The Merit Order Effect of Czech Photovoltaic Plants

Petra Luňáčková[*,a], Jan Průša[a] and Karel Janda[a,b]

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Abstract

We assess the impact of photovoltaic power plants on the electricity supply curve in the Czech Republic. The merit order effect is estimated as the elasticity of electricity spot price with respect to change in supply of electricity from renewable sources. Data for the Czech electricity spot market from 2010 to 2015 are analyzed as this is the period with the steepest increase in a renewable generation capacity. The effect is estimated separately for solar and other renewable sources. We find a significant difference between these two groups. Our results show that based on hourly, daily and weekly data energy produced by Czech solar power plants does not decrease electricity spot price, creating double cost to the end consumer. However, the merit order effect based on averaged daily and weekly data is shown to exist for other renewable sources excluding solar (mainly water and wind). This contributes to the conclusion that the Czech renewables policy that prefers solar to other renewable sources may be considered as suboptimal.

Keywords: energy subsidies; photovoltaic; renewables; merit order effect
JEL codes: Q42; H23; M21

a Institute of Economic Studies, Charles University in Prague, Opletalova 26, 11000 Prague, Czech Republic.

b Department of Banking and Insurance, Faculty of Finance and Accounting, University of Economics, Prague, Naměstí Winstona Churchilla 4, 13067 Prague, Czech Republic.

∗ Corresponding author. Tel.: +420 222 112 330. E-mail address: lunackova.petra@gmail.com (P.Lunackova).

1 Introduction

Photovoltaic power plants in the Czech Republic were subsidized as a part of the EU "20-20-20" energy strategy implementation. The combination of a very generous public support scheme and a significant photovoltaic technology price reduction led to a solar boom (Timilsina et al., 2012; Janda et al., 2014). Nowadays, in the Czech Republic there are four times more photovoltaic plants than wind plants (in terms of the MWh production, for details see Table 5), in spite of the fact that in other central European countries wind plants prevail. Before legislation reacted to the photovoltaic boom (by the end of 2010), the Czech installed solar capacity rose from 40 MW in 2008 to 1960 MW in 2010 (ERU, 2015). The Czech subsidy for solar electricity dropped from initial 15,565 CZK/MWh (i.e. about 620 euros) in 2006 to zero for newly built commercial photovoltaic plants in 2014 (ERU, 2013).

Progressively more ambitious goals of the Energy Strategy of the EU (2014) indicate the growing importance of energy sustainability and of renewable energy sources (RES) support. This paper contributes to the current merit order effect (MOE) discussion through the analysis of the Czech electricity market with the focus on renewable sources, in particular solar power plants.

The merit order effect of renewable energy sources stems from their almost zero short run marginal costs (SRMC) (given by the nature of sunlight, wind or water). Consider the merit order (supply) curve which ranks power plants according to their short run marginal costs. Because of very low SRMC, RES enter "first" (from the left) shifting the entire supply curve to the right.

This shift of the supply curve to the right that happens when RES enter the market, ceteris paribus, causes price decrease. This is the mechanism of the merit order effect, for graphical illustration see Figure 1. Large amounts of renewable energy may push the marginal (price setting) plant out of the market and cause a price decrease. This effect is reinforced by fixed spot demand.

The exact marginal costs differ but there is some general merit order as illustrated by Figure 1, from the left to the right according to the typical SRMC: supported renewable sources – solar, wind, hydro –, baseload nuclear plants, lignite and coal (often marginal) and peaking gas and oil (marginal in case of no wind, no sun and high demand). Merit order curve is not "fixed" but in the short-run, it is usually fairly stable.

Given the specific Czech electricity market conditions, our analysis focuses on the photovoltaic power plants. In 2013 photovoltaic plants produced less than one quarter of the total volume of the supported energy sources in the Czech Republic but they received more than 60% of 37 billion CZK subsidies paid (OTE, 2013) as shown in Figure 2. Current Czech RES production shares are quite surprising when compared to the predictions made before the solar boom. Back then Czech Republic expected the biomass to constitute about 80-85% of RES (Havlíčková et al., 2011).

The MOE in theory decreases electricity wholesale price (i.e. it is negative) which benefits the consumers, yet at the same time, RES causing the MOE are financed through electricity surcharge and subsidies which are passed on the end consumers, causing additional costs to consumers. Thus, do benefits outweigh the costs? There are studies that claim that MOE off-

Figure 1: Merit order effect mechanism (illustrative scheme)

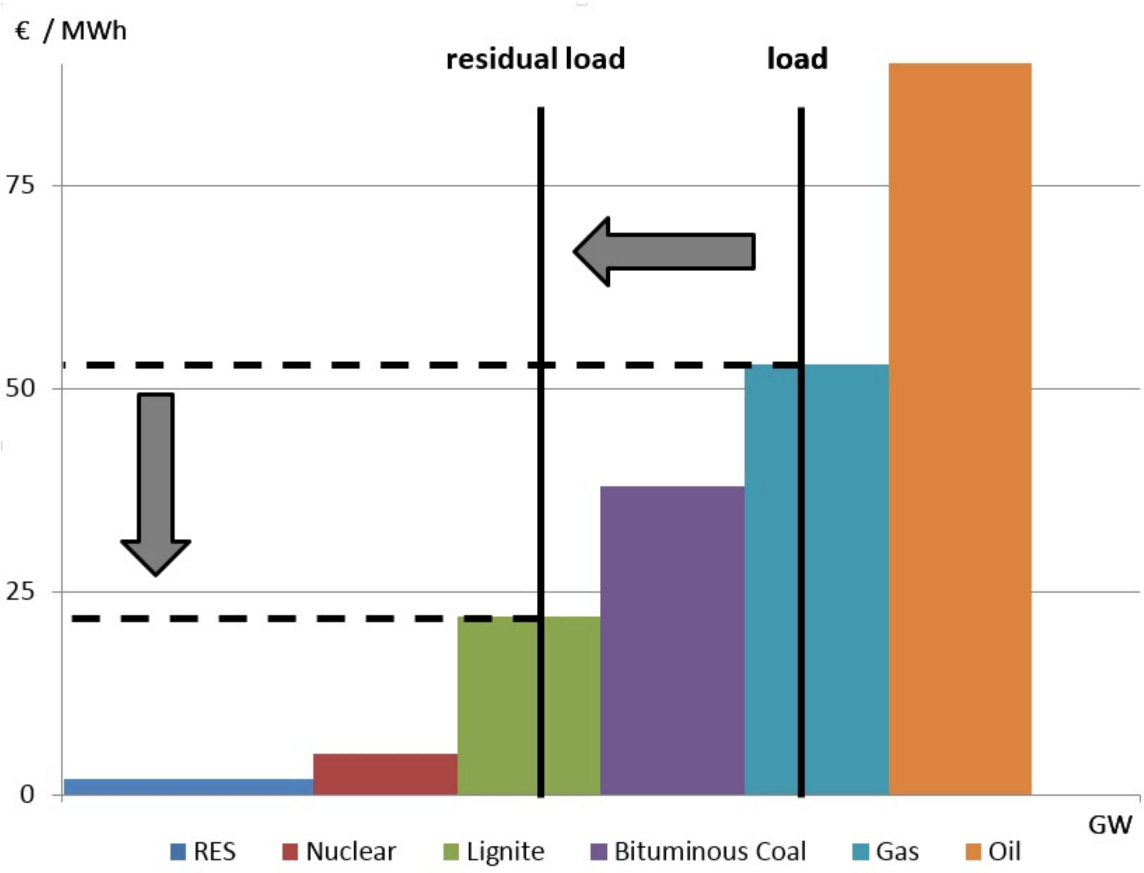
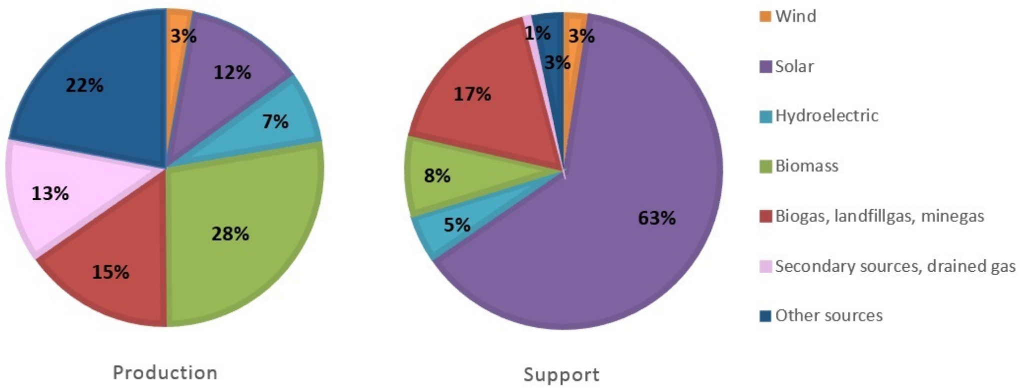


