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Keywords

Slovakia, Photovoltaics, Energy policy, Merit order effect

JEL Classification

Q42, H23, M21

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1 Introduction

The Slovak Republic is quite an interesting example of OECD country with a per capita globally second highest (after France) share of nuclear power electricity, a very low share of fossil electricity and a government policy driven average share of photovoltaic electricity in its electrical energy production. This article for the first time provides an overview of Slovak electrical market with a focus on photovoltaic electricity and its merit order effect.

Compared to other European countries, the Slovak Republic, especially its southern part, belongs to a relatively sunny region. This implies a good potential for solar generation (Suri et al., 2007), better than in geographically close countries of Germany or the Czech Republic, which produce significantly more solar electricity both in absolute and relative (per capita) terms. Thanks to EU Renewable Energy Directive (EC, 2009), the photovoltaics in Slovakia have been largely supported by the government policy through generous subsidies, guaranteed feed-in tariffs and legal preferential treatment (RONI, 2016a). Effort to comply with Slovak national target of reaching 24% share of renewable electricity in 2020 (MECSR, 2010) led to a Slovak installed photovoltaic capacity in Watt per capita (108) comparable to countries such as Austria (109), France (101), or Spain (114) in 2015 (SolarExpert, 2017). While photovoltaic energy is in general a subset of solar energy, there is no concentrating solar power (CSP) project in Slovakia thus in this paper these terms are interchangeable, i.e. Slovak solar means photovoltaic.

Due to very low marginal costs of solar electricity we may expect that photovoltaic development contributes to the decline of wholesale electricity prices. Indeed, in a number of countries (Australia, Spain, Italy, Ireland, Germany and others- see section 3) this so-called merit order effect of renewables has been shown. Yet the costs of photovoltaic support schemes are borne by final consumers. In Slovakia they fall within the tariff for system operation that is incorporated in the retail price and has been pushing it upwards.

While the main research question in the empirical part of this article deals with the existence of the photovoltaic merit order effect in the Slovak electricity market, we also answer following partial research questions: What is the size of possible merit order effect? To what degree the savings attributable to the merit order effect offset the costs of the related support scheme? Although numerous studies exist concerning the above-mentioned phenomenon in a number of countries, up to now nobody has assessed the merit order effect in the Slovak electricity market.

In the rest of this study we take a look at the Slovak electricity market (section 2) and evaluate the impact of solar generation on spot prices over the years 2011-2016. Building on approaches described in the literature (section 3) we construct a model (section 4) and run an OLS regression on time series data (section 5), the outcomes of which quantify the Slovak merit order effect and determine savings arising from a larger supply of electricity coming from photovoltaics (section 6). We further calculate the costs and compare the results in order to conclude (section 7) whether or not the savings outweigh the expenses and thus create a consumer surplus or loss.

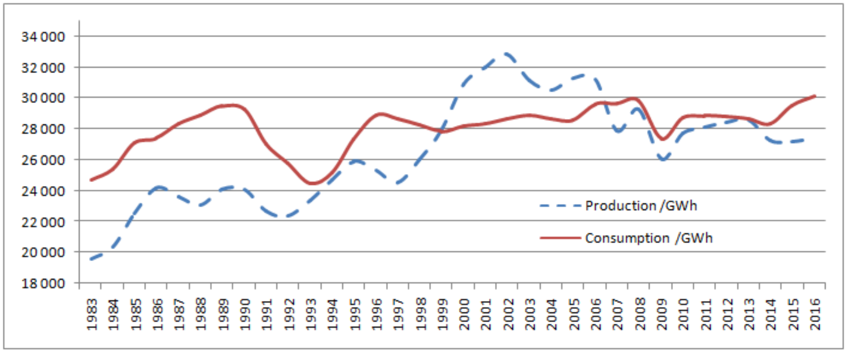
2 Slovak electricity market

2.1 Production, consumption and interconnections

In Figure 1 we summarize Slovak electricity production and consumption from 1983 to 2016. Since 1983 up to the end of 1990 the steady growth of electricity consumption was driven be energy-inefficient process of industrial development and general increase of Slovak consumption of goods and services. The sudden end of centrally planned economy after the November 1989 Velvet Revolution led to significant changes in Slovak economy which was in centrally planned Czechoslovakia oriented towards electricity intensive heavy manufacturing, in particular of military equipment. After the first few transition years and the establishment of independent Slovak Republic in 1993, the electricity consumption grew back to almost pre-transition level. Since 1996 the electricity consumption remains relatively steady, ranging from 27 386 to 30 103 GWh (the sudden drop in 2009 was due to the global crisis). However the generation is far more volatile. It went through a steady increase from 1997 to 2002 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 in July 1998 (1st block) and December 1999 (2nd block).

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



Source: Slovak electricity transmission system

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, and further decrease in 2009 due to the global 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, 2018).

Focusing on the most recent years we observe a widening gap between the consumption and the production. The significance of the import has 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 while the transmission systems of Slovakia and neighboring Austria are not connected at all. The volume of the electricity exported and imported is summarized in Table 1.

