burden created by generous subsidies that is borne by final consumers through the tariff for system operation explained in the price structure section. Therefore the crucial question in this case is whether or not the savings from the MOE offset the costs of the photovoltaics support scheme.

Figure 9: Spot price in 2011-2016



Source: Short-term electricity market operator

The Slovak case is one of a small open economy with a genuinely large share of nuclear power in the energy mix (54%). This interesting feature substantially affects the merit order in Slovakia due to rather low marginal costs for nuclear power production. Consequently, we expect the merit order effect of the photovoltaics to be smaller (and the position of the photovoltaics in the system to be less significant generally) than in other economies which produce electricity mainly from more expensive sources – there is greater potential for the intermittent sources to have a bigger merit order effect.

As the merit order effect has not been assessed in the nuclear-share-leading countries yet, it is hard to comment on whether or not the large nuclear share does have a direct impact on the size of the photovoltaic MOE. The evaluation of the solar MOE with regards to the nuclear power production might become one of possible ramifications for this thesis.

3 Literature review

In recent years, the electricity generation from renewable sources has been the subject of numerous debates and studies that stand against or are in favor of the "green production" affecting the electricity system in many aspects. One of the consequences of this type of production is the merit order effect – an important tool for the economic evaluation of renewable sources (Wurzburg et al., 2013).

Authors use various methods in order to assess the impact on the whole electricity price. The studies differ in the approach employed, regions and countries observed, frequency of data processed and naturally, results. Papers exclusively focused on wind generation outnumber those on the solar generation. Others exercise analyses on the renewables either jointly or separately. This section provides a review of the existing literature across several countries.

The first authors to mention that the renewable energy generation should decrease the electricity price due to its low marginal costs were Jensen and Skytte (2002) who carried out a theoretical study of the green certificates system. The reduction in the wholesale price due to the renewable energy production was also confirmed in the literature based on time-series regression analyses. These studies take advantage of available ex-post data concerning electricity prices and generation from renewable sources. Although the econometric models differ, the results converge towards the conclusion that the coefficient on the renewables is significant and negative thus proving the existence of the merit order effect.

In Spain, Gelabert et al. (2011) evaluate the renewables jointly over the period of 2005–2010 and find evidence of a 4% decrease in the electricity price on average. The electricity prices decline by 1.9€/MWh with each GWh of electricity produced from renewable sources. In the multivariate regression model daily averaged data are used in order to diminish unwanted noise i.e. to reduce the influence of particular hours with temporary and exceptional events. The authors also state that the "decrease in electricity prices is not necessarily a welfare-enhancing process, rather an actual transfer between consumers and traditional producers.” These results are in line with the findings of Gil et al. (2012) whose authors employ a conditional probability approach when processing data on the Spanish market between 2007 and 2010. The authors find that the average price decrease, caused by wind production is 9.72€/MWh which represents an 18% lower price than under a no-wind scenario. They further claim that with increasing wind power production, the price decrease becomes more likely.

The German electricity market has been described in a large number of studies. According to Rathmann (2007), the Emission Trading Scheme contributes to the electricity price decline. He studies the energy market in the years 2005–2007 and finds that additional electricity from RES substitutes electricity from fossil fuels; thus CO_2 emissions are reduced and the CO_2 emission trading scheme has a considerable impact on the reduction of electricity prices. The reduction in this specific case equals to 6.4€/MWh over the above-mentioned period. Tveten et al. (2013) develop an analytic model to assess the impact of solar generation in 2009–2011. They find evidence of a 7% reduction in the electricity price what corresponds to 3.9€/MWh. Their study also deals with the variance of spot prices which was proven to decrease by 23%. Moreover, Cludius et al. (2014b) contribute to the German literature in this field, providing a time-series regression analysis, aiming to quantify the merit order effect of wind and photovoltaic generation jointly. The dataset covers the years 2008–2012 and the MOE ranges from 6€/MWh to 10€/MWh. They further introduce a near-term forecasting tool. The projections for 2016 amount to 14-16€/MWh. The authors also comment on redistributive transfers between consumer groups, focusing on energy-intensive industries that benefit from lower wholesale electricity prices while being largely exempted from contributing to costs of the scheme. Furthermore, Wurzburg et al. (2013) run a multivariate regression on data concerning production from renewables in the Austrian-German region over the period 2010–2012. The average price decrease represents 7.6€/MWh.

According to the authors, the merit order effect seems to be larger for high-load days. The most updated study has been elaborated by Kyritsis et al. (2017) who investigate the effects of intermittent solar and wind power generation on electricity price formation in Germany. Their work covers the years 2010 to 2015 – the period of the rapid integration of photovoltaic and wind power sources, as well as the phasing out of nuclear energy. The authors confirm the Granger causality of both solar and wind power and provide evidence that although both intermittent sources induce a merit order effect, the impact on electricity price volatility differs. The solar generation diminishes the price volatility by scaling down the use of peak-load power plants. As opposed to that, the wind power generation increases the volatility of electricity prices by challenging electricity market flexibility.

The non-parametric regression model employed by Jonsson et al. (2010) to deal with wind generation in Denmark in the years 2006–2007 confirms a drop in prices as well as the study exercised in the Irish market by O'Mahoney and Denny (2011). The authors' time-series OLS regression run on data from 2009 shows that had it not been for the wind generation the price would have been higher by 12%, and the country would have not saved 141 million euros. In this case, the positive externalities outweigh the costs, particularly when one also considers the CO_2 saving.

The savings offset the costs in the Italian electricity market too, but this only holds true for the wind generation which decreased the wholesale price by 4.2€/MWh with marginal increase of 1 GWh in production over the period 2005–2013. The merit order effect of the solar was quantified to 2.3€/MWh over the same period. The monetary savings from solar generation, however, were not sufficient to compensate the cost of the related supporting scheme—which is considered one of the most generous worldwide. The impact on prices decreased over time corresponding to the increase in solar and wind electricity production and the volatility of the prices amplified (Clo et al., 2015).

The merit order effect was also confirmed outside Europe. The studies on the Australian electricity market prove a decline in the wholesale price. Forrest and MacGill (2013) only consider two regions and quantify the total merit order effect of the wind generation that reaches \$8.05/MWh and \$2.73/MWh in South Australian and Victorian area respectively in the years 2009–2011. Cludius et al. (2014a) build on the previous results by expanding the market of interest the to national level, using data for the years 2011–2012 and 2012–2013. The price decreased by \$2.3/MWh and by \$3.29/MWh respectively. On the other side, McConnell et al. (2013) focus on the photovoltaic generation in 2009–2010 and confirm the downward pressure on the wholesale price caused by the solar generation which saved \$1.8 billion dollars over the period of two years. Consequently, the depression of wholesale prices offsets the costs of support mechanisms.

We observe similar results in the Texas market. Woo et al. (2011) find the reduction of the spot price caused by displacing the high fuel-cost marginal generation when running a time-series regression on data covering 2007–2010 (using 15-minutes intervals). One GWh of wind intermittent production decreases the price by \$3.2/MWh to \$15.3/MWh, depending upon the zone examined. In this case also, the wind penetration onto to the grid is likely to enlarge the spot price variance.

Besides papers based on an empirical approach, there are several authors assessing the merit order effect through electricity market modeling, simulating various scenarios. Sensfuss et al. (2008) provide an agent-based simulation platform for the German market. Their PowerACE model processes the data concerning the renewables for the year 2006 and shows a significant reduction of the market price equal to 7.83€/MWh. The merit order effect causes savings of 4.98 million € and outweighs the net support payments. In a similar way Saenz de Miera et al. (2008) notice that the wind power generation substantially decreased the electricity price the over the period 2005–2007. The size ranges from 7.08€/MWh to 12.44€/MWh between the years. These results are in accordance with findings of the empirical research-based literature. For a more exhausting review of the world's literature on the merit order effect see Wurzburg et al. (2013).

Furthermore we review available literature on the Czech electricity market because in many aspects it is similar to the Slovak market. We gather important information that helps clarify the situation in Slovakia. The most helpful for our purpose is definitely the study of Lunackova et al. (2017) who aim to quantify the impact of the solar generation on the electricity spot price. The dataset covers the years 2010–2015. The authors provide calculations of the merit order for two groups–first the solar generation is observed, and then renewable sources excluding solar. Surprisingly, the merit order effect caused by the former appears to be non-negative (specifically +0.067%). Thus the electricity price does not decrease with increasing amounts of energy produced by the solar power plants. However, the results for the other renewables show existence of the MOE. With a 10% increase in the generation from renewable sources (excluding solar), the electricity price declines by 2.2% and 2.5% as proven by the regression analysis run on the daily and weekly data respectively. The sensitivity of the frequency of data used appears to be significant. Although the non-negative merit order effect is unexpected, there is a reasonable explanation. The Czech Republic is not a particularly sunny country hence the solar sources are not sufficient to displace the marginal type of plant and push the price downward. Besides this study, the non-negativity issue only arose in the case of Israel, so far. Milstein and Tishler (2011) state that the growing adoption of PV due to declining PV capacity cost can increase the average market price and price volatility. This result is confirmed by an application of data for the Israeli electricity sector.

Another useful analysis is the study on solar energy and its future in Central Europe by Janda and Tuma (2016). The authors quantify the total average merit order effect of photovoltaics to 4.544 €/MWh over a five-year period. They further elaborate hypothetical scenarios concerning the deployment of new solar power plants. Their conclusions portray solar energy as an unreasonable choice for the Czech Republic given that new solar projects are not viable without subsidies.