Figure 2: Shares of volumes produced (left) and shares of support paid (right) by type of RES or secondary sources, Czech Republic, 2013



Source: OTE Annual Report 2013

sets the cost of subsidies like Dillig et al. (2016) or McConnell et al. (2013), there are also studies like Clò et al. (2015) which distinguish between RES plants whose MOE counterbalances the costs of support (wind) and those that does not (solar) and finally there are studies such as Munksgaard and Morthorst (2008) that show that cost of subsidies are compensated by the MOE only to some extent. There is not a general agreement as the effect is always case specific reflecting market design, feed-in tariffs, rules and other conditions.

Our results suggest that not only is the overall Czech MOE fairly small, but in addition, it does not apply to all RES. Specifically, we find the relationship between electricity wholesale market spot price and photovoltaic production to be non negative (i.e. higher quantity does not lead to lower price). As a result, solar electricity creates a double cost to the end consumer — both through the subsidy and through the inverse merit order effect.

The rest of the paper is structured as follows. Section 2 introduces the Czech energy market and renewable sources policies. It is followed by Section 3 which focuses on the relevant literature. Section 4 describes the utilized dataset, followed by Section 5 on methodology. Section 6 presents the results, Section 7 provides further discussion of the results and Section 8 concludes.

2 Czech Energy Market and Renewable Sources Policies

2.1 Market Design

The Czech electricity market is characterized by a very positive attitude towards nuclear power (Keller et al., 2012), by a dominant position of brown coal in the Czech electricity generation (Bejbl et al., 2014; Recka and Scasny, 2016) and by a strong role of electricity export since the Czech Republic ranks sixth in the world and fourth in Europe in electricity exports (Sivek et al., 2012b). For the amount of Czech electricity export and its share on consumption see Table 1. In the long run Czech electricity demand is expected to grow slowly (CEPS, 2015b) but given that the country is a net exporter the reserve margin is significant, see also Table 2 on installed capacity and actual production.

The difference between installed capacity and production is significant, however, better way of describing the available capacity overhang is through Figure 3 which pictures the expected overall Czech available power in 2015 as the sum of the necessary reserves, national load (gross consumption) and what "remains" can be perceived as possible trade opportunity. Figure 4 displays the excess supply i.e. what remains when national load and necessary reserves are covered. The expected total available production includes all planned outages and maintenance and it is based on detailed information from individual generators provided to the Czech Electricity Transmission System (CEPS, 2015b).

Full liberalization of the Czech electricity market was reached in 2006. Since then generation, transmission and distribution are vertically unbundled and consumers are free to choose their supplier. Transmission and distribution are regulated (due to their network nature), generators and suppliers operate in free market. Electricity produced by the generators is traded in electricity wholesale market (KU Leuven Energy Institute, 2015). Czech electricity market is energy-only market, which means that utility companies are paid for generated electricity, as opposed to the capacity market design used elsewhere under which the utility companies would be paid for maintaining reserve capacity.

Similarly to a majority of the European electricity markets Czech electricity market employs a price based approach which motivates generation up to the point where SRMC and price of an extra MWh of electricity are equal (Cramton et al., 2013). This in combination with quite inflexible demand contributes to significant price volatility and variability during a day/week/season. In order to avoid scarcity or even electricity blackouts, there is a system of markets which insures that electricity supply and demand are always in equilibrium.

Majority of the Czech electricity demand is covered by over-the-counter trading contracts (around 70% (OTE, 2015b)). These contracts are settled before the actual delivery, without knowing the exact amount of electricity needed at the moment of delivery. A day before the delivery suppliers correct their portfolio in day ahead market and on the delivery day they correct it in the intra-day market. The remaining mismatch between supply and demand is covered by the balancing market where positive and negative imbalances of various participants are matched and resulting system imbalance is covered by the reserves of the Czech Electricity Transmission System (CEPS). Market participants are charged for their imbalances which motivates them to be balance responsible (OTE, 2015b).

As opposed to US or Australian "gross pool" approach to system balancing which ignores the bilateral contracts signed by system users and traders, the Czech system uses "net pool" approach which measures imbalances as the difference between a system participant's net contract position and his net physical output. Net contract position is given as sales minus purchases while net physical output is computed as production minus consumption. The difference between contract and physical position is recorded as an imbalance. This imbalance is settled at a price which is determined not by a market, but by a set of rules included in the compulsory balancing and settlement agreement.

In the Czech system the subjects of settlement are rewarded or penalized according to the type of their own imbalance. If a subject of settlement helps to bring the grid to stability, it is rewarded for it. However, if its imbalance has the same direction as the overall one, it has to pay a penalty. Czech electricity and gas market operator (OTE) defines market participants, who are responsible for their own imbalance as subjects of settlement. Not every electricity producer or consumer is a clearance subject. However, every production or consumption has to be assigned to a clearance subject. As of June 2015 OTE registers around 100 subjects. These are mostly energy trading companies, big producers or big customers. Czech households are not subjects of settlement but their responsibility is taken over by their supplier. Further details of Czech electricity balancing system and a quantitative estimation of the impact of solar production on Czech electricity grid system imbalance is provided by Janda and Tuma (2016).

