Market viability of photovoltaic plants: merit order effect approach

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3 November 2016

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Abstract. We consider future prospects of solar energy in Central Europe. We first provide the description of the Czech energy situation with emphasize on photovoltaic energy. After that we estimate the merit-order effect. In last five years the Czech wholesale price of electricity decreased on average by 0.009 EUR/MWh. The total average merit-order effect over five-year period was 4.544 EUR/MWh. The effects were more pronounced in later years. New Czech solar projects are not viable without subsidies and new projects would not be able to profitable without public support. Thus solar power plants do not appear to be a reasonable choice in the Czech Republic. Nevertheless, low Czech wholesale electricity prices make all electricity sources not competitive.

Key words: solar; photovoltaics; electricity; merit order effect

JEL classification: Q41, Q42, Q47

[#] This project has received funding from the European Union's Horizon 2020 Research and Innovation Staff Exchange programme under the Marie Sklodowska-Curie grant agreement No 681228.We also acknowledge support from the Czech Science Foundation (grant 16-00027S) and from University of Economic, Prague (institutional support IP100040). Karel Janda acknowledges research support provided during his long-term visits at Australian National University and McGill University. The views expressed in the paper are those of the authors and not necessarily those of our institutions.

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1. Introduction

In the recent decade most discussed questions in the field of the electricity production were the sustainability and the climate change. Policymakers in line with the acceptance of the idea of anthropogenic climate change started to implement measures, which were thought to mitigate the climate change and also limit the dependence on fossil fuels and increase the sustainability.

Notably the European Union set the goal of renewable sources production to 20 % of overall consumption until 2020 for its members. This thesis' aim is to investigate the future of one type of renewable sources – solar energy. We will evaluate the potential and reasonability of choosing photovoltaic plants. Our analysis will be regionally limited, we will not asses the future of solar energy in the global context but the thesis will be aimed only to Central Europe. To be exact, the Czech Republic will be examined as the representative of the Central European region.

The goal if this paper is to assess viability of the solar energy in the context of current market environment. That is whether solar projects could be started now without a public support. The renewable energy can be analyzed form many points of view. The past authors who investigated this topic used the perspective of climate change, green jobs, energy mix, intermittency and grid integration and others. This paper focuses on the income and cost site of solar power plants. The main focus of this paper is on the merit order effect of photovoltaic electricity.

2. Literature review

Jenner (2012) performed econometric analysis of longitudinal data to assess the effect of feed-in tariffs on the new installations in Europe. The findings of the study were not surprising, EU-wide sample showed that feed-in tariffs efficiently supported biomass, geothermal and photovoltaic generation and without subsidies the construction of the sources would have never happened.

Průša, et al. (2013) compiled economic assessment of PV plants using financial statements data from 2010. The paper suggests that proliferation of photovoltaic plants translate in the loss in general welfare and the annual lost amounts to 11 % of the initial investment. Even if, the paper's methodology is reliable because of the use of audited financial statements data, the computation omits timing aspect of production, climate benefits or the aspect of energy security. These aspects are relevant for the cost-benefit analysis but their value is difficult to determine and there is not a consensus on doing so.