The Slovak electricity market has barely been examined so far. To our knowledge there are only a few authors lightly touching on Slovak renewable (and specifically photovoltaic) generation. Dusonchet and Telaretti (2010) review photovoltaic support policies in eastern EU countries (including Slovakia) and perform an economic analysis based on the calculation of the cash flow, the net present value and the internal rate of return for the main support mechanisms that are implemented in these countries. The results indicate that support policies can be inconvenient for the owner of the photovoltaic system. The Czech Republic, Bulgaria and Slovakia have, however, the most profitable support strategies for small photovoltaic systems. Misik (2016) analyzes Austria, the Czech Republic and Slovakia and their decision makers' perceptions of the states' ability to cope with three energy security challenges (external, internal and business). Out of 52 officials and representative from relevant institutions and companies, the Slovak representatives are the least confident about their ability to deal with these challenges. They perceive that their country is in a disadvantageous position regarding the energy business.

Jirous (2012) provides a national report on the integration of electricity from renewables to the electricity grid and to the electricity market. As the result of interviews with representatives from the Slovak market stakeholder companies the author further describes the deployment of renewable electricity and grid connection, operation and development. The rentability of photovoltaic plants in regards to the installed capacity, location of the plant and initial investment is assessed in the study of Taus and Tausova (2009). They confirm a relationship between the rentability of the input capital and the expected solar output of the plant because of its location, as the solar radiation differs across the area of Slovakia.

Moreover, Lofstedt (2008) focuses on possible confrontation between Austria and Slovakia concerning the generation from nuclear and renewable sources. Austria's hostile attitude towards Slovakia's biggest electricity power source and difference between the policies is evaluated. The author delivers recommendations arising from the Austrian expertise in the field of renewables as well as suggestions as to how future energy dialogue between the countries should be conducted. When speaking of cross-border connections, Meszaros et al. (2014) analyzes the electricity market and pinpoints that the liberalization not only created a competitive environment, but it also brought up risk related to several options of electricity purchase on the Czech-Hungarian-Slovak interconnected market. To conclude, Culkova et al. (2015) introduce various methods and tools in order to support the economic evaluation of solar power plants. Specifically they apply the Monte Carlo method to analyze the investment risk and provide future expectations prediction.

To the best of our knowledge, no literature has approached the merit order effect of the photovoltaic power plants in Slovakia so far. Thus we aim to enlighten the situation on the Slovak electricity market and contribute to the MOE discussion.

4 Data

This section describes the variables used in our analysis which is based on time series data. The hourly wholesale electricity spot market prices are given in €/MWh and publicly available on the website of the Organizer of the short-term electricity market (OKTE). Load and solar generation data were provided by SEPS. Both are on hourly basis too, with MWh being the unit used.

Due to lack of data describing the photovoltaics at the Slovak national level at the desired frequency, we execute our analysis in two subsets. First, the dataset comprising the information for the entire country incorporates two full years from 1/1/2015 to 31/12/2016. Second, the data for the Middle Slovakia is available from 1/1/2011 to 31/12/2016. The installed capacity of solar power plants in the Middle Slovakia region represents 50% of the national installed capacity and the related generation, approximately 55% of the national PV generation throughout the observed years (SSE). Thus we consider the data suitable and relevant for the purpose of this thesis and use this subset to provide a more complete picture of the merit order effect in Slovakia. The approach remains the same for both subsets and the methodology applies to all cases regardless the year and the area taken into consideration.

The data frequency involved in analyses differs across the literature. Since the photovoltaic energy generation is volatile over the day and follows strong daily patterns, we stick to the hour-by-hour approach and account for the different effects of individual intervals. The specific solar profile is also aligned with peak demand (Lunackova et al., 2017), i.e. the PV production during hours with sunshine matches the hours of increased electricity demand. Therefore the time of production is crucial in regard to the demand. Had we primarily used averaged daily data, the merit order effect might have been smoothed over and less obvious. The mentioned features of solar generation would have not been possible to capture by averaging over a longer time sequence.

Nevertheless, some authors prefer daily and weekly averages and use them in order to diminish the intra-day price volatility caused by the intermittency of photovoltaic power production due to its unreliable nature and the geographical conditions (Clo et al., 2015). Indeed, the evidence of a positive relationship between RES production and price volatility was found by Woo et al. (2011), among others. This procedure is, however, more suitable for forecasting. For the statistical purposes of evaluating merit order effect and its impact on a consumer, the volatility issue does not have direct influence and the analysis remains qualitatively unchanged – see Clo et al. (2015). We follow Cludius et al. (2014b) and Lunackova et al. (2017) and process the daily data as a robustness check. In order to downsample we determine the weight of every hour by computing its share on the daily load, multiply the hourly observation by the respective weight and summarize 24 obtained values in a given day, using the following formula:

$$x = \sum_{i=1}^{24} x_{h_i} \cdot \frac{\text{load } h_i}{\text{daily load}} ,$$

where h_i stands for i-th hour of the day and x denotes a variable.

The basic features of our dataset can be seen in Table 3 and 4. The range of values given by the minimum and the maximum of the observations shows evidence of high volatility of the variables. There are no missing values, all 17544 observations are included for Slovakia and 52608 for the Middle Slovakia region.

Table 3: Summary statistics: Slovakia 2015-2016

Variable	Mean	Std. dev.	Min.	Max.	N
spot price	32.518	13.74	-30	121.1	17544
PV	59.282	92.032	0	387.23	17544
load	3249.018	419.497	2230.62	4360.107	17544

Source: author's computations

For the sake of interpretability we need our variables to be taken in logarithms – so the merit order effect can be explained as "the elasticity of

Table 4: Summary statistics: Middle Slovakia 2011-2016

Variable	Mean	Std. dev.	Min.	Max.	N
spot price	38.269	16.688	-150	200	52608
PV	32.802	52.366	0	207.175	52608
load	3201.614	420.773	2118.862	4395.835	52608

Source: author's computations

electricity wholesale spot price with respect to change in supply of electricity from photovoltaics" (Lunackova et al., 2017). The first major issue arises from the nature of photovoltaic generation – for most hours during the day it simply equals zero.

Another bothersome, yet interesting feature of our dataset is negative wholesale prices. A sudden drop in the amount of electricity demanded and/or very high intermittent sources production due to hardly predictable weather conditions cause oversupply and can push the electricity spot price below zero. Such situations usually occur at night and only last for a few hours. The operators of conventional power plants are not able to react immediately and cease the production. Although those plants are dispatchable, they are not easily responsive. A shutdown and consequent startup would be expensive. Hence they maintain the production at a lower level. As a result, suppliers are willing to pay the consumers in order to get rid of the excessive electricity in the grid. That is often less costly than compensating for emerged imbalances. In some countries negative prices are not authorized thus nil prices are adopted. For a more exhaustive explanation see Sukupova (2012), Nicolosi and Fursch (2009) and Vlachynsky (2015).

For the purpose of dealing with zero and negative values and transforming the available data we follow the approach called the inverse hyperbolic sine (IHS) transformation. It was first introduced by Johnson (1949) within an alternative transformation family and is defined as: $log(y + \sqrt{y^2 + 1})$.

Later also Burbidge et al. (1988), MacKinnon and Magee (1990), Pence (2006) and many others built on Johnson's work and enriched the literature on the IHS. As the inverse sine approximately equals $log(2y)$, we can interpret it in the very same way as a standard logarithmic dependent variable, yet the IHS is in addition defined on the entire real line comprising zero and all the negative values. This transformation is useful for adjusting skewness, preserving zero and negative values, examining sensitive changes in the distribution and eliminating the natural log drawbacks – stacking and disproportionate misrepresentation of zero and negative values (Friedline et al., 2012).

5 Methodology

5.1 Merit order effect

We assess the size of the merit order effect of the photovoltaic production i.e. we evaluate what part of the wholesale price change is attributable to the generation from solar power plants. As we cannot directly observe the influence of price of conventional sources alone, we introduce a multivariate time series regression analysis. In the relevant literature, slightly different models are employed. For the purpose of the Slovak electricity market examination we follow Janda and Tuma (2016) and construct the following OLS regression model:

$$p_t = \beta_0 + \beta_1 PV_t + \beta_2 load_t + \gamma \, dummies_t + \text{time} + u_t$$

where p denotes the spot market price as the response variable and our explanatory variables comprise the photovoltaic generation and the total load. The solar power generation denoted as PV is supposed to push the price downwards thanks to the low – close to zero marginal costs, so we expect β_1 to be negative. The total load is used in line with numerous studies that find this information strongly relevant for price formation as it affects the price through the supply curve, and we expect a positive sign on its coefficient β_2.

Furthermore, we include the intercept β_0, a time trend and a vector of dummy variables $dummies_t$ in order to control for systematic changes (Wooldridge, 2012). We use six dummies for days in a week to capture the fluctuations – possible differences between workday and weekend and eleven for months in a year to capture seasonal patterns. This approach was widely adopted by numerous authors, e.g. Wurzburg et al. (2013) or O'Mahoney and Denny (2011). The dummies also affect the electricity demand and the availability of solar. The u_t denotes residuals and the subscript t represents an individual observation in time – an hourly sequence.

Following the described approach, we perform the analysis at these stages:

1, We use the given model for assessment of the merit order effect of photovoltaic generation over the entire observed period, accounting for a linear time trend and adjusting for potential arising issues such as non-stationarity, autocorrelation and/or heteroscedasticity. We also include dummies in order to see how much the weekday and season patterns matter for electricity prices. These results will provide an overall picture.

2, We quantify MOE of the photovoltaics separately for individual years, mainly in order to be able to determine resulting savings on a yearly basis, but also to endeavor to understand changes between the years.

3, We run the same regressions on averaged daily data for joint years as a robustness check.

Given two different subsets of interest we label the Slovakia region as “A”with the years 2015-2016 covered and the Middle Slovakia region as “B”– the observed period comprises time span of six years from 2011 to 2016.