The central market of Czech electricity system is the day ahead market, which is organized since 2002. This market is crucial also for our analysis as we work with price set at this market. The day ahead price serves as a reference price also for other markets such as for futures or for bilateral contracts.

The Czech day ahead "spot" electricity market is coupled with the Slovak, Hungarian and Romanian markets. Romania has been included since November 2014 as the latest partner (OTE, 2014). "Market Coupling trading means that bids for purchase or sale of electricity for the following day are matched jointly even from neighboring market places without the need to acquire transmission capacity, up to the level of of transmission capacity reserved for market coupling" (OTE, 2015b, p. 7) . Moreover, Czech market is naturally interconnected with the German market through electricity flows and export, which influences Czech electricity market spot prices. Detailed description of electricity transmission network in Central Europe with focus on Germany and Czech Republic is provided by Janda et al. (2016).

2.2 Renewable Sources Policies

Similarly to other EU countries, the Czech renewable sources policies are driven mainly by climate change concerns, especially by efforts to reduce greenhouse gas emissions and its associated social costs (Havranek et al., 2015). Besides the renewable electricity generation, which is the subject of this article, significant attention is paid to energy efficiency (Karasek and Pavlica, 2016) and to bioenergy. The wind and solar energy are fundamentally new energy resources with new economic policy constituency and issues (Torani et al., 2016).

Czech geographic conditions allow the installation of renewable energy plants which make use of weather, like wind or sun, however, due to the natural environment these types of plants yield only average results. The Czech solar policy had no foundations in intensity or hours of sunshine (Šúri et al., 2007). While photovoltaic energy is in general a subset of solar energy, there is no concentrating solar power (CSP) project in the Czech Republic (NREL, 2015) thus for us both terms are interchangeable and Czech solar means photovoltaic.

The EU indicative target for 2010 for the Czech Republic was set to 8% share of RES on consumption (Act, 2005) (to 13% for 2020 (Act, 2012)). In order to reach it, the government enacted economic incentives for renewable energy sources, which were supposed to motivate investment into RES, by passing the Act on Promotion of Electricity Produced from Renewable Energy Sources No.180/ 2005 Coll. (Act, 2005). Since then there is an explicit priority dispatch for all RES generation in the Czech Republic set in the law

(Act, 2012), according to which every MWh of green electricity produced has to be paid a guaranteed (subsidized) price, based on the year the respective generation capacity was put in operation.

The renewable energy sources are not competitive on their own (especially not the Czech solar plants as shown by Prusa et al. (2013)) so the support was very generous and fixed for every MWh of the green energy produced and supplied to the grid. As stated in Section 1, munificent support scheme together with photovoltaic technology price decrease gave rise to a boom.

The logic of the support scheme was changed in consequence of the solar boom. First, amendment of the Act (2005) introduced a solar tax of 26% for the period of 2011-2013 for solar plants with installed capacity over 30kW and launched in the boom years (2009-2010). Second, Act (2005) was replaced by the Czech legal Act No. 165/2012 Coll., on Supported Energy Sources. Third, amendment of Act (2012) extended the solar tax period, the tax remained valid for plants launched in the great boom year 2010 and in the amount of 10% it is to be paid till the end of their technical lifetime (20 years). Support for solar plants was significantly cut and canceled for all solar plants launched after 2013, see Table 4. Due to the solar boom, national target of 13% share of RES on Czech gross final energy consumption planned for 2020 was reached already in 2013, see Table 7.

Intense support in combination with solar boom created financial burden which was passed on consumers. Consequently the retail surcharge increased tenfold between 2009 and 2013, see Table 3. Fixed guaranteed price (feed-in tariff) was the sum of market price and subsidy, so with the electricity spot market price falling in 2011-2013 (OTE, 2015b) the surcharge was rising and

Table 1: Czech Electricity Production, Consumption and Export 2010-2015

Electricity in GWh	2010	2011	2012	2013	2014	2015
Gross production	85 910	87 561	87 574	87 065	86 003	83 888
Gross consumption	70 962	70 517	70 453	70 177	69 622	71 014
Export	14 948	17 044	17 120	16 887	16 300	12 516
Share of Export on Consumption	21%	24%	24%	24%	23%	18%

Source: ERU Annual Report on the Operation of the Energy System in the Czech Republic in 2015

since 2011 the subsidies were financed also through state budget (enacted by the amendment of Act (2005)).

Even though the support was cut, because of the previously launched plants with guaranteed price, the costs will remain high. Theory suggests that renewables could decrease wholesale price through MOE (and increased supply) and counterbalance the costs of subsidies to some extent. However, our research clearly shows that this does not hold in the Czech Republic because solar plants cause no MOE there and the MOE of other renewable plants is negligible compared to the subsidies.

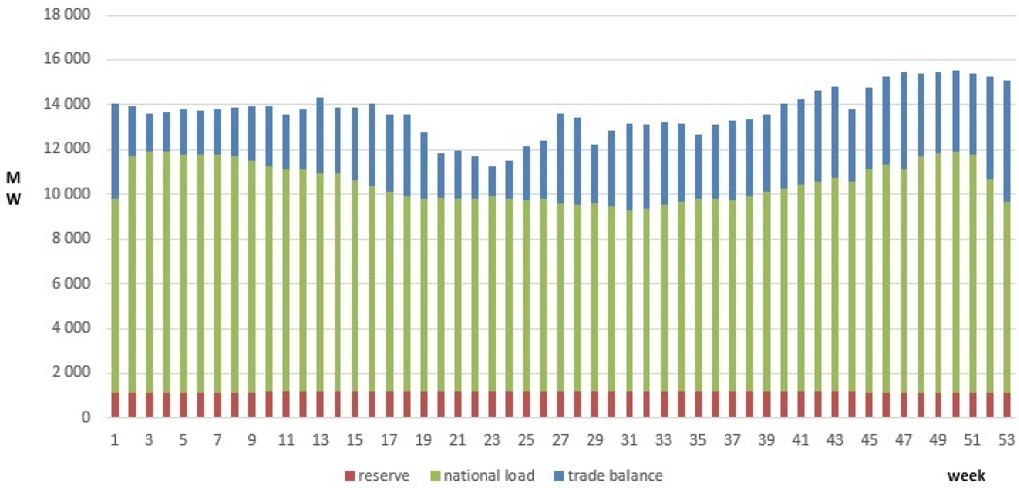
The case of the Czech solar power policy is a story of enormous costs, huge subsidies and even bigger scandals. It is a good example of how market principles can be misunderstood by political leaders (Smrčka, 2011). The EU strategy demanding growing share of energy to come from renewable sources was simply adopted with neither public discussion nor cost analysis (Sivek et al., 2012a). The mismatch between a guaranteed price of 620 euros (ERU, 2013) and a market price around 30-40 euros at the time, was highly beneficial for the solar power producers.