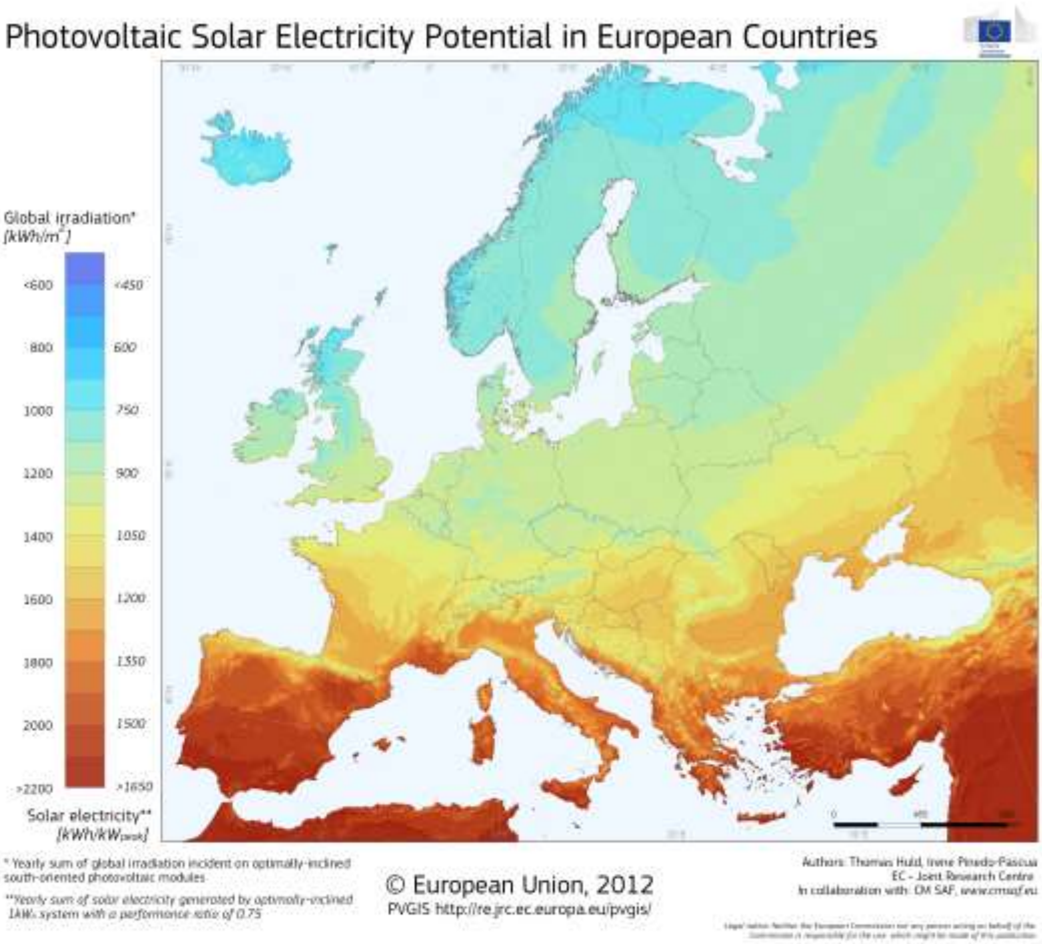
The authors determined that in order to achieve economic profit, wholesale prices of electricity had to increase or technology costs have to decrease approximately ten times.

Janda, et al. (2014) determined the public expenses spent on the promotion of solar energy in the next decade. The Czech Republic, in an attempt to achieve the goal set by the European Union, which is 20 % renewable share of total electricity production, created the system of feed-in tariffs that guarantee the sale price to producers. The guarantees are issued for expected lifetime of the power plants – 20 years. This setting causes that in following years there will be 20 bn. CZK annual outflows of public funds to photovoltaic plants' operators. The outflow amounts to approximately 2% of the central government yearly budget.

Still, feed-in tariffs were not used in only in Central Europe. This scheme was used European Union-wide to support proliferation of renewable sources of electricity, not only PV plants but biomass, geothermal and wind as well so some other EU-states also deal with the redistribution of funds connected to new green power plants.

The location factor and intermittency are two important features that are renewable and solar specific. The location of solar cells directly influences the output of the plant. The production is higher in sunny parts of Europe such as Italy, Spain or Greece whereas in Central Europe the level of insolation is lower.

Figure 0.1: Photovoltaic solar potential in European countries



Source: European Commission

Intermittency stems from the fact that PV plants can produce only during the daylight and that the production depends on physical conditions. Besides the insolation, it is notably temperature, which influences the output.

However the peak of the production occurs almost in the same time when the demand peaks. Borenstein (2012) proposes that this concurrence increase the value added by PV plants by up to 20 % because the production of solar plants is sold when the prices are high as well.

Despite this plausible positive aspect, intermittency also brings some negatives. Since it is not possible to predict weather with certainty, it is not possible to forecast the output of the plants either because their production is tied with the weather. This unreliability can be solved by having backup generators in place. However their planning, construction and maintenance are other costs which should credit the liability account of solar energy, On top of that, backups increase overall capacity and having unused capacity that does not supply on regular basis requires additional maintenance costs.

Moreover, variable output of renewable resources can create higher pressure on grid stability. Still, solar plants are more grid stability-friendly than wind ones, whose output is regionally more correlated and the output patterns are less correlated with demand. Borenstein (2012) proposes that effect on grid stability starts to be material when the production of renewable sources exceeds 20 % of total.