5.2 Assumptions and related tests

This analysis requires an important assumption of exogeneity. In order for OLS regression estimators to be unbiased and consistent, the explanatory variables must be determined exogenously (Wooldridge, 2012). That suggests a mean independence of disturbance or, said differently, that the causal relationship between the independent and dependent variables only functions one way. The response variable (spot price in our case) only depends upon the explanatory variables (grid load and PV generation). This assumption holds valid in the case of photovoltaic generation in the short-run as well as in the long-run since it is driven only by natural phenomena and dispatched according to priority treatment and low marginal cost (Lunackova et al., 2017). Generally, intermittent sources cannot bid strategically according to price dynamics (Clo et al., 2015). For the exogeneity of demand, we assume it is price insensitive and inelastic. This seems to be reasonable as consumers do not base their behavior and changes in consumption pattern on spot price variations in the short-run because they have long-term contracts and do not observe the wholesale prices. The price volatility risks and costs are absorbed by agents in the market.

If the aforementioned exogeneity assumption did not hold, we would expect to run into the endogeneity issue just like in the studies performed by Lunackova et al. (2017) or Woo et al. (2011). That is typically caused by an omitted variable that affects explained as well as explanatory variables. For instance, supply of conventional production is endogenous and correlated with the observed price (Lunackova et al., 2017). In such a case, the dispatching rule might be the cause (Clo et al., 2015). We consider any other omitted variables uncorrelated with the included explanatory variables. Any correlations are assumed negligible so that no omitted variable bias is present (Forrest and MacGill, 2013). We also observe the years separately in order to detach possible side effects caused by systematic change, e.g. in carbon, gas and coal prices (Cludius et al., 2014b).

Due to characteristics of the electricity, the stationarity of time series might be violated, i.e. the joint probability distribution of such process might change when shifted in time. This is caused either by presence of a unit root or a time trend, the process being called trend stationary in the latter case. There exist various econometric tools in order to deal with these issues if the evidence of the violation is found (Wooldridge, 2012). Thus we first run the augmented Dickey-Fuller test with a linear time trend to verify the stationarity of the time series (Dickey and Fuller, 1979). If the null hypothesis of presence of unit roots cannot be rejected, we have to conduct the analysis with estimation of first differences, as suggested by Gelabert et al. (2011) and Cludius et al. (2014b).

Time-series usually show evidence of autocorrelation in residuals. Thus we employ the Durbin-Watson test in order to detect its presence (Durbin and Watson, 1971). If the test rejects the null hypothesis of serially uncorrelated errors, it confirms autocorrelation in the residuals. Moreover, the Breusch-Pagan test checks on the heteroscedasticity. If its presence gets approved upon rejection of the null hypothesis of equal error variances across all the observation points (Wooldridge, 2012), the standard errors and test statistics will be not valid under such conditions. The Gauss-Markov assumptions require homoskedasticity and serially uncorrelated standard errors for an OLS estimator to be the best linear unbiased estimator. In order to fix the situation, we would use the Newey and West (1987) standard errors that are robust to heteroscedasticity and serial correlation. We would also obtain the Prais-Winsten standard errors in pursuance of robustness check.

5.3 Consumer welfare analysis

The fast development of the photovoltaics bears non-negligible monetary cost for customers through the support scheme. We endeavor to determine whether or not electricity generation from PV brings about a consumer´s monetary surplus, i.e. whether the savings outweigh the costs thanks to substantial deployment of photovoltaics which should reduce the electricity price. To answer the crucial question we need to know the volume of the savings first. It can be easily derived from our previous findings.

Once we estimate the impact of the increased supply of renewables on wholesale market prices, we apply the result on the average spot price in the respective year and evaluate the savings per MWh. Then we simply multiply the figure by the yearly production and get the approximate savings attributable to the merit order effect of photovoltaic generation.

On the other hand, we need the costs of the photovoltaics' support that are borne by final consumers. As mentioned in section 2, these expenses are incorporated in the retail electricity price as the tariff for system operations, part of which is devoted to RES support. Out of this amount, approximately 50% serves to pay off the guaranteed feed-in tariffs for photovoltaics as given by calculations of SSE. We multiply this figure by the yearly consumption to find out how much the consumers contribute to the support scheme through their electricity bills. For the sake of simplicity we assume the same policy applies to small and medium enterprises and large companies as well.

To conclude we compare estimated savings and costs and comment on consumer surplus or loss. The data concerning the TSO and the Slovak production and consumption come from RONI and SEPS respectively.

6 Results

Pursuing the approach built in the previous section 5, we present our findings as follows: the outcomes of our estimations concerning the hourly data are presented in the first part, then we move on to regressions on the average daily data and conclude with a comparison of the savings established by the merit order effect and the costs of the support of the photovoltaics.

6.1 Merit order effect

All the tests we performed on hourly data in accordance with the methodology yielded the same qualitative results regardless the area or year in question. The OLS time series regression provided anticipated results in line with expected sign and approximate size of the estimated coefficients.

The first step of the analysis consisted in testing for unit roots. Application of the augmented Dickey-Fuller test including a linear trend term showed that all the series, but load are stationary over a trend at a 1% critical value. The load is stationary over a trend at a 5% critical value, thus we also run the Phillips-Perron test to clarify the result (Phillips and Perron, 1988). As it soundly rejects the null hypothesis of presence of unit roots at a 1% critical value throughout all the cases, no adjustment or transformation to first differences in order to unburden unit roots is necessary.

We proceeded by running the regression of spot price on solar generation, total load, dummies and time trend. Whereas the explanatory variables – photovoltaics and load – were proven to be statistically significant as indicated by p-value smaller than 0.001 in both subsets, in some cases insignificant daily and/or monthly dummies had to be dropped in order to avoid overspecification of the model.

Tables 5 and 6 summarize the most relevant outcomes of OLS estimations and some test statistics results. They provide β coefficients and Newey-West standard errors for photovoltaics, load and the constant. Furthermore, R-squared and adjusted R-squared are included (note relatively steady values across all the regressions) as well as the F-statistic and the number of observations. For the Durbin-Watson test dw_0 denotes the original and dw the transformed value. Comprehensive reports on coefficients of all the variables in our regressions (including dummies), their significance and Newey-West standard errors are attached in Appendix, see Tables 17 and 18.

Conforming with the principle of the merit order effect and the majority of existing literature, the coefficient on the photovoltaic generation variable is negative and statistically different from zero at the 99% confidence level in all of our regressions. The intuitive expectations are supported by the empirical findings indicating that *ceteris paribus*, 1% increase in the solar generation is associated with a decrease of the spot price equal from 0.016% to 0.067%, the figures corresponding to the first and last year of the Middle Slovakia analysis respectively. β_1 coefficients representing the merit order effect tend to rise over the observed periods – although they are volatile rather than showing a linear trend. These figures are essential for further computations of related savings.

The overall results for Slovakia are quite similar to those in the Middle Slovakia region thus we assume robustness of our results. The outcomes summing up the observed periods jointly only differ by 0.001 point: a 1% increase in PV generation is linked to 0.054% and 0.055% spot price decrease in the entire Slovakia and the Middle Slovakia region respectively.

The load has a positive effect on the price, its β_2 coefficient ranges from 2.803 to 4.559, i.e. 1% increase in the total hourly load explains approximately 2.8% to 4.56% increase in the wholesale price. The underlying logic is that moving up the merit order curve, the electricity is generated from more expensive sources in terms of marginal costs.

When observing the results of separate years, we notice certain differences. Those are attributable to several external factors such as expensive fuel and high CO_2 prices – marginal cost of electricity generation is higher and therefore the merit order curve steeper. Naturally, the merit order effect is the smallest in 2011 due to the smallest volume of electricity produced by photovoltaic sources.

Table 5: Summary of regression outcomes: Slovakia 2015-2016

	2015	2016	2015-2016
PV	-0.0461*** (0.0054)	-0.0606*** (0.0079)	-0.0539*** (0.0047)
load	3.659*** (0.183)	3.732*** (0.260)	3.771*** (0.154)
cons	-99.627*** (30.123)	47.738* (27.611)	-21.586*** (1.555)
Rsqr	0.383	0.371	0.360
adj Rsqr	0.382	0.369	0.359
dw0	0.22	0.18	0.19
dw	1.89	1.97	1.93
F	271.45	257.95	493.59
N	8760	8784	17544

Source: author's computations

***p<0.01; **p<0.05; *p<0.1

Furthermore, we moved on to tests concerning potential autocorrelation and heteroscedasticity. The Durbin-Watson statistic rejects the null hypothesis of no serial correlation in all cases and the Breusch-Pagan test indicates the presence of heteroscedasticity across all regressions by rejecting the null hypothesis of constant variance. In order to fix the arisen issues we used the Newey-West standard errors robust to both the serial correlation and heteroscedasticity and double check by Prais-Winsten estimators – the transformed Durbin-Watson statistic proves substantial improvement.

We approached the weighted daily averages over joint periods on both subsets in a similar way, keeping the model and the variables just like in case of hourly data. This time, the non-stationarity could not be rejected thus we ran the analysis in first differences where no unit roots could be detected. Although the load and all the daily dummies are statistically significant at 99% confidence level, the monthly dummies are far from being significant with p-values ranging from 0.723 to 0.995.

The estimated merit order effect of the photovoltaic generation is stat-

Table 6: Summary of regression outcomes: Middle Slovakia 2011-2016

	2011	2012	2013	2014	2015	2016	2011-2016
PV	-0.0157*** (0.0025)	-0.0633*** (0.0067)	-0.0664*** (0.0063)	-0.0586*** (0.0050)	-0.0529*** (0.0056)	-0.0670*** (0.0084)	-0.0549*** (0.0025)
load	2.803*** (0.111)	4.559*** (0.326)	4.549*** (0.238)	3.7131*** (0.183)	3.686*** (0.183)	3.736*** (0.256)	3.882*** (0.092)
cons	-41.161*** (14.271)	100.060*** (26.705)	-22.625 (29.693)	-23.864 (17.499)	-100.340*** (30.121)	46.280* (27.533)	-24.002*** (0.827)
Rsqr	0.464	0.417	0.477	0.418	0.385	0.372	0.404
adj Rsqr	0.462	0.416	0.476	0.416	0.384	0.371	0.404
dw0	0.49	0.17	0.20	0.25	0.22	0.18	0.20
dw	2.15	1.68	1.62	1.73	1.89	1.97	1.86
F	377.72	313.52	398.75	313.46	274.00	259.77	1783.78
N	8760	8784	8760	8760	8760	8784	52608

Source: author's computations

***p<0.01; **p<0.05; *p<0.1

istically insignificant as well; p-value being 0.941 and 0.355 in the A and B subset respectively. From such outcomes we conclude that the hourly effect of photovoltaics specific profile was smoothed out due to downsampling through averaging and first differences. Therefore we cannot consider averaged daily data as a suitable robustness check tool. The results of these regressions are included in Appendix, see Figures 15 and 16.