Table 2: Czech 2015 Electricity Production and Installed Capacity

2015	Production (GWh)	Installed capacity (MW)	Installed capacity share (%)
Nuclear	26 840.8	4 290.0	20
Steam	44 816.5	10 737.9	49
Combined cycle gas	2 749.0	1 363.3	6
Gas and combustion	3 574.7	859.9	4
Water	1 794.8	1 087.5	5
Pumped storage	1 276.0	1 171.5	5
Wind	572.6	280.6	1
Photovoltaic	2 263.8	2 074.9	10
TOTAL	83 888.2	21 865.6	100

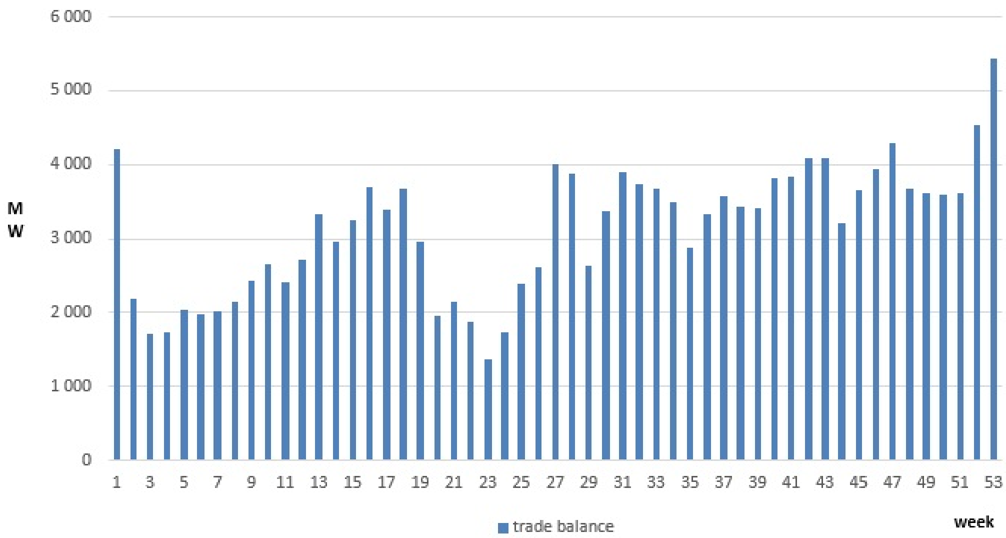
Source: ERU Annual Report on the Operation of the Energy System in the Czech Republic in 2015

Figure 3: Czech Electricity Power Balance, 2015



Source: CEPS Preparation of Annual Operation 2015

Figure 4: Power Balance - Resulting Possible Trade Opportunity, 2015



Source: CEPS Preparation of Annual Operation 2015

Table 3: Czech RES Financing 2009-2015

Year	2009	2010	2011	2012	2013	2014	2015
Consumer RES surcharge per MWh (CZK)	52	166	370	419	583	495	495
State budget RES subsidy (billion CZK)	0	0	11.7	11.7	11.7	15.7	15.7
Solar tax since 2011 (%)	0	0	26	26	26	10	10
Support paid (billion CZK)	3	9	32	35	37	41	44

Note: Solar tax was applied based on the launch year, given rates apply to 2010 launch year. Consumer surcharge in 2015 formed approximately 15% of the electricity price (without taxes) charged to consumers (ERU, 2014).
Source: Ministry of Industry and Trade, Energy Regulatory Office and Czech Electricity and Gas Market Operator

Table 4: Czech Solar Feed-in Tariffs 2005-2014, in CZK

Based on the launch year	Feed-in tariffs in CZK, solar plants > 30kW
2005	7 418
2006	15 565
2007	15 565
2008	15 180
2009	14 139
2010	13 161
2011	5 837 - 6 264
2012	0
2013	0
2014	0

Source: Price Decision of the Energy Regulatory Office no. 4/2013 dated 27.11.2013

When the conditions of the solar plants' support were about to be changed (since January 1st, 2011) there was a fierce chase for the launch of the plants under the "old" favorable terms. Investors wanted to be eligible for higher support and focused on the launch day stamp, sometime through illegal practices. Consequently there was a significant number (and production volume) of photovoltaic plants which were officially listed as in operation by December 31st, 2010, however, they were fully finished and started to produce only several months later during 2011 (CTK, 2014). While these frauds, scandals and law-breaking cases may compromise the validity of photovoltaic capacity data for the year 2010, they do not influence the actual production data reported in our Table 5 and the data used in our empirical analysis.

3 Literature Review

While the studies dealing with RES differ in methods, data (both frequency and source) and objectives, their general conclusion is similar – renewable electricity has a tendency to reduce the wholesale prices on the spot market via the merit order effect. The impact of MOE is greater when the system approaches its capacity limits. Since the different results reported in the literature may be influenced by the choice of data frequency used for the estimation of MOE, in our paper we compare the results obtained both with original hourly data and with their daily and weekly averages.

The influence of wind on electricity prices is an issue mainly in Germany, Spain, Australia and Denmark, where the wind penetration is high. In general, the number of wind analyses exceeds the solar studies by far. However, due to the specific situation on the Czech electricity market described above in detail, we focus on the solar side of the production. Table 5 provides a detailed structure of the Czech electricity production between years 2001 and 2015.

Tveten et al. (2013) study the solar feed-in tariffs (2009-2011) and the MOE in Germany. They develop a model to predict electricity prices in Germany with and without solar electricity production. Their results show that the daily price volatility has decreased and average electricity prices have fallen by 7%. We test whether there is a similar effect present in the Czech market.

Mulder and Scholtens (2013) investigate a suspected increased sensitivity of electricity spot prices to weather conditions, in the Netherlands between

Table 5: Production of Czech power plants 2001-2015, in GWh

Year	Steam	Nuclear	Gas	Water	**Solar**	Wind	Total (GWh)
2001	55 114.3	14 749.3	2 316.0	2 467.4	**0.0**	0.2	74 647.2
2002	52 409.8	18 738.2	2 352.9	2 845.5	**0.0**	1.6	76 348.0
2003	53 045.6	25 871.9	2 511.0	1 794.2	**0.0**	3.9	83 226.6
2004	52 811.0	26 324.7	2 624.6	2 562.8	**0.1**	9.9	84 333.1
2005	52 137.2	24 727.6	2 665.4	3 027.0	**0.1**	21.3	82 578.6
2006	52 395.4	26 046.5	2 612.1	3 257.3	**0.2**	49.4	84 360.9
2007	56 728.2	26 172.1	2 472.9	2 523.7	**1.8**	125.1	88 023.8
2008	51 218.8	26 551.0	3 112.7	2 376.3	**12.9**	244.7	83 516.4
2009	48 457.4	27 207.8	3 225.2	2 982.7	**88.8**	288.1	82 250.0
2010	49 979.7	27 988.2	3 600.4	3 380.6	**615.7**	335.5	85 900.1
2011	49 973.0	28 282.6	3 955.1	2 835.0	**2 118.0**	396.8	87 560.6
2012	47 261.0	30 324.2	4 435.1	2 963.0	**2 173.1**	417.3	87 573.7
2013	44 737.0	30 745.3	5 272.4	3 761.7	**2 070.2**	478.3	87 064.9
2014	44 419.3	30 324.9	5 699.1	2 960.7	**2 122.9**	476.5	86 003.4
2015	44 816.5	26 840.8	6 323.7	3 070.8	**2 263.8**	572.6	83 888.3