2.1. Influence on the price of electricity

Jenner (2012) showed that policies in Europe definitely contributed to the emergence of solar energy but the proliferation brought also negative aspects.

Kalkuhl, et al. (2013) stress that subsidy schemes were designed to promote selected technological solutions. They state this manner of subsidies leads to the race to the bottom, when the recipients of the support are indifferent to the current market prices because their price is guaranteed and moreover they have guarantees that their output will be bought.

Borenstein (2008) states that excess capacity leads to lower wholesale price of electricity, which is the trend we witness now in Central Europe. The exact numbers will be shown in the econometric part.

There is a consensus that renewable sources lower the wholesale electricity price in the short-term but aforementioned but lower prices may have other consequences. Depressed prices may discourage future investments and make it difficult to recover already invested capital.

Moreover due to higher volatility of the production, increased back-up capacity may be required. Green & Vasilakos (2011) propose that thermal capacity would fall slightly if more intermittent sources were to be built. However, there would be a shift towards power stations with low fixed and high variable costs. The need for investment into new sources and high variable costs drive prices in an opposite direction than original merit-order effect caused by intermittent sources.

Nevertheless, Wurzburg, et al. (2013) note that this is another complex issue which makes it difficult to calculate costs and benefits of renewable sources. Wurzburg, et al. (2013) list 17 studies written in the last ten years that researched the effect of renewable electricity generation on the wholesale price. Even if the studies were not carried in the same regions, its comparison is interesting.

Thirteen papers concluded that deployment of renewables induces the decrease of the price. Three studies did not have a clear result. According to them renewables could drive prices up or down depending on other conditions such as penetration, energy prices or the type of customers.

Only the article published by Milstein & Tishler (2011), which focuses on the long-term development of prices suggest that large deployment of PV power stations may lead to higher average prices. Furthermore the data from Israel were used in the study and Israel is a country with higher insolation than the Czech Republic.

Investment in the renewable sources in Europe has been associated with subsidies and redistributive implications. Cludius, et al. (2014) provide the summary of studies on the merit-order effect in Germany, the market adjacent to the Czech Republic. The synthesis shows that merit-order effect lowered the price between 2001 and 2012 by 2 – 13 EUR/MWh.

Still the reduced wholesale price does not have to lead to lower electricity bills because of the green surcharge. The surcharge is the form of tax, which is added to the wholesale price. The surcharges are used for financing the subsidies such as feed-in tariffs. Wurzburg, et al. (2013) note that the scheme for the support of renewables may lead to the reduced wholesale price but in the same time to higher consumer price. In 2014, transmission operators reported surcharge for non-privileged customers (mainly households) was 6.24 ct/KWh, whereas for privileged customers (notably capital intensive industries) the surcharge was only 0.05 ct/KWh.

In addition to the lowering prices in the short-term, the intermittency feature of photovoltaic power plants makes predicting the total output more difficult and increases the uncertainty of the supply. Ketterer (2012) demonstrates that higher penetration of intermittent sources may lead to the increased volatility of wholesale prices but also suggests that regulatory measures may lead to its stabilization.

The article notes that in Germany the operators of PV plants are not exposed to the market-risk due to guarantees of feed-in tariffs. The same applies to the Czech Republic. Hiroux & Saguan (2010) suggest that market-based support, where the producers of the intermittent energy are exposed to the certain degree of the market risk, is more welfare efficient. The key proposition of the article is that the costs for integration should be shared by the transmission operator and the operator of the power plant.

2.2. Grid parity

The grid parity, also called socket parity, is the state when the renewable source of electricity becomes cost-competitive with conventional sources.

Even if there are some proponents that suggest the grid parity of PV modules was achieved at least in some regions. High share of authors still believe that there is a gap in front of reaching grid parity.

In long-term prediction Lund (2011) forecasts that photovoltaic energy will reach full-cost breakthrough in 2032 in the global scale. However, reaching the goal is conditioned with the public support of 1432 EUR billion. Nonetheless, the grid parity is not one single fixed number. The parity is dynamic variable, with the increasing renewable capacity the demand for traditional resources such as coal goes down. Lower operating costs of conventional sources mean that level of grid decreases as well. In this context, Olson & Jones (2012) argue that the dynamics of the grid parity may prevent solar energy from competing on the cost basis only.