All in all, summarizing the regressions on hourly data, the outcomes of estimations are in line with existing literature. Nevertheless, the results shall be interpreted carefully. We omitted several factors that might potentially have had an impact on the magnitude of the effect. Also the limited access to data on the hourly photovoltaic generation constrains the analyzed period and region. A follow-up to this elementary analysis is recommended.

6.2 Consumer welfare analysis

The data concerning the size of the tariff for system operations, national production and consumption as well as recent estimates of merit order effect throughout 2011-2016 enable us to elaborate a table summarizing savings and costs resulting from the photovoltaics deployment in the last six years.

Previously estimated MOE indicates that 1% of additional power generation from photovoltaics implies a drop in the spot price, the size of which differs across the years and ranges from 0.016% to 0.067%, see Table 6. We multiply the MOE by the share of photovoltaics in the Slovak energy mix in the respective year. Then we apply the obtained figures on the corresponding average spot price in order to find out yearly spot price reduction (savings in € per MWh). Knowing the annual production volume we easily calculate the total savings in individual years.

As the counterpart, we determine the costs borne by end consumers. The national consumption is taken into consideration and multiplied by cost of one MWh produced from solar power plants financed by end consumers through the RES support within the tariff for system operation. Given the size of the tariff and the fact that photovoltaics consume approximately 50% of resources gained through the RES component of TSO, we calculate the annual volume of payments charged to end consumers in order to finance the solar systems support scheme.

The consumers might expect a payment reduction ranging from 252 045 € to 1 517 283 € in individual years. However, the costs imposed by the Regulatory Office for Network Industries through the tariff for system operation amount from 127 137 110 € to 230 890 000 €, increasing every year according to rising TSO (see Figure 3). The estimated costs turn out to be significantly greater than the savings derived from the negative merit order effect of the photovoltaics in each observed year which implies a heavy consumer loss, similarly to the Czech Republic (Lunackova et al., 2017), Italy (Clo et al., 2015) or Spain (Gelabert et al., 2011). Table 7 provides a comparison of the above-mentioned calculations.

Table 7: Comparison of savings and costs resulting from PV generation in 2011-2016 (€)

Year	Savings	Costs	Consumer benefit
2011	252 045	127 137 110	-126 885 065
2012	1 517 283	174 155 300	-172 638 017
2013	1 438 980	197 898 900	-196 459 920
2014	946 621	198 768 550	-197 821 929
2015	933 705	206 540 520	-205 606 815
2016	1 082 398	230 890 010	-229 807 612

Source: author's computations

7 Conclusion

To the best of our knowledge, this is the very first study to discuss the merit order effect of photovoltaic generation in Slovakia. We hope that it fills the gap in the literature and enlightens the situation in the Slovak electricity market with regards to rising production from renewable energy sources. This thesis contributes to research in the energetics field through a simple analysis based on an OLS regression run on time series data concerning spot prices, total load and volume of photovoltaic production. The outcomes quantify the merit order effect. As the variables are taken in logarithms we interpret the MOE as elasticity of electricity price with respect to the change in photovoltaic production volume. Due to limited availability of hourly data on the photovoltaics, the empirical part has to be divided into two subsets which are processed over the whole time span as well as separately on a yearly basis. The full years 2015-2016 are covered at the national level and the data on the Middle Slovakia region comprises the years 2011-2016.

The model is built on approaches employed by different authors studying the presence of merit order effect in various countries in the world. The data were first modified using the inverse hyperbolic sine transformation in order to preserve zero values caused by the nature of photovoltaic production as well as negative spot price values that standard logarithmic transformation cannot deal with. We further adjust the model for disclosed autocorrelation and heteroscedasticity by using Newey and West standard errors. The estimated regressions confirm the negativity of the MOE in accordance with intuitive anticipations.

The major finding is that a small portion of reduction of the spot electricity price can be atrributed to merit order effect. Specifically 1% increase in the solar generation decreases the wholesale price by 0.055% as shown by the regression covering the Middle Slovakia region over time span from 2011 to 2016 and seconded by the national level estimation on 2015-2016 data. The effect was found to be stable throughout separate years and the reported figures are in line with existing literature results. The estimates yielded by daily data are not useful for this analysis as regressing in first differences on averaged data most likely smoothed out the specific photovoltaic profile. Thus the coefficient on photovoltaics is not statistically significant from zero.

Another important conclusion of this study is that the savings clearly do not outweigh the solar support costs. The photovoltaics' economic beneficial influence is minimal and overcome by large subsidies. The wholesale electricity price dropped by 38% between 2011 and 2016 but such decrease shall be related to factors other than photovoltaic merit order effect, e.g. general decrease of commodities' price in the market, decline of CO_2 price and near-collapse of the European emission trading scheme, lower electricity demand or less expensive coal and natural gas (Hirth, 2016). The expectation that the spot price reduction might compensate the support scheme costs does not hold true in this case.

The size of the PV merit order effect in Slovakia is also considerably lower than in other countries, but it ought to be mentioned that similar analyses were elaborated in countries with favorable geographic conditions and an energetics status allowing for much greater generation from renewables. Said differently, it is reasonable that the photovoltaics and the related MOE, for instance in sunny Italy and Spain, reach much higher figures than in Slovakia. Moreover, the notably large share of nuclear power in the Slovak energy mix possibly affects the size of the solar merit order effect and pushes it downwards.

Touching on the politics behind the photovoltaics, we would like to point out that the exaggerated governmental subsidies and guaranteed feed-in tariffs might have triggered a solar boom and initiated the development of solar energy in Slovakia, however, this policy appears to be economically suboptimal, causing a tremendous consumer loss as reflected by this study. On the other hand, the technology development, the number of brand new power plants, a market structure change — all these turn the country a bit more "green" while pushing it towards the EU strategic goals which is definitely advantageous for the environment. To conclude – the EU targets are tailored with regard to national geography, but the political decisions concerning the related support schemes should be optimized.

We hope to have built the very first stage of approximation to the issue and answered some fundamental questions. The complexity of this topic is broader than the scope of a bachelor's thesis and only a preliminary analysis could be conducted and simple questions answered. Although we would appreciate more data at the national level, we assume that the outcomes of the analysis depict the situation quite accurately and are in line with findings of other authors around the world. In any case, they should be interpreted carefully.

A comprehensive cost-benefit analysis for RES support scheme in Slovakia is necessary and might become subject of an enlargement for a master's thesis. Among possible points to expand on there is, for instance, inclusion of export and import to model as explanatory variables (Wurzburg et al., 2013) or national holidays as dummies, see Lunackova et al. (2017) and O'Mahoney and Denny (2011). Would the effect be bigger if we considered an isolated market? We could question the impact the interconnections have on the size of MOE (Cludius et al., 2014b) as well as reduce the dataset to the upper quarter of high-load days and the lower quarter of low-load days. This might verify the hypothesis that renewable production has a much higher impact on electricity prices when the electricity system is closer to full capacity (observed by Gelabert et al. (2011), Jonsson et al. (2010)). Moreover, we could examine in detail the amplified volatility of prices due to renewables or elaborate forecasts based on a more complex modelling. Hopefully, by that time, more data of a better quality and structure will be available and new approaches explored.

References

Act 251/2012 coll., 2012.

ACER. REMIT Annual Report 2013, 2013. Agency for the Cooperation of Energy Regulators.

Julius Bems, Jaroslav Knapek, Tomas Kralik, Martin Hejhal, Jan Kubancak, and Jiri Vasicek. Modelling of nuclear power plant decommissioning financing. *Radiation Protection Dosimetry*, 4:519–522, 2015.

Julius Bems, Tomas Kralik, Jaroslav Knapek, and Anna Kradeckaia. Bidding zones reconfiguration – Current issues literature review, criterions and social welfare. In *2nd International Conference on Intelligent Green Building and Smart Grid*, pages 1–6, 2016.

John Burbidge, Lonnie Magee, and Leslie Robb. Alternative Transformations to Handle Extreme Values of the Dependent Variable. *Journal of the American Statistical Association*, 83:123–127, 1988.

Stefano Clo, Alessandra Cataldi, and Pietro Zoppoli. The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. *Energy Policy*, 77:79–88, 2015.

Johanna Cludius, Sam Forrest, and Iain MacGill. Distributional effects of the Australian Renewable Energy Target (RET) through wholesale and retail electricity price impacts. *Energy Policy*, 71:40–51, 2014a.

Johanna Cludius, Hauke Hermann, Felix Matthes, and Verena Graichen. The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications. *Energy Economics*, 44:302–313, 2014b.

Katarina Culkova, Lucia Domaracka, and Maria Muchova. Legislative and economic tools of photovoltaic power support in Slovakia. *Acta Montanistica Slovaca*, 20:220–224, 2015.

David Dickey and Wayne Fuller. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, 74:427–431, 1979.

James Durbin and Geoffrey Watson. Testing for serial correlation in least squares regression. *Biometrika*, 58:1–19, 1971.

Luigi Dusonchet and Enrico Telaretti. Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in eastern European Union countries. *Energy Policy*, 38:4011–4020, 2010.