Source: ERU Annual Report on the Operation of the Energy System in the Czech Republic in 2015

2006 and 2011, taking into account the situation in Germany as well, due to the interconnection of the markets (there is a similar interconnection between the Czech and German electricity markets). With the use of daily price averages, they conclude that the German wind negatively affects Dutch electricity spot prices. However, they do not find any similar effect in the case of sunshine intensity.

Keles et al. (2013) simulate wind data using an autoregressive approach. They estimate the MOE on the German data for years 2006-2009, obtaining results showing that electricity price drops by 1.47 EUR/MWh per additional GWh produced by RES. Also Würzburg et al. (2013) aim at determining the size of the MOE in the Austrian-German region. Their multivariate regression model using prices in form of daily averages estimates the MOE to be 2%. Based on data between VII/2010 and VI/2012 they show that electricity price drops by 1 EUR/MWh per additional GWh produced by RES.

Sensfuss et al. (2008) analyze the price effect of RES on German spot market in detail. Their results are based on simulations and they show a considerable price reduction. Their calculations indicate that the price was on average lower by 7,83 EUR/MWh due to RES in 2006. They suggest that the MOE may exceed the net support payments. Other German authors such as Dillig et al. (2016) go even further and claim that had there been no RES, not only would electricity have cost more but the system would have even been on the verge of shortages.

Unlike others, McConnell et al. (2013) focus on photovoltaic plants and they model the MOE in Australian National Electricity Market retrospectively. According to the authors, the overall effect has been desirable – the system favors the consumers in the financial terms. They show that in 1% of the time, during high wind, electricity prices were even negative. Clò et al. (2015) analyze the Italian market, concluding that there is a solar merit order effect reducing Italian wholesale prices by the minimum of 2.3 euros per MWh for every GWh increase (2005-2013). They find the wind MOE to be even stronger – 4.2 euros per MWh for every GWh increase.

Moreno et al. (2012) take into account another factor – a degree of competition – and they are among the few whose results suggest that with the deployment of RES, the electricity prices increase by a small amount. Their empirical analysis of panel data from Eurostat (EU27, 1998-2009) shows that RES need not be beneficial.

Our brief literature review, supported also by current study by Welisch et al. (2016), indicates that most authors have found the presence of merit order effect, i.e. that RES decrease electricity wholesale prices. The literature also acknowledges the costs RES impose on the entire system. High volatility/variability puts reserves and balancing capacity under costly pressure, where under high wind RES overload the transmission system causing extra costs (Vrba et al., 2015). Also, RES negatively affect investment into other technologies, mainly by contributing to a generally high uncertainty of future prospects of energy markets. Critics also perceive the RES support as a regressive form of taxation (McConnell et al., 2013).

The literature on the Czech electricity market is very limited. Besides the study of Krištoufek and Luňáčková (2013), who analyze properties of hourly prices of electricity in the Czech Republic, the Czech data has only been viewed as a part of the EU or the Central European region datasets. To the best of our knowledge, there is no published journal article on the Czech merit order effect. Therefore, we contribute to its analysis and to the investigation of the MOE behavior in general. Our results in this paper highlight the sensitivity of MOE estimations to frequency (hourly, daily or weekly) of the data used in the empirical work and to suitable geographic conditions.

4 Data

The electricity spot market price in the Czech Republic, which is our variable of interest, is quoted in euros and it is thus not influenced by the exchange rate conversion or connected risk factors. In our analysis, we use publicly available data. We employ hourly spot price in EUR/MWh from OTE (Czech electricity and gas market operator) and generation in MWh from CEPS (Czech Electricity Transmission System). Specifically, we use detailed hourly total gross electricity generation within the Czech power system according to the individual power plant types – thermal, combined-cycle gas turbine, nuclear, hydro, pumped-storage, alternative, photovoltaic and wind power plant. Production data represent our explanatory variables. Table 6 summarizes the basic characteristics of the analyzed variables. Throughout the paper, price always refers to the electricity wholesale day ahead (spot) market price and generation means the entire Czech production (i.e. the sum of demand and export).

The dataset covers period from January 2010 to September 2015. This

Table 6: Summary of utilized variables, in MWh, 50 371 observations

Variable	Mean	Std.Dev.
Solar	197.4	350.4
Total production	9546.0	1318.8
Price (EUR/MWh)	40.0	16.1
Conventional	8201.5	1227.3
RES	1344.4	472.8
RES without solar	1147.0	369.5

five-year period has seen a historic development of solar generation in the Czech Republic, including the boom. While in 2009, the solar generation was simply insignificant (its share in renewables was below 2% and only 0.13% in the total consumption), in 2010 the upward tendency began at 10% share in renewables reaching 30% share in 2011 (ERU, 2015), see Table 7.

Given that there is a general agreement in the literature that for electricity production, consumption and pricing intra-day timing (the location of consumption and production peaks and troughs) matter, we first compute the MOE based on hourly data. Since some literature provides MOE estimates based on lower frequency data, we subsequently also provide a robustness check of our results by performing the regression analysis with daily and weekly averages. Such analysis (MOE on averaged data) was done by Würzburg et al. (2013) on German daily averages or by Gelabert et al. (2011) on Spanish data.

The rationale for using averaged data follows: under the energy-only market regime (which is the case of the Czech Republic) electricity prices on the day ahead (spot) market are extremely volatile, the volatility feature could actually interfere with the results, and therefore averaging limits the influence

Table 7: Share of photovoltaics in renewables and total consumption 2006 - 2015, in MWh

Year	Photovoltaics production	RES total	Consumption gross	RES share on cons.(%)	Photovol. share on RES (%)
2006	170	3 512 650	71 729 500	4.90	0
2007	1 754	3 393 509	72 045 200	4.71	0.05
2008	12 937	3 738 459	72 049 267	5.19	0.35
2009	88 807	4 668 514	68 600 000	6.81	1.90
2010	615 702	5 886 915	70 961 700	8.30	10.46
2011	2 182 018	7 247 504	70 516 541	10.28	30.11
2012	2 148 624	8 055 026	70 453 278	11.43	26.67
2013	2 032 654	9 243 382	70 177 356	13.17	21.99
2014	2 122 869	9 169 709	69 622 096	13.17	23.15
2015	2 263 846	9 422 950	71 014 254	13.27	24.02

Source : ERU Annual Report on the Operation of the Energy System in the Czech Republic in 2015

of the volatility on the results.