In order to facilitate the aforementioned exchanges, Slovakia became part of the 4M

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, http://sepsas.sk/Vyroba_Spotreba.asp?kod=568

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 remains identical with the political area of the country. It means that electricity can be transferred without requirement of transmission capacity allocation only between any two points within the Slovak Republic (Bems et al., 2016).

2.2 Market mechanism

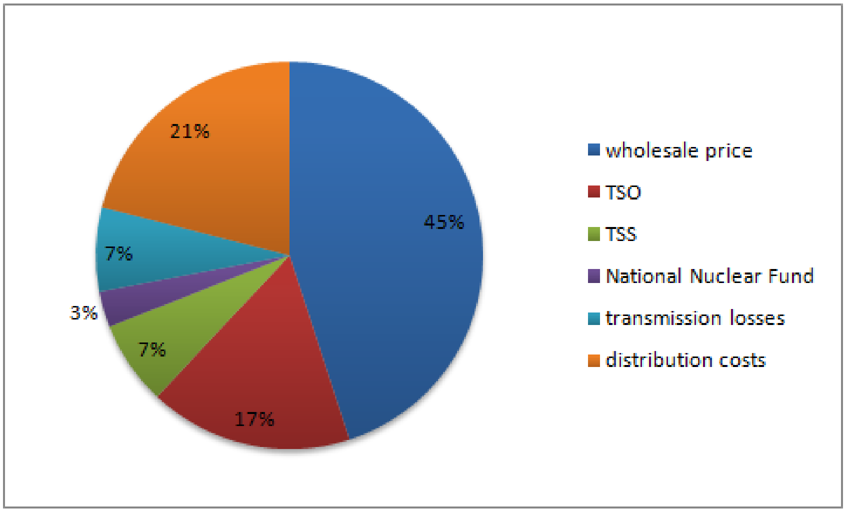
Since the vertical unbundling implemented in Slovakia in 2007, competition has arisen among electricity suppliers and consumers are free in their choice (Meszaros et al., 2014). Electricity is traded as a commodity on an over-the-counter market or an exchange – in Slovakia it is the Power Exchange Central Europe (PXE, 2018), which is a part of the EEX Group since 2016. Products are usually monthly, quarterly and yearly packages, either traded on a forward (the delivery will be executed next year) or on a spot market (day-ahead basis) (Meszaros et al., 2014).

Due to the spot market nature, 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 in 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 (2018), 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.

2.3 Price structure

In Slovakia the price of electricity is solely determined by market forces without any form of regulation at the wholesale level. The retail price for end consumers, however, consists of several components, see Figure 2.

Figure 2: Final price structure in 2016



Source: National Control Center of Slovakia

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 (TSS in Figure 2). Furthermore, the distribution fees cover costs incurred by the DSOs and the fee for the levy to the National Nuclear Fund is included.

For our analysis, the most important is the tariff for system operation (TSO in Figure 2). Its purpose is to contribute to the financing of electricity produced 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 the tariff for system operation. The RES item represents 67% as of 2017 and can be further subdivided. According to calculations of the Middle Slovakia regional energy distribution company (SSE) in 2017, 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 which results in pushing the final price upwards through the rising tariff for system operation. Table 2 summarizes the size of the tariff over the years 2009-2017 (RONI, 2018).

Table 2: Tariff for system operation in 2010-2017 (€/MWh)

	2010	2011	2012	2013	2014	2015	2016	2017
Tariff total	6.3	14.85	15.7	19.88	21.82	21.82	22.9	26.203
RES part	1.7	8.81	12.1016	13.7952	14.0209	13.8147	14.6885	17.5751

Source: http://www.urso.gov.sk/sites/default/files/ZhodnotenieRO2012-2016.pdf

Transmission and distribution related fees, as well as system fees are set by the Regulatory Office for Network Industries. In addition, end customers other than households, which are exempted, are charged an excise duty. They are also subject to the value added tax pursuant to applicable laws. The price cap method applies – the retail price for households and small businesses is regulated by setting the maximum, tracking the market trends.

2.4 Electricity mix

The composition of the Slovak electricity mix has not changed dramatically throughout the last few years. The shares of individual sources in 2016 can be seen in Table 3.

The Slovak electricity production is heavily focused on nuclear generation that currently represents 54.1% of the energy mix according to the International Atomic Energy Agency (IAEA, 2018). In 2016 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.

In Slovakia, all the nuclear energy comes from two power plants (NPP) operated by Slovenske elektrarne, a.s., situated in Bohunice and Mochovce (south-west of the country). Three out of five Bohunice NPP's units were shut down in 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 number 3 and 4 are currently under construction. They are expected to be finalized and connected to the grid by 2019 (SE, 2018). Consequently, the nuclear generation that has been steady over the observed period (see the Table 3) will increase sharply. A yearly production from the two new blocks ought to save 7 billion tons of CO_2 emissions by replacing electricity from coal and from imports (under assumption that all replaced imported electricity is generated from fossil resources) and it ought to cover 26% of the Slovak national electricity consumption (SE, 2016).