EC. Directive 2009/28/ec, 2010.

EuroSTAT. European union statistical office. URL `http://ec.europa.eu/eurostat`.

Sam Forrest and Iain MacGill. Assessing the impact of wind generation on wholesale prices and generator dispatch in the Australian National Electricity Market. *Energy Policy*, 59:120–132, 2013.

Terri Friedline, Rainier Masa, and Gina Chowa. Transforming Wealth Using the Inverse Hyperbolic Sine and Splines to Predict Youth's Math Achievement. The University of Kansas, 2012.

Liliana Gelabert, Xavier Labandeira, and Pedro Linares. An ex-post analysis of the effect of renewables and cogeneration on Spanish electricity prices. *Energy Economics*, 33:S59–S65, 2011.

Hugo Gil, Catalina Gomez-Quiles, and Jesus Riquelme. Large-scale wind power integration and wholesale electricity trading benefits: Estimation via an ex post approach. *Energy Policy*, 41:849–859, 2012.

Lion Hirth. What caused the drop in European electricity prices? a factor decomposition analysis. 2016.

IAEA. International atomic energy agency power reactor information system. URL `https://www.iaea.org`.

Karel Janda and Ladislav Tuma. Market viability of photovoltaic plants: merit order effect approach. *Munich Personal RePEc Archive*, 2016.

Stine Grenaa Jensen and Klaus Skytte. Interactions between the power and green certificate markets. *Energy policy*, 30:425–435, 2002.

Filip Jirous. Integration of electricity from renewables to the electricity grid and to the electricity market– RES-INTEGRATION. Technical report, eclareon, 2012.

Norman Johnson. Systems of Frequency Curves Generated by Methods of Translation. *Biometrika*, 36:149–176, 1949.

Tryggvi Jonsson, Pierre Pinson, and Henrik Madsen. On the market impact of wind energy forecasts. *Energy Economics*, 32:313–320, 2010.

Rudiger Kiesel and Florentina Paraschiv. Econometric analysis of 15-minute intraday electricity prices. *Energy Economics*, 64:77–90, 2017.

Evangelos Kyritsis, Jonas Andersson, and Apostolos Serletis. Electricity prices, large-scale renewable integration, and policy implications. *Energy Policy*, 101:550–560, 2017.

Ragnar Lofstedt. Are renewables an alternative to nuclear power? an analysis of the Austria/Slovakia discussions. *Energy Policy*, 36:2226–2233, 2008.

Petra Lunackova, Jan Prusa, and Karel Janda. The merit order effect of Czech photovoltaic plants. *Energy Policy*, 106:138–147, 2017.

James MacKinnon and Lonnie Magee. Transforming the Dependent Variable in Regression Models. *International Economic Review*, 31:315–339, 1990.

Dylan McConnell, Patrick Hearps, Dominic Eales, Mike Sandifor, Rebecca Dunn, Matthew Wright, and Lachlan Bateman. Retrospective modeling of the merit-order effect on wholesale electricity prices from distributed photovoltaic generation in the Australian National Electricity Market. *Energy Policy*, 58:17–27, 2013.

Alexander Meszaros, Marek Pavlik, and Roman Toth. Analyza trhu s elektrinou. Faculty of Electrical Engineering and Informatics of the Technical University of Kosice, 2014.

Irena Milstein and Asher Tishler. Intermittently renewable energy, optimal capacity mix and prices in a deregulated electricity market. *Energy Policy*, 39:3922–3927, 2011.

Matus Misik. On the way towards the energy union: Position of austria, the czech republic and slovakia towards external energy security integration. *Energy*, 111:68–81, 2016.

Whitney Newey and Kenneth West. A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55:703–708, 1987.

Marco Nicolosi and Michaela Fursch. The Impact of an increasing share of RES-E on the Conventional Power Market – The Example of Germany. *Zeitschrift fur Energiewirtschaft*, 33:246–254, 2009.

OKTE. Short-term electricity market operator. URL `https://www.okte.sk/en`.

Amy O'Mahoney and Eleanor Denny. The Merit Order Effect of Wind Generation on the Irish Electricity Market. Munich Personal RePEc Archive, 2011.

OPKZP. Operational programme quality of environment. URL `http://www.op-kzp.sk/`.

Karen Pence. The Role of Wealth Transformations: An Application to Estimating the Effect of Tax Incentives on Saving. *The B.E. Journal of Economic Analysis & Policy*, 5, 2006.

Peter Phillips and Pierre Perron. Testing for a unit root in time series regression. *Biometrika*, 2:335–346, 1988.

PVGIS. European commission photovoltaic geographical information system. URL `http://re.jrc.ec.europa.eu/pvgis/`.

PXE. Power exchange central europe. URL `http://www.pxe.sk/`.

Max Rathmann. Do support systems for RES-E reduce EU-ETS-driven electricity prices? *Energy Policy*, 35:342–349, 2007.

RONI. Regulatory office for network industries. URL `http://www.urso.gov.sk/?language=en`.

RONI. Porovnanie podpory OZE a vykupnych cien elektriny vyrobenej z OZE v okolitych krajinach. Technical report, Regulatory Office for Network Industries Slovakia, 2014.

RONI. Porovnanie podpory OZE a vykupnych cien elektriny vyrobenej z OZE v okolitych krajinach. techreport, Regulatory Office for Network Industries Slovakia, 2016a.

RONI. National report 2015. techreport, Regulatory Office for Network Industries Slovakia, 2016b.

Gonzalo Saenz de Miera, Pablo del Rio Gonzalez, and Ignacio Vizcaino. Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, 36:3345–3359, 2008.

SE. Slovenske elektrarne. URL `seas.sk`.

SE. Annual report 2015. techreport, Slovenske elektrarne, a.s., 2016.

Frank Sensfuss, Mario Ragwitz, and Massimo Genoese. The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy*, 36:3086–3094, 2008.

SEPS. Slovak electricity transmission system. URL `http://sepsas.sk/en.index.asp`.

SkREA. Pv in slovakia. Slovak RE Agency, 2008.

SSE. Stredoslovenska energetika, a.s. URL `https://sse.sk`.

Karolina Sukupova. Problematika zapornych spotovych cen elektricke energie. Master's thesis, Masarykova univerzita, 2012.

Marcel Suri, Thomas Huld, Ewan Dunlop, and Heinz Ossenbrink. Potential of solar electricity generation in the European Union member states and candidate countries. *Solar Energy*, 81:1295–1305, 2007.

Peter Taus and Marcela Tausova. Ekonomicka analyza fotovoltaickych elektrarni podla instalovaneho vykonu. *Acta Montanistica Slovaca*, 14: 92–97, 2009.

Asa Grytli Tveten, Torjus Folsland Bolkesjo, Thomas Martinsen, and Havard Hvarnes. Solar feed-in tariffs and the merit order effect: A study of the German electricity market. *Energy Policy*, 61:761–770, 2013.

Martin Vlachynsky. Elektricka dan, 2015. INESS.

WEC. World energy council. URL `worldenergy.org`.

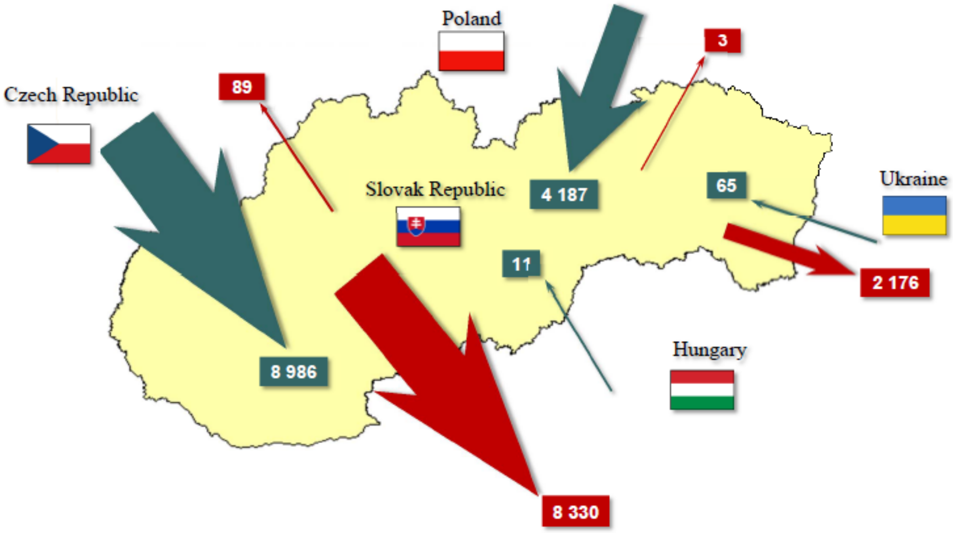
Chi-Keung Woo, Ira Horowitz, Jack Moore, and Andres Pacheco. The impact of wind generation on the electricity spot-market price level and variance: The Texas experience. *Energy Policy*, 39:3939–3944, 2011.

Jeffrey Wooldridge. *Introductory Econometrics A Modern Approach*. South-Western College Pub, 2012.

Klaas Wurzburg, Xavier Labandeira, and Pedro Linares. Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. *Energy Economics*, 40:S159–S171, 2013.