Volatility is typical for electricity generation in general but solar is regularly zero most of the day, increasing the volatility impact further. Such characteristic in fact goes against the standard assumption of the regression analysis which assumes the independent variables to have finite second moment, or in other words, an invertible design matrix. Even though the hourly solar data does not violate this assumption directly, it increases the variance of estimators considerably. Regardless the frequency of input data, our main conclusion remains qualitatively without any substantial change.

Electricity consumption is weather and temperature dependent and follows strong seasonal patterns (daily, weekly, yearly) (Lucia and Schwartz, 2002) which means that production of this non-storable commodity needs to follow the same patterns. Wind and solar power plants, intermittent sources, are totally weather dependent and non-dispatchable. Production of solar power plants is usually easier to accommodate as it is supplementary to peak hours, since the hours of sunshine correspond to the hours of high electricity consumption. Wind does not match the peak demand and it may oversupply the market causing negative prices peaking even at −100 EUR/MWh as reported by Nicolosi and Fürsch (2009). Contrary to RES, conventional sources like baseload nuclear plants, or coal and gas power plants are dispatchable but not truly flexible (Sovacool, 2009). Our dataset reflects the above-described characteristics, thus we expect to run into autocorrelation, non-stationarity and endogeneity problems.

Our analysis consists of four steps. First, we build the fundamental regression equation where we regress price on conventional production and renewable sources, and solve the related problems such as autocorrelation or endogeneity. Second, we split the renewable sources into photovoltaic and other RES, to quantify the MOE of photovoltaic plants. Third, we run our regression on hourly data and fourth, we perform the same analysis on daily and weekly data.

5 Methodology

Our model belongs to the class of parsimonious fundamental models which describe the basic relationship between production and price (Weron, 2014). The purpose is to understand the effect of renewable sources on the power price and to quantify this merit order effect. Schematically, we aim to decompose

$$P = P_c + M, \tag{1}$$

where P is the observed market electricity price, P_c is the projected price without the supply of renewable sources (with conventional sources only, c stands for conventional) and M is the merit order effect of renewable sources. However, P_c is unknown so that we cannot make use of the above split. Instead, we estimate the linear regression model

$$p = \alpha + \beta_c q_c + \beta_r q_r + \epsilon, \tag{2}$$

where ϵ is the error term, r stands for renewables, and price p as well as generation q are taken in logs to enhance interpretability. Given the variables in logarithmic forms, the MOE, represented by the β_r coefficient, could be defined as the elasticity of electricity wholesale spot price with respect to change in supply of electricity from renewable sources:

$$\beta_r = \frac{dP/P}{dQ_r/Q_r}. \tag{3}$$

Physical characteristics of electricity suggest that our time series is not stationary. Stationarity, broadly said, means that the series is mean-reverting, without periodic fluctuations or trends. However, electricity clearly shows seasonal fluctuations. We employ the Dickey-Fuller test (Dickey and Fuller, 1979) with a linear time trend for testing the non-stationarity. We further define a vector of dummy variables for months of the year (11 dummy variables), days of the week (6), years (5) and Czech national holidays (11).

Time series typically suffer from autocorrelated residuals. This is valid for the power time series even more strongly. For this purpose, we utilize the Durbin-Watson test (Durbin and Watson, 1971). As the residuals in fact suffer from strong serial correlation, we correct for it using the Prais-Winsten methodology (Prais and Winsten, 1954) which gives us estimates which are in addition robust to heteroscedasticity.

One of the crucial assumptions of the ordinary least squares regression to be unbiased and consistent is the mean independence of disturbances. One of the possible ways of interpreting such assumption is that the dependent (response) variable depends on independent (impulse) variables, and not vice versa. If the opposite holds, one has to solve the endogeneity problem. A classic cause of endogeneity is an uncontrolled for variable that influences both explanatory and explained variables. In our case, e.g. the dispatching rule might be the cause (see Clò et al. (2015) for a detailed discussion). One of the feasible methods to overcome the endogeneity problem is via the instrumental variables (IV) estimation.

On the one hand, we assume that q_r is given exogenously, both in the long run and in the short run. Long term supply in the Czech electricity market was driven mainly by subsidies defined by the law. Short term supply is driven by exogenous weather conditions (temperature, cloud cover, wind speed, etc.). On the other hand, supply of the conventional sources q_c is endogenous and correlated with the observed price p. As a valid instrument, we consider the total production Q (q in logs), which is by definition highly correlated with the production of conventional sources, but less so with p. The reason for lower correlation of p and q is that q contains exogenous components, such as q_r, planned outages, exports and available transmission capacities. Moreover, electricity demand is not motivated by a changing spot price as households have long-term contracts and consume electricity without any regard for pricing on the wholesale market. As we have found our instrument, we regress q_c on q in the first stage and in the second stage, we use the fitted values $\hat{q}_c$ for the estimation of MOE.

Building on the just developed approach, we add dummy variables and simple time trend to Equation 2, employ Prais-Winsten methodology and instrumental variables to estimate our model and to obtain the MOE. First, we look for the overall MOE:

$$p = \alpha + \beta_c \widehat{q_c} + \beta_r q_r + time + dummies + \epsilon, \tag{4}$$

where $\widehat{q_c}$ is obtained from the instrumental variable regression using the overall production. Our data contains not just the sum of RES production but figures for every type of green generation so that we can easily run the regression on the two types of renewables – "solar" and "others" – and estimate the solar MOE and MOE of other RES excluding solar, i.e

$$p = \alpha + \beta_c \widehat{q_c} + \beta_s q_s + \beta_o q_o + time + dummies + \epsilon, \tag{5}$$

where s stands for the solar, o for the other renewable sources and c for the conventional production.

6 Results

We first estimate Equation 4 without instruments on hourly data using the autocorrelation adjustment by Prais-Winsten. The Durbin-Watson (DW) statistic of 0.40 indicates autocorrelation, while the transformed statistic of 1.88 indicates a strong improvement. We follow by estimating the Equation 5 using the total production instrument. The null hypothesis of under-identification (that the instrument is not correlated with the instrumented q_c) is rejected even at 1% level. Similarly, the null hypothesis of weak identification (that the instrument is only weakly correlated with the instrumented q_c) is rejected even at 1% level.

The results are reported in Table 8, and show non-negative merit order effects both for solar with $\widehat{\beta}_s = 0.003$ and other renewable sources with $\widehat{\beta}_o = 0.08$. In particular MOE of solar plants is not statistically significantly different from zero (p-value = 0.224). In order to avoid over-specification of the model we dropped yearly dummies as not all of them were statistically significant and worked with dummies for hours, holidays, days and months. Dummies coefficients in Table 8 are skipped for the sake of brevity.