Yang (2010) notes that reaching cost-competitiveness does not guarantee market viability. The author uses the example of solar hot water technology, which reached the grid parity but still has low market penetration. High initial costs and limited experience with the technology are mentioned as the plausible reasons for the fact. The author suggests that the same may apply also to the PV plants because the growth in penetration was mainly driven by support intencives.

On the other hand, Barnham, Knorr, & Mazzer (2013) defend the German version of feed-in tariffs. In accordance with aforementioned authors, they state that without public support the emergence of the renewable sources were not possible but they perceive the green subsidies in the positive way. They suggest that Italy and Great Britain should adopt the same system of feed-in tariffs to reach the goals of production from renewable sources between 2015 and 2020.

The paper claims that the parity grid was already achieved in Germany in the peak hours and in Italy overall on the grounds of levelized cost of electricity. On the basis of their results, the authors recommend that other countries should follow the path of Germany in order to contribute to the mitigation of the climate change. On top of that, they stress the importance of experiment in Germany, when the whole German demand was covered by wind, solar and biogas. They state that the grid was able to cope with the load from intermittent sources so the German grid is able to absorb the production from renewable sources. Moreover they claim the further penetration of renewables leads to the displacement of conventional sources as it was mentioned before in our literature review. The old-economy sources are not subsidy free either. Notably externalities such as pollution are charged by the taxpayers. The policy recommendation of the paper is the savings originally aimed to support conventional sources should be transferred into better infrastructure to allow the integration of other renewables.

3. Czech electricity market

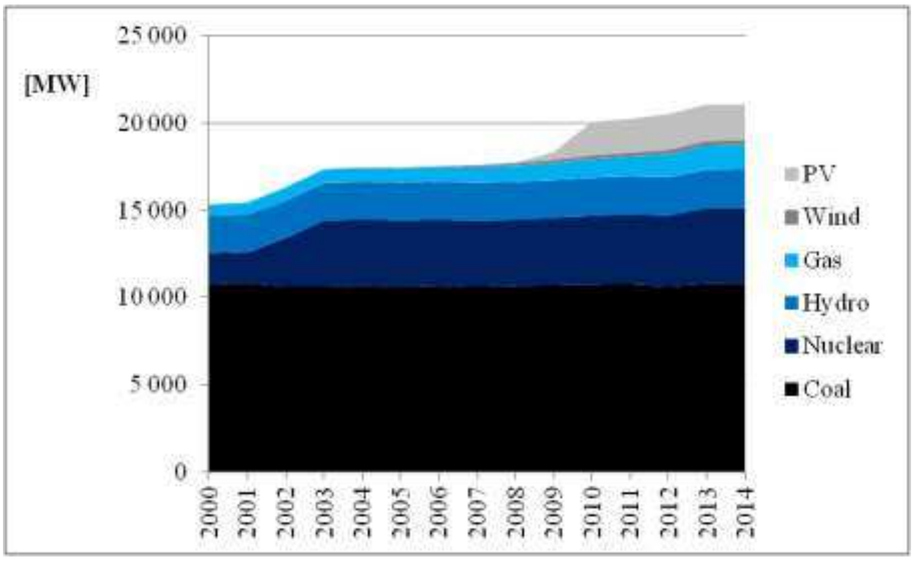
3.1. PV plants and the Czech energy mix

The Czech Republic relies mainly on coal and nuclear energy as far as the production of electricity is concerned. Other sources are hydro power plants including pumped-storage ones. These sources are accompanied with gas stations and renewables. The Czech grid is connected with all its four neighbors. The Czech, Slovak and Hungarian electricity markets have been coupled since 2012. The Polish and Romanian markets should be added in the future.

Since 2000 two significant events influenced the Czech energy mix. The first one was the launch of nuclear power plant Temelín in the beginning of 2000's. The second event is the emergence of the renewable energy.

Notably the use of solar energy exponentially emerged literally from zero to 10 % of total installed capacity. The **Figure 0.2** depicts the development of installed capacity in the last years with visible increment of newly installed photovoltaic power plants. The **Table 0.1** provides a snapshot of capacity available in the end of 2014.