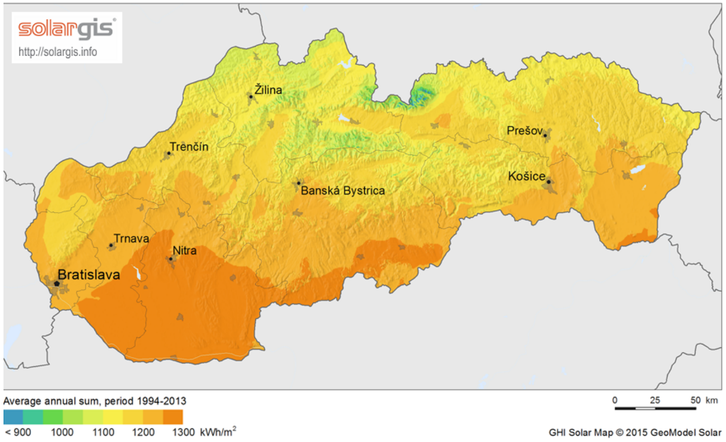
Appendix

Figure 10: Cross-border flows of electricity in 2016 (GWh)



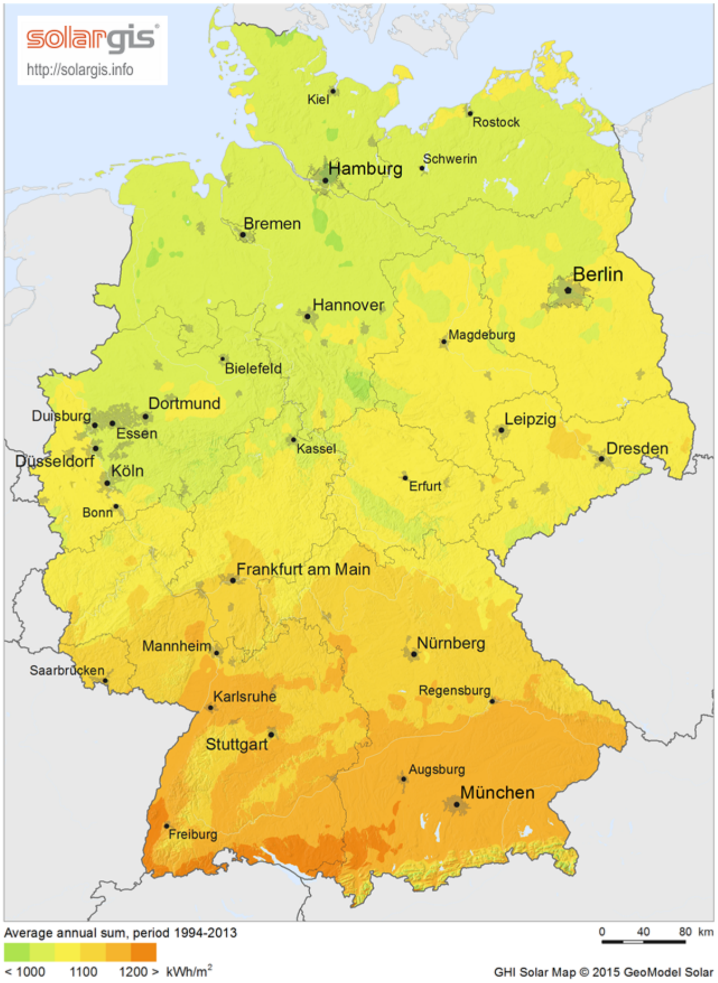
Source: National Control Center of Slovakia