This construction with total budgeted investment costs 4.6 billion euros is the largest ever investment in the private sector in Slovakia since the establishment of the country in 1993 (SE, 2017). It will strengthen the country's role in a prominent nuclear region involving the Czech Republic, Hungary and Ukraine (Bems et al., 2015). Also it might shift Slovakia to the world's first position in the nuclear generation share by reaching approximately 80% and moving ahead of the current number one – France. This ranking projection, however, depends 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, 2018). The Slovak wind electricity production of 10 GWh in 2015 (Oenergetice, 2018) was about 50 times smaller than corresponding photovoltaic production. With an installed wind generation capacity of only 3 MW at the end of 2017 (WindEurope, 2018) Slovakia (together with Slovenia and Malta) is a clear outlier in the European Union. Comparison with installed wind energy capacities in neighboring Austria (2828 MW), Czech Republic (308 MW), Hungary (329 MW), and Poland (5848 MW) clearly shows that the negligible presence of wind electricity in Slovakia is not driven by geographical conditions but by policies and public preferences.

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 (Gelabert et al., 2011; Cludius et al., 2014b).

Table 3: Production of Slovak power plants in 2006-2016 (GWh or %)

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
2016 %	54	19	18	2	2	6	100

Source: Slovak electricity transmission system, http://sepsas.sk/Rocenka.asp?kod=496

2.5 Development of photovoltaics in Slovakia and its support scheme

Utilization of the solar energy was at a very low level when Slovakia joined the European Union in May 2004. This was mainly caused by high investment costs and no governmental support. 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 (with Bulgaria, Ukraine and Croatia) stayed at the very bottom of the list. By 2016 the total PV installed capacity increased to 533 MW which shifted the country to the 15th position in Europe (WEC, 2018). In the Watt per capita ranking Slovakia holds 15th position in Europe and 17th in the world.

The beginning of such substantial progress of the Slovak PV situation dates back to 2009 – to the Europe 2020 Strategy implementation (EC, 2009). The national target of reaching 24% share of renewable electricity in 2020 was challenging for the energy policy. The solar generation had a potential, yet required governmental support and inevitable legislative changes. In general, various mechanisms can reinforce the renewable electricity production and depend upon the country's location, the weather conditions and the energy policy. The support is usually executed through numerous channels – guaranteed feed-in tariffs (FIT) for a fixed number of years, legal priority dispatch, quota obligations, tradeable green certificates, fixed premium system, tax credits etc. The final support scheme design is determined by each country individually (RONI, 2014).

The Slovak renewable electricity support was shaped by the legislation adjustments based on the Slovak legal Act 309/2009 and defined 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 entire volume of the electricity generated by renewables; the responsibility for imbalance assigned to the regional DSO and a constant guaranteed feed-in tariff throughout the entire obligation period that 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 (RES Act 309/2009). This last support instrument provided strong incentive to the investors, promising a high reward of 448.12 € per each MWh of the solar energy produced from a plant built in 2009. Moreover, operators of photovoltaic and wind power installations were eligible for subsidies under the Operational Programme Quality of Environment (OPKZP, 2018) financed by the European structural and investment fund.

This generous investment 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 new photovoltaic plants sharply increased owing to the aforementioned incentives. 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 (RONI, 2018). For more information on eligibility and size of FIT see Culkova et al. (2015).

As a result of this renewable electricity policy the Slovak share of electricity from renewable sources in gross electricity consumption grew from 15.4% in 2004 to 22.5% in 2016 (EuroSTAT, 2018), approaching the country specific 24% Europen Union's target (MECSR, 2010). Over the same period EU share of electricity from renewable sources in gross electricity consumption grew from 14.3% in 2004 to 29.6% in 2016.

Table 4: Share of electricity from renewable sources in gross electricity consumption (%)

	Slovakia	Belgium	Czech Republic	France	Hungary	EU
2004	15.4	1.7	3.6	13.8	2.2	14.3
2005	15.7	2.4	3.7	13.7	4.4	14.8
2006	16.6	3.1	4.0	14.1	3.5	15.4
2007	16.5	3.6	4.6	14.3	4.2	16.1
2008	17.0	4.6	5.2	14.4	5.3	17.0
2009	17.8	6.2	6.4	15.1	7.0	19.0
2010	17.8	7.1	7.5	14.8	7.1	19.7
2011	19.3	9.1	10.6	16.2	6.4	21.7
2012	20.1	11.3	11.7	16.4	6.1	23.5
2013	20.8	12.5	12.8	16.8	6.6	25.4
2014	22.9	13.4	13.9	18.3	7.3	27.4
2015	22.7	15.5	14.1	18.7	7.3	28.8
2016	22.5	15.8	13.6	19.2	7.2	29.6

Source: Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php

Table 4 shows that the Slovak current renewable electricity share is below the EU countries' average of 29.6%. However considering some of the EU countries with high per-capita nuclear electricity generation, Slovakia's share is comparable with Czech Republic (13.6%), Belgium (15.8%), or France (19.2%) and three times higher than in Hungary

(7.2%).

Because of the support scheme and favorable geographical conditions the Slovak solar potential is quite promising, see the European Commission Photovoltaic Geographical Information System (PVGIS, 2018) and Suri et al. (2007). The Slovak average global horizontal irradiation is rather high, ranging between 1100-1150 kWh/m2/year, while in Germany it is only 1000 kWh/m2/year. 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.