Figure 0.2: Installed capacity in the Czech Republic



Source: Energy Regulatory Office

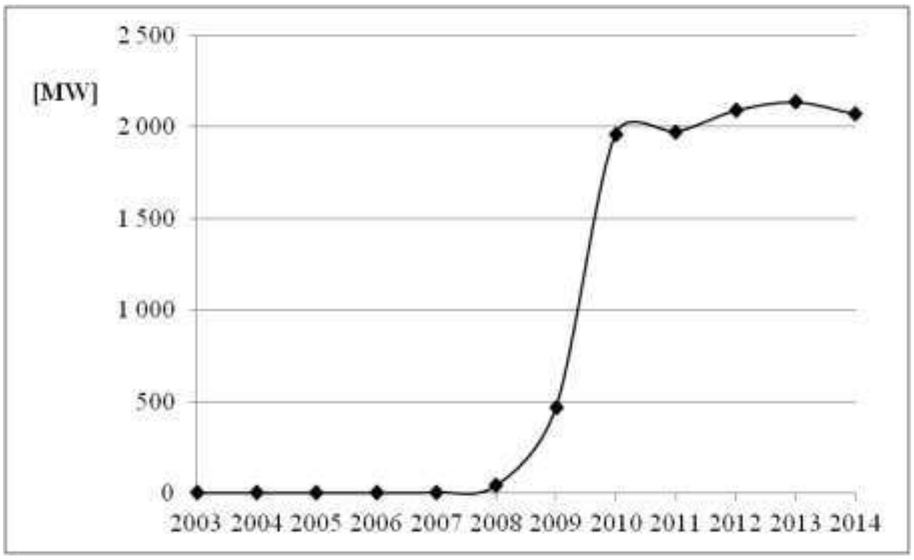
Table 0.1: Installed capacity in the Czech Republic 31 December 2014

Plant type	[MW]	Share [%]
Coal	10 837	51.3
Nuclear	4 290	20.3
Hydro	2 252	10.7
PV	2 067	9.8
Gas	1 353	6.4
Wind	278	1.3
Total	**21 087**	**100.0**

Source: Energy Regulatory Office

It is important to stress that the increment in solar capacity was not gradual. **Figure 0.3** shows the dynamics of power stations' construction. The massive construction began in 2009 and continued to a larger degree in 2010. In the subsequent years the pace of growth decelerated significantly. Its reasons will be discussed later in this chapter.

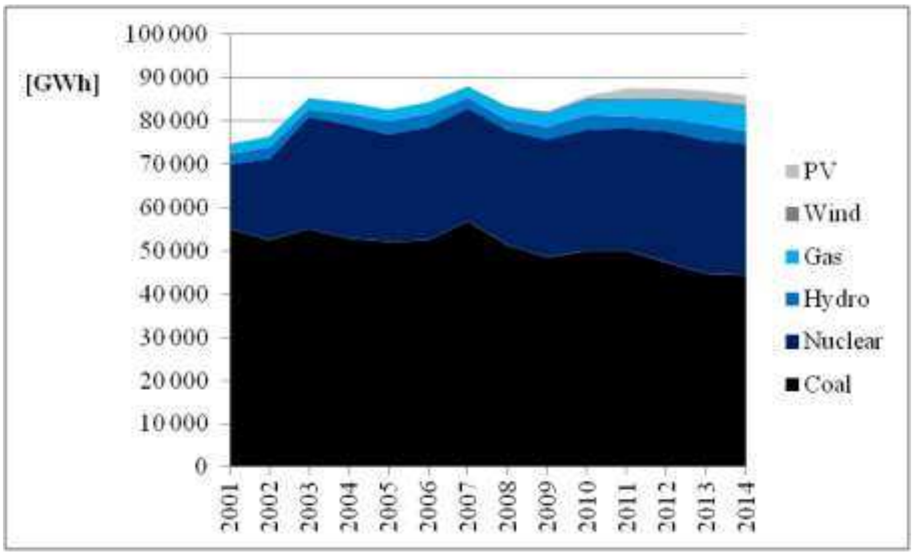
Figure 0.3: PV stations installed capacity



Source: Energy Regulatory Office

To complete the perspective of the electricity, we also present the view on the production. The output of station using renewable energy is dependent on the weather so the plants are not able to produce their full capacity. Output of PV plants is dependent on the radiation and in the night the production is zero. Felcman (2014) states that in 2011 the Czech PV power stations produced 12.5 % of total theoretical output. (Theoretical output represents full usage of capacity every single hour in a year including nights.)