Figure 11: Global horizontal irradiation in Slovakia



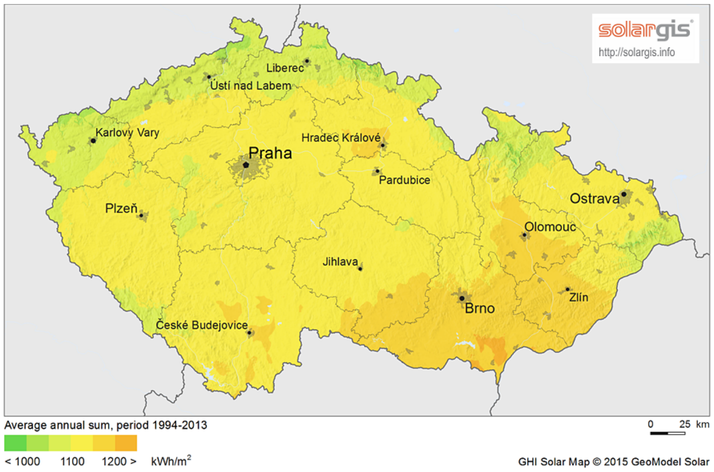
Source: Solargis

Figure 12: Global horizontal irradiation in Germany



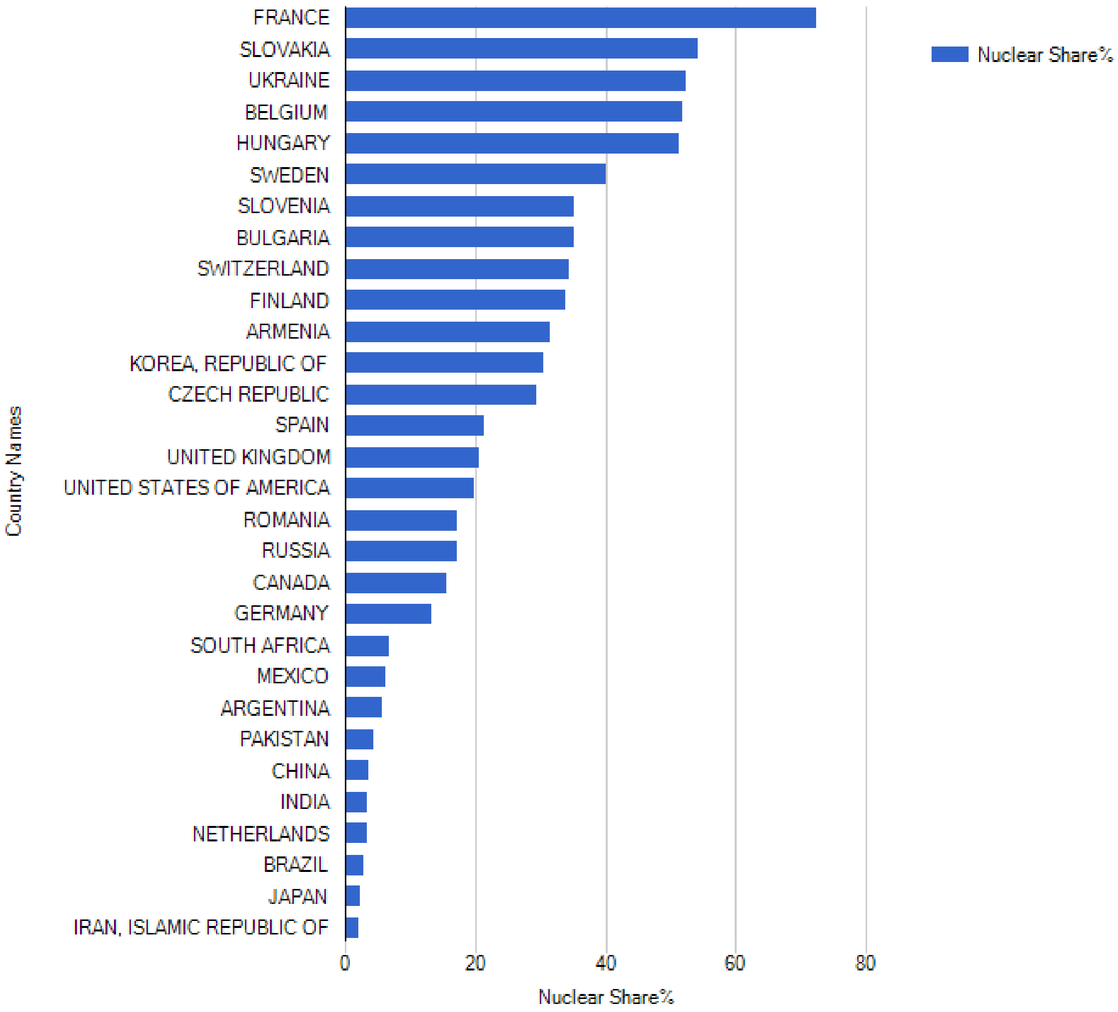
Source: Solargis

Figure 13: Global horizontal irradiation in the Czech Republic



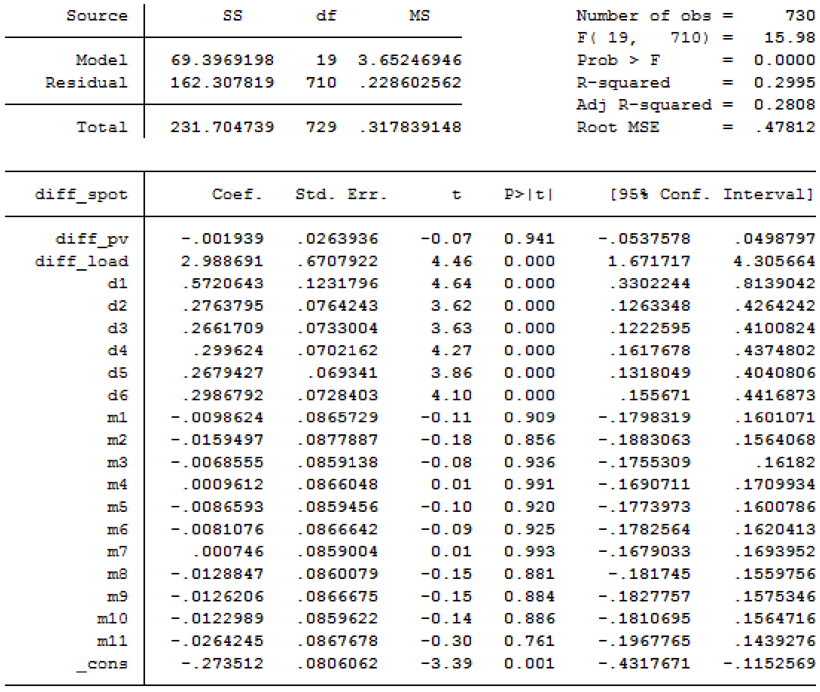
Source: Solargis

Figure 14: List of countries according to the nuclear share



Source: Power Reactor Information System

Figure 15: OLS estimation results: Slovakia 2015-2016, daily data

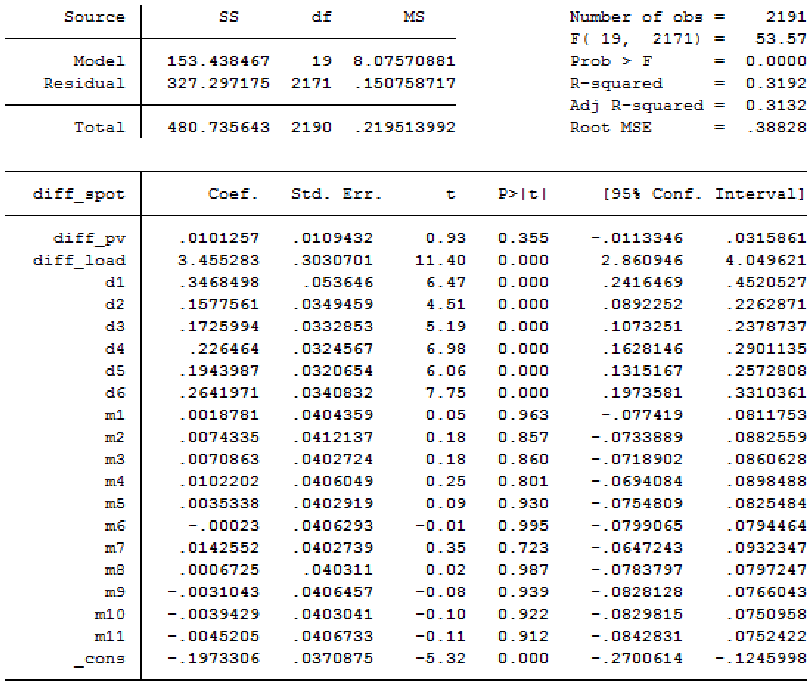


```
      Source |       SS       df       MS              Number of obs =     730
-------------+------------------------------           F( 19,   710) =   15.98
       Model |  69.3969198    19  3.65246946           Prob > F      =  0.0000
    Residual |  162.307819   710  .228602562           R-squared     =  0.2995
-------------+------------------------------           Adj R-squared =  0.2808
       Total |  231.704739   729  .317839148           Root MSE      =  .47812

------------------------------------------------------------------------------
   diff_spot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     diff_pv |   -.001939   .0263936    -0.07   0.941    -.0537578    .0498797
   diff_load |   2.988691   .6707922     4.46   0.000     1.671717    4.305664
          d1 |   .5720643   .1231796     4.64   0.000     .3302244    .8139042
          d2 |   .2763795   .0764243     3.62   0.000     .1263348    .4264242
          d3 |   .2661709   .0733004     3.63   0.000     .1222595    .4100824
          d4 |    .299624   .0702162     4.27   0.000     .1617678    .4374802
          d5 |   .2679427    .069341     3.86   0.000     .1318049    .4040806
          d6 |   .2986792   .0728403     4.10   0.000      .155671    .4416873
          m1 |  -.0098624   .0865729    -0.11   0.909    -.1798319    .1601071
          m2 |  -.0159497   .0877887    -0.18   0.856    -.1883063    .1564068
          m3 |  -.0068555   .0859138    -0.08   0.936    -.1755309      .16182
          m4 |   .0009612   .0866048     0.01   0.991    -.1690711    .1709934
          m5 |  -.0086593   .0859456    -0.10   0.920    -.1773973    .1600786
          m6 |  -.0081076   .0866642    -0.09   0.925    -.1782564    .1620413
          m7 |    .000746   .0859004     0.01   0.993    -.1679033    .1693952
          m8 |  -.0128847   .0860079    -0.15   0.881     -.181745    .1559756
          m9 |  -.0126206   .0866675    -0.15   0.884    -.1827757    .1575346
         m10 |  -.0122989   .0859622    -0.14   0.886    -.1810695    .1564716
         m11 |  -.0264245   .0867678    -0.30   0.761    -.1967765    .1439276
       _cons |   -.273512   .0806062    -3.39   0.001    -.4317671   -.1152569
------------------------------------------------------------------------------
```

Source: author's computations

Figure 16: OLS estimation results: Middle Slovakia 2011-2016, daily data



```
      Source |       SS       df       MS              Number of obs =    2191
-------------+------------------------------           F( 19,  2171) =   53.57
       Model |  153.438467    19  8.07570881           Prob > F      =  0.0000
    Residual |  327.297175  2171  .150758717           R-squared     =  0.3192
-------------+------------------------------           Adj R-squared =  0.3132
       Total |  480.735643  2190  .219513992           Root MSE      =  .38828

------------------------------------------------------------------------------
   diff_spot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     diff_pv |   .0101257   .0109432     0.93   0.355    -.0113346    .0315861
   diff_load |   3.455283   .3030701    11.40   0.000     2.860946    4.049621
          d1 |   .3468498    .053646     6.47   0.000     .2416469    .4520527
          d2 |   .1577561   .0349459     4.51   0.000     .0892252    .2262871
          d3 |   .1725994   .0332853     5.19   0.000     .1073251    .2378737
          d4 |    .226464   .0324567     6.98   0.000     .1628146    .2901135
          d5 |   .1943987   .0320654     6.06   0.000     .1315167    .2572808
          d6 |   .2641971   .0340832     7.75   0.000     .1973581    .3310361
          m1 |   .0018781   .0404359     0.05   0.963     -.077419    .0811753
          m2 |   .0074335   .0412137     0.18   0.857    -.0733889    .0882559
          m3 |   .0070863   .0402724     0.18   0.860    -.0718902    .0860628
          m4 |   .0102202   .0406049     0.25   0.801    -.0694084    .0898488
          m5 |   .0035338   .0402919     0.09   0.930    -.0754809    .0825484
          m6 |    -.00023   .0406293    -0.01   0.995    -.0799065    .0794464
          m7 |   .0142552   .0402739     0.35   0.723    -.0647243    .0932347
          m8 |   .0006725    .040311     0.02   0.987    -.0783797    .0797247
          m9 |  -.0031043   .0406457    -0.08   0.939    -.0828128    .0766043
         m10 |  -.0039429   .0403041    -0.10   0.922    -.0829815    .0750958
         m11 |  -.0045205   .0406733    -0.11   0.912    -.0842831    .0752422
       _cons |  -.1973306   .0370875    -5.32   0.000    -.2700614   -.1245998
------------------------------------------------------------------------------
```

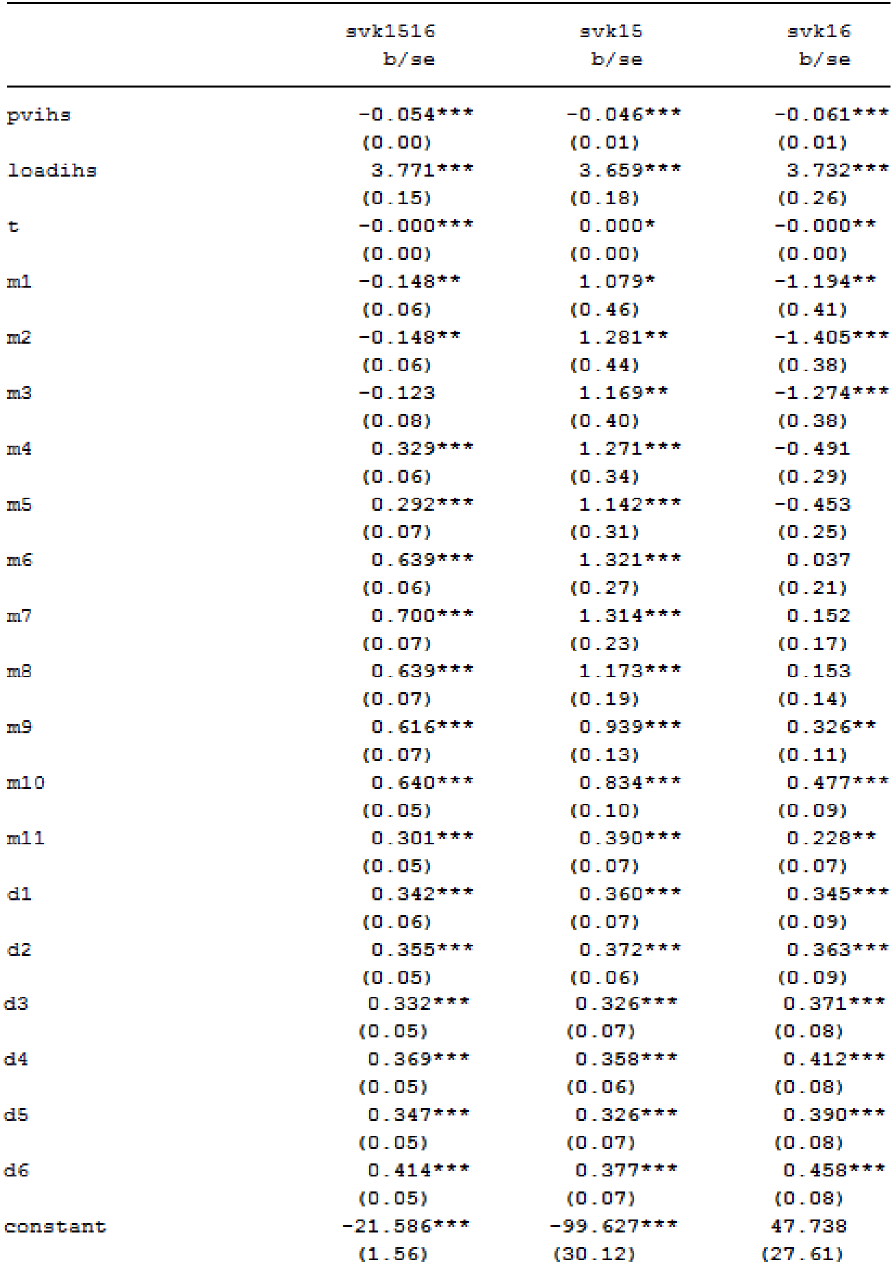
Source: author's computations

Table 8: Feed-in tariff in 2008-2017 (€/MWh)