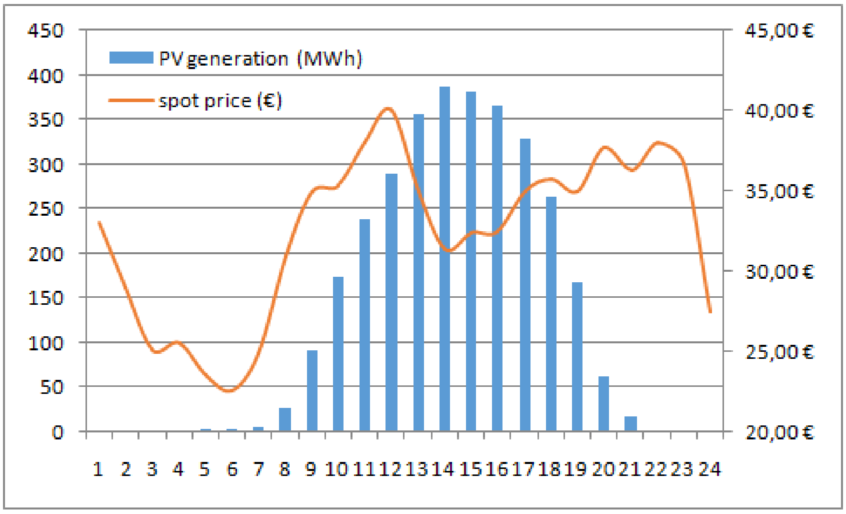
2.6 Merit order effect

The merit order effect is an expression of correlation between the composition of the energy mix and the spot price of electricity. 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 should be employed according to the price of the last MWh generated. In Slovakia, the priority of the renewable sources is strengthened by the dispatch rule established by Slovak legal 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 force. One way or another, the renewables are the cheapest source in terms of marginal costs hence the principle would remain the same.

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 3, which provides an illustration for one particular sunny summer day favorable for optimal utilization of photovoltaic generation, the price increases with rising demand in the early hours and is diminished by the solar feed-in during the day.

The electricity spot price has, indeed, dropped in Europe in recent years. Besides

Figure 3: Daily profile 23/06/2016 (Prices in EUR/MWh)



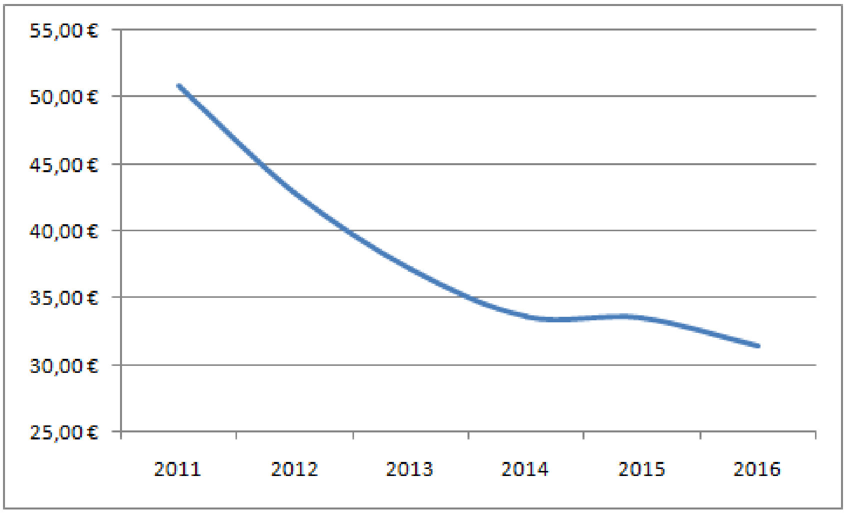
Source: SEPS and OKTE

other reasons such as general decrease of commodities' prices 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 4. 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 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. Therefore an interesting question in this case is to what degree the savings from the MOE partially offset the costs of the photovoltaics support scheme.

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 of nuclear energy production. Consequently, we expect the MOE of the photovoltaics to be smaller (and the position of the photovoltaics in the system to be less significant) than in other economies that

Figure 4: Spot price in 2011-2016 (in EUR/MWh)



Source: Short-term electricity market operator

produce electricity mainly from more expensive sources which creates 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 is therefore one of the contributions of this paper.

3 Literature review

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 RES generation. 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.

Given the leading position of Germany in the public promotion of photovoltaic and wind electricity, the German electricity market and the RES merit order effect have been described in a large number of studies. According to Rathmann (2007), the Emission Trading Scheme contributes to the electricity price decline. He 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 price. In this specific case the price decreases by 6.4€/MWh in 2005–2007. 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. Cludius et al. (2014b) provide a time-series regression analysis, aiming to quantify the MOE of wind and photovoltaic generation. Their dataset covers the years 2008–2012 and the MOE ranges from 6€/MWh to 10€/MWh. 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. Kyritsis et al. (2017) confirm the effects of solar and wind power generation on electricity price formation in Germany during 2010–2015 – the period of the rapid integration of PV and wind power sources, as well as the phasing out of nuclear energy.