Figure 0.4: Gross Production by source in the Czech Republic



Source: Energy Regulatory Office

The importance of production from PV plants increased as well as the installed capacity but the increment is not so significant due to low usage of installed capacity. In 2013, intermittent sources of electricity produced less than three percent of overall production. The contribution of PV plants was 2.4 %.

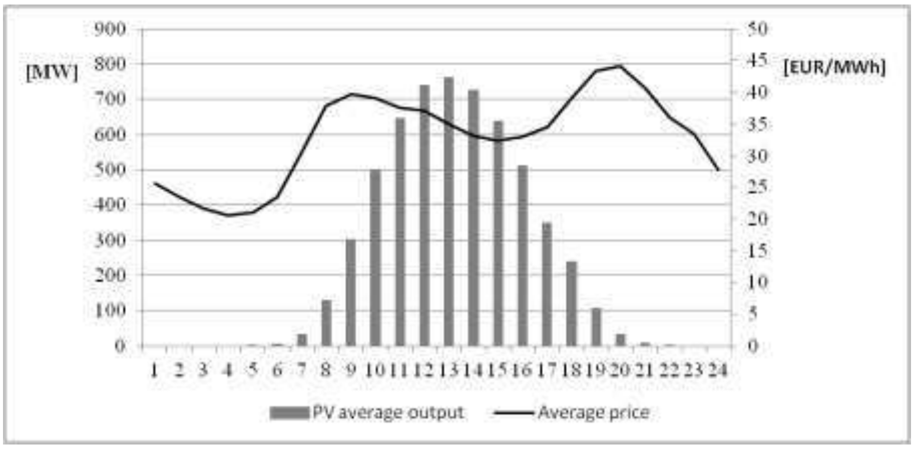
Table 0.2: Gross production in the Czech Republic 2014

Plant type	[GWh]	Share [%]
Coal	44 419	51.6
Nuclear	30 324	35.3
Hydro	2 961	3.4
Gas	5 698	6.6

Wind	477	0.6
PV	2 123	2.5
Total	**87 065**	**100.0**

Source: Energy Regulatory Office

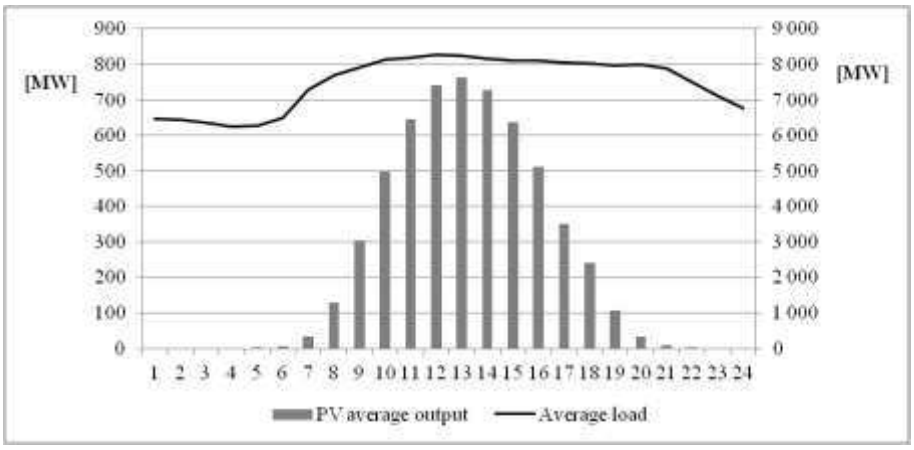
Figure 0.5: Average PV output and prices in the Czech Republic in 2014



Source: OTE and CEPS

The Figure 0.5 shows hourly averages of PV output and spot price. The peaks of two variables did not coincide in 2014. Rather, the price peaks occurred before and after the solar peak.

Figure 0.6: Average PV output and load in the Czech Republic in 2014



Source: CEPS

PV average output and average load are displayed in the Figure 0.6. Here it is possible to say that peak of both variables coincide. The definition of load by CEPS stands as load (butto) = production (brutto) + import –export – pumping. The term brutto in parenthesis means that transmission and distribution losses are not included. So load can in this case be perceived as consumption (demand).