Reported results suggest that high volatility of solar production could have influenced the results. Therefore, it suggests that the model should be developed further, so we proceed with averaged data analysis to perform a check and get easily comparable results.

Electricity consumption, and hence also production, has a specific daily profile, see Figure 5 example, which reflects weather as well as working day habits (commercial demand during the day, rise of residential demand in

Table 8: Results of IV Regression, hourly data

	Coefficient	p-value
α	-3.3555	< 0.01
$\widehat{\beta}_c$	1.2495	< 0.01
$\widehat{\beta}_s$	0.0029	0.224
$\widehat{\beta}_o$	0.0811	< 0.01
Time	$-3.1\text{x}10^{-12}$	< 0.01
Holiday	-0.3807	< 0.01
Hourly dummies		all < 0.01
Daily dummies		all < 0.01
Monthly dummies		all < 0.01
Obs.	31 296	
$\bar{R}^2$	0.3776	

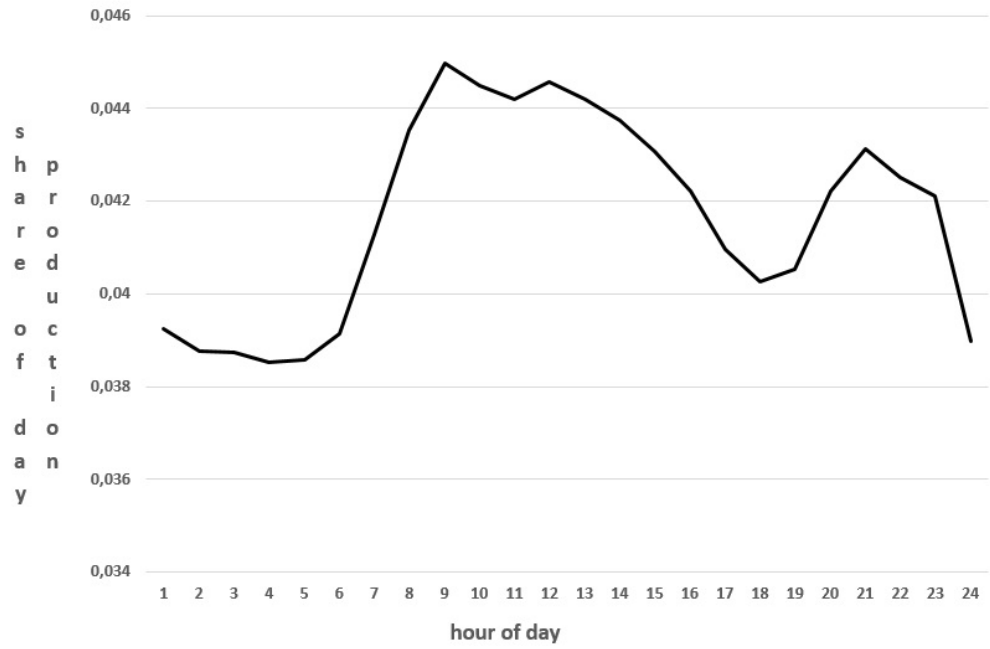
the morning and evening). Energy Regulatory Office publishes consumption profiles for every month based on previous years' data and weather. So there is no typical profile representative of every single day thus, data cannot be averaged using only one set of weights. Every hour of production is a share of total daily production, thus we weigh each hour of the day by its share on that day production, i.e.

$$\text{weighted daily average of variable } a = \sum_{i=1}^{24} a_{h_i} \cdot \frac{\text{production } h_i}{\text{day production}} ,$$

where h_i is the i-th hour of the day. The weekly average is then a plain average of daily data.

The results of the regression on daily data are reported in Table 9 and confirm the above: merit order effect of solar appears non-negative. Statisti-

Figure 5: Production Profile Example, Czech Republic, April 17th, 2014



Source: CEPS Generation Data

Table 9: Results of IV Regression, daily data

	Coefficient	p-value
α	-3.7543	0.0264
$\widehat{\beta}_c$	0.6031	< 0.01
$\widehat{\beta}_s$	0.0716	< 0.01
$\widehat{\beta}_o$	-0.2154	< 0.01
Time	0.0002	0.025
Holiday	-0.5664	< 0.01
Day2	0.0803	< 0.01
Day3	0.0907	< 0.01
Day4	0.0824	< 0.01
Day5	0.0551	0.0580
Day6	-0.0899	< 0.01
Day7	-0.4764	< 0.01
Year2011	-0.0172	0.6851
Year2012	-0.2998	< 0.01
Year2013	-0.5323	< 0.01
Year2014	-0.7077	< 0.01
Year2015	-1.0176	< 0.01
Obs.	2100	
$\bar{R}^2$	0.4392	

cally insignificant monthly dummies were dropped to avoid over-specification. Based on daily data regression there is a MOE present in the Czech electricity market but it is not global, meaning that not all renewable sources contribute to the merit order effect. Our results clearly show that the MOE of solar plants is non-negative, actually it has small positive effect on price, thus solars are not decreasing the price as expected. Other renewable sources are found to cause the MOE. With their production increasing, the electricity spot price decreases. Specifically, a 10% increase in production of other renewable sources results in a 2.2% price decrease.

Table 10: Results of IV Regression, weekly data

	Coefficient	p-value
α	9.9761	< 0.01
$\widehat{\beta}_c$	0.4435	< 0.01
$\widehat{\beta}_s$	0.0667	< 0.01
$\widehat{\beta}_o$	-0.2554	< 0.01
Year2011	0.4206	0.3054
Year2012	-1.0900	< 0.01
Year2013	-2.2573	< 0.01
Year2014	-3.0349	< 0.01
Year2015	-5.0653	< 0.01
Obs.	300	
$\bar{R}^2$	0.5030	

Our daily model explains 44% of the price variability (measured by adjusted R-squared) and all variables are statistically significant with the exception of the dummy variable for the year 2011. Moreover, the individual years effect corresponds to the fact that the wholesale price of electricity has been decreasing in recent years.

When we run the regression on weekly data, the results based on daily data are confirmed, in fact the effect even grows (because of the weekly data, we drop daily and holiday dummies). The adjusted R-square reaches 50% and all variables are significant with the exception of year 2011. For the weekly data, the merit order effect of other renewable sources is found to be - 2.5% with the inverse merit order of solar remaining + 0.7% (for 10% increase in production). Results are reported in Table 10.

Given that our results, at least at the first sight, contradict the MOE theory, following discussion presents the reasons why Czech solar MOE could be non-negative.

7 Discussion

The difference between solar and other sources and non-negative solar MOE is not as odd as it may seem. The Czech Republic is not a sunny country, according to the Czech Hydrometeorological Institute in August 2016 (the sunniest month of that year) Prague had 244 hours of sunshine, which gives on average less than 8 hours per day, and it had only 53 hours of sunshine in January 2016. As a consequence during an average day there are only about 5 hours with the solar production influencing the market (CHMI, 2016).