For Italy, the second most important photovoltaics market, Clo et al. (2015) use a regression model to find the solar MOE of 2.3€/MWh. The monetary savings from solar generation, however, were not sufficient to compensate for the related supporting scheme's costs – which is considered one of the most generous worldwide. In Spain, which is according to the per capita solar energy production only slightly behind Slovakia, Gelabert et al. (2011) evaluate the renewables jointly over the period of 2005–2010 and find evidence of a 4% decline in the electricity price on average, i.e. decrease of 1.9€/MWh with each GWh of electricity produced from RES.

The merit order effect of renewables 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 MOE of the wind generation that reaches \$8.05/MWh and \$2.73/MWh in South Australia and Victoria respectively in 2009–2011. Cludius et al. (2014a) build on the previous results by expanding the market of interest to the Australian 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.

While we are not aware of any attempt to quantify merit order effect of Slovak photovoltaics, Lunackova et al. (2017) investigate the neighboring Czech electricity market and confirm the existence of merit order effect for non-solar renewables. Moreover, they show that the electricity price does not decrease with increasing amounts of solar energy. Non-existence of photovoltaic merit order effect was also reported by Milstein and Tishler (2011) in the case of Israel.

The Slovak electricity market has barely been examined so far. To our knowledge there are only a few authors 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. 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).

Jirous (2012) provides a Slovak national report on the integration of electricity from RES to the electricity grid and market. 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). Lofstedt (2008) focuses on possible confrontation between Austria and Slovakia concerning the generation from nuclear and renewable sources. Meszaros et al. (2014) analyze the Slovak electricity market and pinpoint 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. 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.

4 Methodology

4.1 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. We follow Cludius et al. (2014b) and construct the following OLS regression model:

$$p_t = \beta_0 + \beta_1 PV_t + \beta_2 load_t + \gamma\, dummies_t + time + u_t, \tag{1}$$

where p denotes the spot market price as the response variable and our main explanatory variables are 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. A positive sign on its coefficient β_2 is expected.

Furthermore, we include the intercept β_0, a time trend and a vector of dummy variables 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 unobserved error term and the subscript t represents an individual observation in time – an hourly sequence.

First we use the given model for assessment of the MOE 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. These results provide an overall picture. Subsequently 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 see changes between the years.

4.2 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 is satisfied 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 be 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.

4.3 Consumer welfare analysis

The fast development of the photovoltaics bears non-negligible monetary costs for customers through the support scheme. We determine whether or not electricity generation from PV brings about a consumer's surplus, i.e. whether the savings outweigh the costs thanks to substantial deployment of photovoltaics which should reduce the electricity price. To answer this 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 $\bar{p}_t$ and evaluate the savings per MWh. Then we multiply the figure by the yearly production and get the approximate savings B_t attributable to the PV merit order effect MOE_t according to formula

$$B_t = MOE_t \cdot \bar{p}_t \cdot m_t \cdot Q_t, \tag{2}$$

where Q_t is a Slovak production of electricity in a year t and m_t is a share of photovoltaic production in a year t.

We also need the costs of the photovoltaics' support that are borne by final consumers (S_t). 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 F_t as given by calculations of the Middle Slovakia regional energy distribution company (SSE) in 2017. We multiply this figure by the yearly consumption C_t to find out how much the consumers contribute to the support scheme through their electricity bills:

$$S_t = F_t \cdot C_t. \tag{3}$$

While different consumers face different final prices, the same tariff for system operations (the same amount of EUR/MWh) applies to all households, small and medium enterprises and large companies as well. The data concerning the tariff for system operation and the Slovak production and consumption come from RONI (2018) and SEPS

(2018) respectively. To conclude we compare estimated savings and costs and comment on consumer surplus or loss CB_t:

$$CB_t = B_t - S_t. \tag{4}$$

5 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 provided in €/MWh by the Organizer of the Short-term Electricity Market (OKTE, 2018). Load (how much of electricity is in the grid at a given point of time) and solar generation data are provided by SEPS (2018). Both are provided as hourly averages, in MW units. Because of hourly aggregation, average load (in MW) is equal to energy (in MWh).

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 dataset covers the entire country from 1/1/2015 to 31/12/2016. Second dataset for the Middle Slovakia covers the period 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 (SSE).

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 use the hour-by-hour approach. 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.

The basic features of our dataset before any kind of transformation can be seen in Tables 5 and 6. 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 all 52608 for the Middle

Slovakia region.

Table 5: Summary statistics: Slovakia 2015-2016

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

Source: authors' computations

Table 6: Summary statistics: Middle Slovakia 2011-2016

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

Source: authors' computations

For the sake of interpretability the researchers usually use logarithmic transformation of the data so the merit order effect can be explained as the elasticity of electricity spot price with respect to change in supply of electricity from photovoltaics (Lunackova et al., 2017). However the major issue arises from the nature of photovoltaic generation – for most hours during the day it is simply zero. Another interesting feature of our dataset is negative wholesale prices, which do not allow the logarithmic transformation. 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 spot price below zero. Such situations usually occur at night and last for a few hours. The operators of conventional power plants are not able to react immediately and cease the production. Although the plants are dispatchable, they are not easily responsive. A shutdown and consequent startup would be expensive. They maintain the production at a lower level and suppliers are willing to pay the consumers in order to get rid of the excessive electricity in the grid which is often less costly than compensating for emerged imbalances. For a more exhaustive explanation see Sukupova (2012), Nicolosi and Fursch (2009) and Vlachynsky (2015).