3.2. Drivers of the solar boom

This subsection presents the rationale behind the exponential growth of new solar plants in 2009 and 2010. Also the regulatory measures, whose goal was to limit the redistributive nature of business, are presented. Decreasing PV modules' prices and the subsidy scheme are two plausible complementing reasons for the emergence of new photovoltaic stations. This part does not attempt to quantify the contribution of each feature to the solar boom but it only offers the description of market and legal environment, which motivated the investments into renewable resources.

Table 0.3: Feed-in tariffs [CZK/MWh] for PV plants in the Czech Republic for 2014 based on the year of the launch

<table>
<tr><th>Plant output [kW]</th><th>2005</th><th>2006-7</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>1-6/2013</th><th>7-12/2013</th><th>2014</th></tr>
<tr><td>0 - 5</td><td rowspan="4">7 418</td><td rowspan="4">15 565</td><td rowspan="4">15 180</td><td rowspan="2">14 243</td><td rowspan="2">13 265</td><td rowspan="2">7 959</td><td rowspan="2">6 410</td><td>3 478</td><td>3 050</td><td rowspan="4">0</td></tr>
<tr><td>5 - 30</td><td>2 887</td><td>2 479</td></tr>
<tr><td>30 - 100</td><td rowspan="2">14 139</td><td rowspan="2">13 161</td><td>6 264</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>>100</td><td>5 837</td></tr>
</table>

Source: Energy Regulatory Office (Energy Regulatory Office, 2013)

The **Table 0.3** summarizes the level of feed-in tariffs attributed to the operators of photovoltaic power plants. The producers receive the feed-in tariff on top of the wholesale price of the electricity and distributors are obliged to buy all the electricity produced by PV stations in their respective regions. This provides the operators with guaranteed revenue. Jenner (2012) used econometric assessment to prove that feed-in tariffs were responsible for the emergence of solar energy in the European Union.

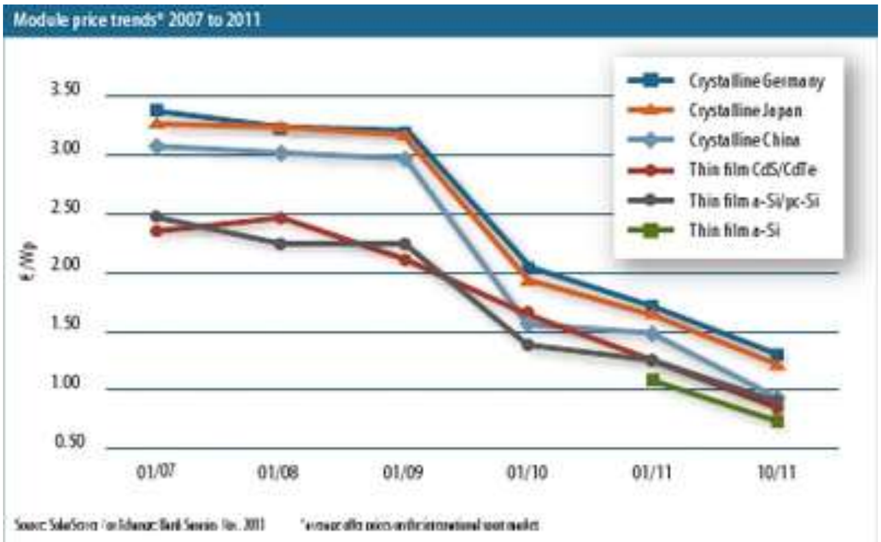
Apart from feed-in tariffs, plant operators can use another incentive. Green bonuses are suitable for operators that consume most of their production. The residual production, which is not consumed, can be sold to other parties. The green bonus is received for every kWh produced. The level of the bonus is fixed for one year but the drop can be 5 % at maximum.

The level of the feed-in tariff is set for the period of twenty years with yearly indexation of 2 % at least. Feed-in tariff's level on the year, when the plant was launched. The **Table 0.3** shows the support for plants built in each year. The highest feed-in tariffs are awarded to the plants built between 2006 and 2008. Still, even the high incentive did not motivate investors to allocate their wealth in renewable projects.