If solar sources shift the supply curve only for few hours, the overall effect in a day does not result in a permanent MOE. The opposite is true for other renewable sources that supply the system continuously and thus they have the ability to shift the supply curve more often and cause the MOE. This is in agreement with Clò et al. (2015) who finds different monetary savings of solar MOE and wind MOE (the former does not compensate for its incentives costs, the latter does).

Photovoltaic production is aligned with peak hours but given that solar plants generate only 3% of the country's gross consumption, see Table 5, solar alone (due to few sunshine hours) may not be enough to push the marginal plant out of the market (i.e. cause price drop). The marginal (type of) plant may produce less because it is dispatchable but will stay in the market thus, the price would also remain. Better said, Czech solar alone could push the marginal plant out of the market, had it been working at its (close to) full capacity. But weather conditions in the Czech Republic do not allow the solar plants to reach reasonable efficiency ratio (defined as production/installed capacity), see Table 2. Another way to view this result is that the additional solar capacity was not able to offset the negative (i.e. price increasing) effect of additional volatility caused by unpredictable production of photovoltaic plants.

Czech Republic is net electricity exporter (see Table 1) so the reserve margin is significant. Given that the Czech electricity market is generally used to excess capacity, see Table 2, extra excess capacity in terms of RES does not mean an important change of market conditions. In case of electricity the downward pressure of growing supply on price is weakened by its non-storability, necessity for instantaneous supply-demand matching and, in case of solar, also by limited production hours depending on sunshine. Should the Czech electricity production cover inland consumption needs only (theoretical case of no export), it is very probable that the electricity spot market price would be lower as a consequence of increased supply.

We would like to highlight that our results are still in accordance with fundamental economic principles in that the market as a whole behaves as expected. Solar electricity is just one part of the market where we do not observe a price increase in reaction to solar supply growth (solar non-negative MOE). Given moderate sunshine intensity, the solar plants should have never consumed 60% (see Figure 2) of the Czech subsidies devoted to RES promotion. This suggests that the Czech application of the solar support scheme was flawed.

Despite market liberalization the market share of the largest generators in the EU countries did not change much (valid also for the Czech Republic), see Moreno et al. (2012) who also conclude that a deployment of RES caused a small price increase for households. Moreover, this study supports our belief that country's fixed effect matters which is part of an explanation of why Czech situation differs from other results documented in the MOE literature. As mentioned above, one of the key differences of the Czech market is its share of exports and solar plants unfriendly weather conditions.

Our results may have important economic policy implications. If we care about being cost effective, then all renewables cannot be treated equally. As we have shown, only other (mainly continuously working) RES cause the MOE in the Czech Republic and thus bring some savings. Given that 60% of Czech RES subsidies goes to solar power plants, then we may consider the current situation suboptimal.

Let us return to the initial intuition from the Methodology section (Equation 1). How much would have wholesale electricity cost, had there been no RES? Our results imply that a 10% increase in production of renewable sources without solar results in a 2.5% decrease in electricity price. In 2014, the share of renewables without solar was approximately 11%. If we estimate this share to be 10%, then we can apply our results to find the electricity wholesale price without RES support. No RES means 0%, the RES support till today caused 10% increase of renewables without solar and we know that a 10% increase in production of renewables without solar saves 2.5%. Thus, thanks to RES without solar electricity, wholesale price today is by 2.5% lower than it would be otherwise.

Let's consider the 2013 (rough) figures, the price of an average MWh was

30 euro, then the savings are 75 cents for every MWh. Given the total annual production of 87 000 GWh, overall savings per year are about 65 million euro. Compared to the subsidies that amount to 2 billion euro, the RES support is shown to be a political decision.

8 Conclusions and Policy Implications

This paper assesses the impact of renewable energy in general and photovoltaic power plants in particular on the electricity supply curve, verifying the presence of merit order effect (MOE) in the Czech market. We estimate the MOE as elasticity of electricity spot price with respect to the change in supply of electricity from the renewable sources. We quantify the MOE based on hourly, daily and weekly data covering the time span of six years from 2010 to 2015.

Our model builds on the instrumental variable method, adjusting for autocorrelation in the time series. The estimated MOE is of the expected negative size but unexpectedly we conclude that it is not a global effect, in the sense that not every renewable source of energy contributes to the MOE. Due to the significant position of solar power in the Czech Republic, we have worked with two groups of renewables – solar, and other renewable sources excluding solar.

The estimated merit order effect of solar renewable sources is non-negative, creating double costs for end consumers – surcharge/subsidies and wholesale price non-decrease. Our results confirm the negative MOE for the remaining renewable sources, denoted as other RES – a 10% increase in production of other RES results in a 2.5% electricity price decrease. As a consequence, we can respond to the fundamental question – how much would electricity cost without RES? The share of RES causing MOE is approximately 10%, thus wholesale electricity costs about 2.5% less due to MOE.

Our results do not support the preferential treatment solar enjoyed in the Czech Republic. If we care about being cost effective, then the dominance of solar plants is not recommended as we have shown that the solar RES do not contribute to the MOE. Other mainly continuously working RES cause the MOE and thus bring some savings. Given that 60% of the Czech RES subsidies go to the solar power plants, we may consider the current situation suboptimal. Czech renewables, driven by the public support scheme, are the case of incorrectly implemented policy that should be avoided. We believe it is worth stressing as it is a policy mistake in the first place and it gives a valuable policy lesson.

Compared to the results of other countries, Czech absolute value of the MOE seems lower. This is driven by the dominance of solar plants which is not based on geographic conditions. Most likely the mix of renewable sources elsewhere reflects the natural environment better so that each RES can contribute to the MOE. For example in Germany, wind is the prevailing RES, it influences price also during the night which drives down the average price and the absolute value of the MOE up. In any case, lower wholesale price on the spot market does not directly affect consumer price, as the electricity contracts are long term and Czech wholesale price represents only 45% of the final consumer price. The remaining part is regulated and RES account for 15% of the final price (for the composition of Czech consumer price in 2015, see ERU (2014)).

MOE of solar power plants in the Czech Republic is found to be non-negative which points towards an inappropriate Czech solar policy. Results of our analysis reflect improper RES support implementation. Given Czech solar evolution we could have barely obtained textbook RES implementation results leading to lower prices. Our paper shows that Czech MOE savings do not outweigh the RES support costs. Their beneficial influence is minimal and it is outweighed by the negative impact in the form of costs of RES subsidies. Investment in other technologies for energy production suffers too (Winkler et al., 2016), as allegedly "free" green energy is difficult to compete with. The most important effect of the Czech RES support was not the shift of the supply curve, but the structural change of the market and 28 000 (OTE, 2015b) new solar plants in the Czech Republic.

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