To deal with zero and negative values we transform the available data using the inverse hyperbolic sine (IHS) transformation. It was first introduced by Johnson (1949) within an alternative transformation family and is defined as:

$$z = log(y + \sqrt{y^2 + 1}). \tag{5}$$

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 hyperbolic sine approximately equals $log(2y) = \log(2) + \log(y)$, 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. In this article the IHS is applied to both explanatory variables as well as the response variable and the unit root and Durbin-Watson tests are run on the transformed values.

Augmented Dickey-Fuller test including a linear trend term showed that all the series, but the 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. All the tests we performed on hourly data in accordance with our methodology yielded the same qualitative results regardless the area or year in question.

6 Results

6.1 Merit order effect

We run the regression of spot price on solar generation, total load, dummies and time trend. The explanatory variables – PV and load (p-value smaller than 0.001 in both subsets)– and majority of daily and monthly dummies were proven to have a statistically significant effect and we report them in Tables 7 and 8. A time trend does not have an economically significant effect since the time trend coefficients are uniformly very small (order of magnitude -4 or lower, while all the other coefficients are of order of magnitude between +1 and -2). These small (in absolute value) time trend coefficients fluctuate around zero, in some cases achieving statistical significance on conventional levels, in some cases not.

Tables 7 and 8 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, monthly ($m1, \ldots, m11$) and daily ($d1, \ldots, d6$) dummies and the constant. Furthermore, R^2 and adjusted R^2 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. Durbin-Watson test considers null hypothesis that the errors are serially uncorrelated against the alternative that they follow a first order autoregressive process.

Conforming with the MOE principle and most existing literature, the coefficient on the photovoltaics variable is negative and statistically different from zero at the 99% confidence level in all 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 spot price decrease from 0.016% to 0.067%. Comparison of yearly values of β_1 coefficients representing the merit order effect with the yearly volumes of Slovak photovoltaic production clearly shows that the first year of Slovak photovoltaic production (year 2011) was different. While the photovoltaic generation already exhibited a merit order effect in 2011, it was about four times weaker than for all the following years. This difference was driven by much lower volume of Slovak photovoltaic production in this initial year before it almost doubled and reached stable state for the rest of the analyzed period. Accordingly, the merit order effects for the years 2012 - 2016 keep relatively stable about the value -0.06.

The overall results for Slovakia are similar to those in the Middle Slovakia region thus we confirm 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.

Furthermore, we move 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.

6.2 Consumer welfare analysis

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

The 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 8. We multiply the MOE by the share of photovoltaics in the Slovak energy mix in the respective year and 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 calculate the total savings in individual years.

As the counterpart, we determine the costs borne by end consumers. The national consumption is multiplied by the cost of one MWh produced from solar power plants (the solar energy part of yearly specific tariff for system operations). Given the size of the tariff

Table 7: Summary of regression outcomes: Slovakia 2015-2016

	2015	2016	2015-2016
PV	-0.046***	-0.061***	-0.054***
	(0.01)	(0.01)	(0.00)
load	3.659***	3.732***	3.771***
	(0.18)	(0.26)	(0.15)
m1	1.079*	-1.194**	-0.148**
	(0.46)	(0.41)	(0.06)
m2	1.281**	-1.405***	-0.148**
	(0.44)	(0.38)	(0.06)
m3	1.169**	-1.274***	-0.123
	(0.40)	(0.38)	(0.08)
m4	1.271***	-0.491	0.329***
	(0.34)	(0.29)	(0.06)
m5	1.142***	-0.453	0.292***
	(0.31)	(0.25)	(0.07)
m6	1.321***	0.037	0.639***
	(0.27)	(0.21)	(0.06)
m7	1.314***	0.152	0.700***
	(0.23)	(0.17)	(0.07)
m8	1.173***	0.153	0.639***
	(0.19)	(0.14)	(0.07)
m9	0.939***	0.326**	0.616***
	(0.13)	(0.11)	(0.07)
m10	0.834***	0.477***	0.640***
	(0.10)	(0.09)	(0.05)
m11	0.390***	0.228**	0.301***
	(0.07)	(0.07)	(0.05)
d1	0.360***	0.345***	0.342***
	(0.07)	(0.09)	(0.06)
d2	0.372***	0.363***	0.355***
	(0.06)	(0.09)	(0.05)
d3	0.326***	0.371***	0.332***
	(0.07)	(0.08)	(0.05)
d4	0.358***	0.412***	0.369***
	(0.06)	(0.08)	(0.05)
d5	0.326***	0.390***	0.347***
	(0.07)	(0.08)	(0.05)
d6	0.377***	0.458***	0.414***
	(0.07)	(0.08)	(0.05)
constant	-99.627***	47.738	-21.586***
	(30.12)	(27.61)	(1.56)
R^2	0.383	0.371	0.360
Adjusted R^2	0.382	0.369	0.359
DW_0	0.22	0.18	0.19
DW	1.89	1.97	1.93
F	271.45	257.95	493.59
Observations	8760	8784	17544