Installed capacity	2008	2009	2010	2011	2011	2012	2012	2013	2014	2015	2016	2017
				I.	II.	I.	II.					
up to 30kW									98.94	88.89	88.89	84.98
up to 100 kW	424.88	448.12	430.72	387.65	259.17	194.54	119.11	119.11	-	-	-	-
100kW - 1MW	424.88	448.12	425.12	387.65	-	-	-	-	-	-	-	-
1 - 4 MW	424.88	448.12	425.12	382.61	-	-	-	-	-	-	-	-
more than 4 MW	424.88	448.12	425.12	382.61	-	-	-	-	-	-	-	-

Source: Regulatory Office for Network Industries

Figure 17: Comprehensive OLS estimation results: Slovakia 2015-2016

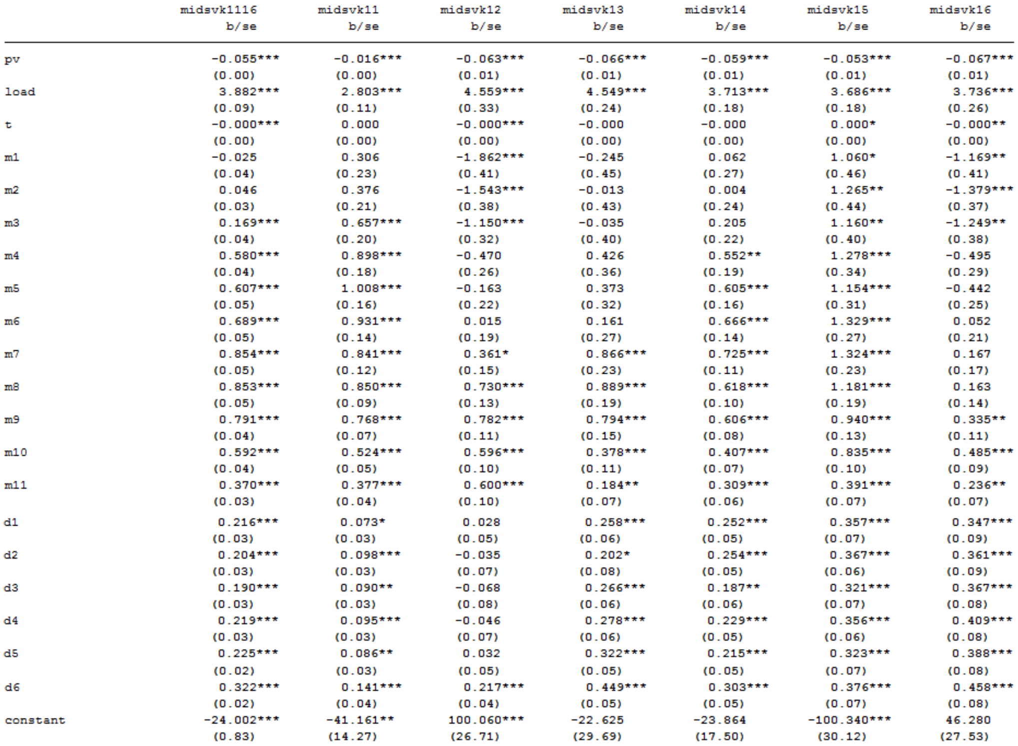


	svk1516 b/se	svk15 b/se	svk16 b/se
pvihs	-0.054***	-0.046***	-0.061***
	(0.00)	(0.01)	(0.01)
loadihs	3.771***	3.659***	3.732***
	(0.15)	(0.18)	(0.26)
t	-0.000***	0.000*	-0.000**
	(0.00)	(0.00)	(0.00)
m1	-0.148**	1.079*	-1.194**
	(0.06)	(0.46)	(0.41)
m2	-0.148**	1.281**	-1.405***
	(0.06)	(0.44)	(0.38)
m3	-0.123	1.169**	-1.274***
	(0.08)	(0.40)	(0.38)
m4	0.329***	1.271***	-0.491
	(0.06)	(0.34)	(0.29)
m5	0.292***	1.142***	-0.453
	(0.07)	(0.31)	(0.25)
m6	0.639***	1.321***	0.037
	(0.06)	(0.27)	(0.21)
m7	0.700***	1.314***	0.152
	(0.07)	(0.23)	(0.17)
m8	0.639***	1.173***	0.153
	(0.07)	(0.19)	(0.14)
m9	0.616***	0.939***	0.326**
	(0.07)	(0.13)	(0.11)
m10	0.640***	0.834***	0.477***
	(0.05)	(0.10)	(0.09)
m11	0.301***	0.390***	0.228**
	(0.05)	(0.07)	(0.07)
d1	0.342***	0.360***	0.345***
	(0.06)	(0.07)	(0.09)
d2	0.355***	0.372***	0.363***
	(0.05)	(0.06)	(0.09)
d3	0.332***	0.326***	0.371***
	(0.05)	(0.07)	(0.08)
d4	0.369***	0.358***	0.412***
	(0.05)	(0.06)	(0.08)
d5	0.347***	0.326***	0.390***
	(0.05)	(0.07)	(0.08)
d6	0.414***	0.377***	0.458***
	(0.05)	(0.07)	(0.08)
constant	-21.586***	-99.627***	47.738
	(1.56)	(30.12)	(27.61)

Source: author's computations

***p<0.01; **p<0.05; *p<0.1

Figure 18: Comprehensive OLS estimation results: Middle Slovakia 2011-2016



	midsvk1116	midsvk11	midsvk12	midsvk13	midsvk14	midsvk15	midsvk16
	b/se	b/se	b/se	b/se	b/se	b/se	b/se
pv	-0.055***	-0.016***	-0.063***	-0.066***	-0.059***	-0.053***	-0.067***
	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
load	3.882***	2.803***	4.559***	4.549***	3.713***	3.686***	3.736***
	(0.09)	(0.11)	(0.33)	(0.24)	(0.18)	(0.18)	(0.26)
t	-0.000***	0.000	-0.000***	-0.000	-0.000	0.000*	-0.000**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
m1	-0.025	0.306	-1.862***	-0.245	0.062	1.060*	-1.169**
	(0.04)	(0.23)	(0.41)	(0.45)	(0.27)	(0.46)	(0.41)
m2	0.046	0.376	-1.543***	-0.013	0.004	1.265**	-1.379***
	(0.03)	(0.21)	(0.38)	(0.43)	(0.24)	(0.44)	(0.37)
m3	0.169***	0.657***	-1.150***	-0.035	0.205	1.160**	-1.249**
	(0.04)	(0.20)	(0.32)	(0.40)	(0.22)	(0.40)	(0.38)
m4	0.580***	0.898***	-0.470	0.426	0.552**	1.278***	-0.495
	(0.04)	(0.18)	(0.26)	(0.36)	(0.19)	(0.34)	(0.29)
m5	0.607***	1.008***	-0.163	0.373	0.605***	1.154***	-0.442
	(0.05)	(0.16)	(0.22)	(0.32)	(0.16)	(0.31)	(0.25)
m6	0.689***	0.931***	0.015	0.161	0.666***	1.329***	0.052
	(0.05)	(0.14)	(0.19)	(0.27)	(0.14)	(0.27)	(0.21)
m7	0.854***	0.841***	0.361*	0.866***	0.725***	1.324***	0.167
	(0.05)	(0.12)	(0.15)	(0.23)	(0.11)	(0.23)	(0.17)
m8	0.853***	0.850***	0.730***	0.889***	0.618***	1.181***	0.163
	(0.05)	(0.09)	(0.13)	(0.19)	(0.10)	(0.19)	(0.14)
m9	0.791***	0.768***	0.782***	0.794***	0.606***	0.940***	0.335**
	(0.04)	(0.07)	(0.11)	(0.15)	(0.08)	(0.13)	(0.11)
m10	0.592***	0.524***	0.596***	0.378***	0.407***	0.835***	0.485***
	(0.04)	(0.05)	(0.10)	(0.11)	(0.07)	(0.10)	(0.09)
m11	0.370***	0.377***	0.600***	0.184**	0.309***	0.391***	0.236**
	(0.03)	(0.04)	(0.10)	(0.07)	(0.06)	(0.07)	(0.07)
d1	0.216***	0.073*	0.028	0.258***	0.252***	0.357***	0.347***
	(0.03)	(0.03)	(0.05)	(0.06)	(0.05)	(0.07)	(0.09)
d2	0.204***	0.098***	-0.035	0.202*	0.254***	0.367***	0.361***
	(0.03)	(0.03)	(0.07)	(0.08)	(0.05)	(0.06)	(0.09)
d3	0.190***	0.090**	-0.068	0.266***	0.187**	0.321***	0.367***
	(0.03)	(0.03)	(0.08)	(0.06)	(0.06)	(0.07)	(0.08)
d4	0.219***	0.095***	-0.046	0.278***	0.229***	0.356***	0.409***
	(0.03)	(0.03)	(0.07)	(0.06)	(0.05)	(0.06)	(0.08)
d5	0.225***	0.086**	0.032	0.322***	0.215***	0.323***	0.388***
	(0.02)	(0.03)	(0.05)	(0.05)	(0.05)	(0.07)	(0.08)
d6	0.322***	0.141***	0.217***	0.449***	0.303***	0.376***	0.458***
	(0.02)	(0.04)	(0.04)	(0.05)	(0.05)	(0.07)	(0.08)
constant	-24.002***	-41.161**	100.060***	-22.625	-23.864	-100.340***	46.280
	(0.83)	(14.27)	(26.71)	(29.69)	(17.50)	(30.12)	(27.53)

Source: author's computations

***p<0.01; **p<0.05; *p<0.1