Source: authors' computations

Newey-West standard errors are reported in parentheses. ***$p<0.01$; **$p<0.05$; *$p<0.1$

Table 8: 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)
m1	0.306 (0.23)	-1.862*** (0.41)	-0.245 (0.45)	0.062 (0.27)	1.060* (0.46)	-1.169** (0.41)	-0.025 (0.04)
m2	0.376 (0.21)	-1.543*** (0.38)	-0.013 (0.43)	0.004 (0.24)	1.265** (0.44)	-1.379*** (0.37)	0.046 (0.03)
m3	0.657*** (0.20)	-1.150*** (0.32)	-0.035 (0.40)	0.205 (0.22)	1.160** (0.40)	-1.249** (0.38)	0.169*** (0.04)
m4	0.898*** (0.18)	-0.470 (0.26)	0.426 (0.36)	0.552** (0.19)	1.278** (0.34)	-0.495 (0.29)	0.580*** (0.04)
m5	1.008*** (0.16)	-0.163 (0.22)	0.373 (0.32)	0.605*** (0.16)	1.154*** (0.31)	-0.442 (0.25)	0.607*** (0.05)
m6	0.931*** (0.14)	0.015 (0.19)	0.161 (0.27)	0.666*** (0.14)	1.329*** (0.27)	0.052 (0.21)	0.689*** (0.05)
m7	0.841*** (0.12)	0.361* (0.15)	0.866*** (0.23)	0.725*** (0.11)	1.324*** (0.23)	0.167 (0.17)	0.854*** (0.05)
m8	0.850*** (0.09)	0.730*** (0.13)	0.889*** (0.19)	0.618*** (0.10)	1.181*** (0.19)	0.163 (0.14)	0.853*** (0.05)
m9	0.768*** (0.07)	0.782*** (0.11)	0.794*** (0.15)	0.606*** (0.08)	0.940*** (0.13)	0.335** (0.11)	0.791*** (0.04)
m10	0.524*** (0.05)	0.596*** (0.10)	0.378*** (0.11)	0.407*** (0.07)	0.835*** (0.10)	0.485*** (0.09)	0.592*** (0.04)
m11	0.377*** (0.04)	0.600*** (0.10)	0.184** (0.07)	0.309*** (0.06)	0.391*** (0.07)	0.236** (0.07)	0.370*** (0.03)
d1	0.073* (0.03)	0.028 (0.05)	0.258*** (0.06)	0.252*** (0.05)	0.357*** (0.07)	0.347*** (0.09)	0.216*** (0.03)
d2	0.098*** (0.03)	-0.035 (0.07)	0.202* (0.08)	0.254*** (0.05)	0.367*** (0.06)	0.361*** (0.09)	0.204*** (0.03)
d3	0.090** (0.03)	-0.068 (0.08)	0.266*** (0.06)	0.187** (0.06)	0.321*** (0.07)	0.367*** (0.08)	0.190*** (0.03)
d4	0.095*** (0.03)	-0.046 (0.07)	0.278*** (0.06)	0.229*** (0.05)	0.356*** (0.06)	0.409*** (0.08)	0.219*** (0.03)
d5	0.086** (0.03)	0.032 (0.05)	0.322*** (0.05)	0.215*** (0.05)	0.323*** (0.07)	0.388*** (0.08)	0.225*** (0.02)
d6	0.141*** (0.04)	0.217*** (0.04)	0.449*** (0.05)	0.303*** (0.05)	0.376*** (0.07)	0.458*** (0.08)	0.322*** (0.02)
constant	-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)
R^2	0.464	0.417	0.477	0.418	0.385	0.372	0.404
Adjusted R^2	0.462	0.416	0.476	0.416	0.384	0.371	0.404
DW_0	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
Observations	8760	8784	8760	8760	8760	8784	52608

Source: authors' computations

Newey-West standard errors are reported in parentheses. ***p<0.01; **p<0.05; *p<0.1

and the fact that photovoltaics consume approximately 50% of resources gained through the RES component of the tariff for system operation, we calculate the annual volume of payments charged to end consumers in order to finance the solar systems support scheme.

The payment reduction due to photovoltaics ranges 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 the rising tariff for system operation (see Table 2). 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 9 provides a summary of our calculations.

Table 9: 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: authors' computations

7 Conclusion

To the best of our knowledge, this is the first study to discuss the merit order effect (MOE) of photovoltaic generation in Slovakia. This study provides a simple MOE analysis based on OLS regressions run on time series data concerning spot prices, total load and volume of photovoltaic production. As the variables are taken in logarithms (using inverse hyperbolic sine transformation) 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.

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 Slovak 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.

Our finding of merit order price benefits not compensating photovoltaic support cost is similar to results of Clo et al. (2015), who show that in the case of Italy monetary savings from solar production do not compensate the cost of the incentives. The results of Clo et al. (2015) are well comparable with our results since they use similar econometric approach to estimation of merit order effect as we use. However an interesting difference is that Italian monetary savings from wind production (which is not relevant for Slovakia) are higher than the cost of the incentives. Considering the literature proposing the possibility of financially viable photovoltaic generation, the simulation results of McConnell et al. (2013) on Australian data that the photovoltaic merit order induced depression of wholesale prices offsets the cost of support mechanisms was not confirmed for the case of Slovakia. The most suitable comparison country for Slovakia would be France with the same share (2%) of solar energy on electricity mix, with similar share of hydro-power (12% as compared to Slovakia's 18%) and with high share of nuclear energy. However we are not aware of any solar electricity merit order effect analysis for France.

We must emphasize that our conclusion of negative balance of solar benefits and costs focuses only on the direct pecuniary effect on electricity consumer. We do not take into account any environmental benefits connected with replacement of fossil energy by photovoltaic energy. However, in case of Slovakia, the photovoltaics might in the future actually at least partially substitute not for coal, oil or gas turbines, but for the nuclear energy. This possible nuclear/photovoltaic tradeoff may be much more important from 2019 when the Slovak nuclear capacity will substantially increase, making Slovakia the per capita globally leading nuclear energy country. Currently over the whole 2011- 2016 period covered by our analysis, the nuclear power production runs at stable maximum level for all days with high consumption. For all six years the utilized capacity of nuclear power was uniformly 1900 MW for each day with maximum consumption. The marginal electricity resource in Slovakia are fossil fuel power stations running on coal (out of two existing gas-fired Slovak power stations one hasn't been used since 2013 since its production is not financially competitive with other resources, and the other one is just a small one outside of portfolio of dominant Slovak electricity producer). The major change brought about by Slovak photovoltaic since its introduction in 2011 was a displacement of pumped storage hydroelectricity from the middle of the day peak towards morning and evening peaks.

While the size of the PV merit order effect in Slovakia is considerably lower than in other countries, 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 reach much higher figures in sunny Italy or Spain 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.

Our study confirms that Slovak photovoltaic generation contributes to lower price of energy, which is a standard result in literature. However there exist empirical studies reaching different conclusions. Milstein and Tishler (2011) show on Israel data that introduction of photovoltaic energy may increase the average electricity price. The reason for this increase are sizeable electricity price spikes in the hours when photovoltaic generation is not physically possible or is insignificant. The Milstein and Tishler (2011) model is based only on two power sources - photovoltaic generation (5% of Isreal electricity generation capacity as of December 2016) and combined cycle gas turbine. Very high (66% as of December 2016 (LNRG, 2018)) share of natural gas in Israel electricity generation (coal accounts for additional 27%) makes it very different from Slovakia and other European countries. Closer to the Slovak conditions is the case of Czech Republic, where Lunackova et al. (2017) also show that increase in photovoltaic production does not decrease the price of electricity. While Czech Republic is similar to Slovakia in generating more than 1/3 of its electricity in nuclear power stations, it has higher share of coal generated electricity and more diversified portfolio of renewable electricity (not including hydro) than Slovakia. Consequently, while Lunackova et al. (2017) do not confirm merit order effect for Czech photovoltaics, they confirm it for other renewable resources.

Untangling the effects of different policies and determining equilibrium market price of electricity in the absence of any government intervention, which is a crucial precondition for comparing economic viability of photovoltaic electricity, is an extraordinary demanding task. However it is much easier to identify the countries with the best progress towards the photovoltaic electricity viable without government support. Vartiainen et al. (2016) show that among European countries, Germany, Italy, Spain and United Kingdom are closest to the situation of levelised cost of photovoltaic electricity reaching true grid parity with retail electricity price.

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 have been fiscally suboptimal, causing a sizable consumer loss as reflected by this study. On the other hand, the technology development, the number of 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 advantageous for the environment.

After the political decision of supporting the Slovak photovoltaics during the start-up period 2009-2011, the "solar boom" political publicity concerned with high public finance support for photovoltaic commercial installation around 2010 led to substantial reversion of this trend and a conservation of Slovak photovoltaic installed capacity on the stable level since 2011. There are no indications pointing towards the change in the Slovak photovoltaic production or in the uptake on wind energy in the foreseeable future. To conclude – while EU renewable electricity targets are tailored with regard to national geography, the political decisions concerning the related support schemes should be optimized in order to minimize politically sensitive national discussions of the cost of photovoltaic policies.

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Appendices

A Stakeholders in the Slovak electricity system

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., which covers 69.1% of the country's generation as of 2016. Slovenske elektrarne, a.s. has two shareholders. Slovak Power Holding B.V. ("SPH") is the majority shareholder; it owns slightly above 66% share of the Slovenske elektrarne, a.s. EP Slovakia B.V. (a subsidiary of Europsky prumyslovy holding Group) owns a 50% share of the registered capital of SPH and the remaining 50% is owned by the Enel Group — one of the world's largest energy companies. The minority shareholder is the Slovak Republic, represented by the Ministry of Economy of the Slovak Republic, owning slightly less than 34% of the shares(SE, 2017).

The sole holder of the national electricity transmission permit is Slovak electricity transmission system, PLC (SEPS, 2018), a company fully 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, 2018) organizes and evaluates the short-term cross-border electricity market as well as provides the clearing of imbalances in Slovakia.

The distribution grid incorporates three regional distribution system operators (DSOs) which 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.