The photovoltaic capacity experienced the exponential growth in 2009 and 2010, despite the subsidies being slightly lower than in previous years. The second driver of the solar boom was the fall of PV modules.

The **Figure 0.7** shows the price development of crystalline silicon modules. The price of modules decreased approximately three times from 2007 to 2011. The drop of modules' prices together with generous feed-in tariffs served as an investment signal

Figure 0.7: PV modules price development



Source: http://www.pv-magazine.com/

There are two main technologies used for the production of PV modules. The crystalline silicon is the older one. The newer thin-film technology provides more efficient conversion. (Fraunhofer Insitute, 2014) reports that crystalline modules' production amounted to 90 % of total.

As far as the authors knowledge is concerned, there is no overview of technology used in the Czech power stations, so we assume that in line with the world trend the overwhelming majority of PV modules use crystalline silicon technology. **Figure 0.7** shows that Germany crystalline price decreased twofold during the time of installation spree.

Not only, are PV modules fundamental technical aspect, which converts the sunlight into direct current, but they key budget element when planning the ne PV power plant. Felcman (2014) estimates that for the construction of new plant PV in the Czech Republic in 2014 modules account for 40 % of total budget. Prior to the sharp drop, the share in the budget was even higher.

3.3. Green Surcharge distribution

The green surcharge is ultimately transferred to the operators of photovoltaic plants but the whole mechanism of feed-in tariffs and surcharges is little bit more complex. The distribution companies (There are three distribution companies in the Czech Republic, each operates in the different region of the country.) are obliged to the production of renewable operators using feed-in tariffs. The distributor pays to the operator the sum with the subsidy included. The suppliers then purchase the electricity in the wholesale market or they rely on the bilateral agreements.

Customers order their power from the suppliers. In the final bill from their supplier a customer can find fees for all services associated with the transport of the electricity. A customer pays for distribution, transmission, contributes to the activity of the electricity market operator and the green surcharge (renewable sources, combined generation of heat and power, secondary sources). The supplier then credits the green surcharge to the transmitter, which forwards the payment to the electricity market operator. Finally the operator reimburses the distributors, who are obliged to purchase the production from renewables, with the feed-in tariff that was paid in the first place. If a producer uses the green bonus mechanism, it receives on the basis of electrical metering the subsidy according to its own consumption.

3.4. Regulatory corrections

The generous promotional programs and favorable development of PV modules' price allowed the proliferation of solar power plants and other renewable sources. However, main source of revenues for PV stations' operators are feed-in tariffs. For example in 2014, the plant launched in 2010 receives the green subsidy over 13 000 CZK/MWh and the wholesale price of electricity, which fluctuates around 1 100 CZK/MWh. Both values are stated before taxes. This means that the operators receive approximately 10 times more from subsidies than from the actual sale of the product.

High unit subsidies associated with increased penetration require high total financing. The funds for the scheme are raised through surcharges to the consumed energy. For 2015, the surcharge is set to 495 CZK/MWh. The surcharge is used to cover all subsidies oriented on promotion of renewables, combined heat and power generation and secondary sources.

Janda, Krška, & Průša (2014) calculated that the expenses on the support of photovoltaic sources would have amounted approximately to 20 billion CZK each year from 2011 to 2020 if new legal measures had not been adopted. The measures will be presented later in this chapter. Also, Průša, Klimešová, & Janda (2013) determined that the economic loss to the Czech economy caused by the promotion of photovoltaic power plants was 14 billion CZK. Fifty-eight percent of the sum constituted redistributive profit captured by the operators. The rest is accounted to the high technological cost.

Increasing solar capacity and future payments forced regulatory bodies to circumscribe the support. The **Table 0.3** shows that the support dropped by a half for plants built in 2011 compared with a previous year. The amount of the support was decreasing also in the following years. Ultimately, for plants built in 2014 their operators are not entitled to any feed-in tariff. **Figure 0.3** demonstrates that investors limited new solar projects after the subsidies were curbed.

On top of cutting the level of subsidies for new plants, at the end of 2010 new tax was imposed on feed-in tariffs. Originally, the tax applied to all stations with output greater than 30 kW built between 1 January 2009 and 31 December 2010. The subject of the tax is feed-in tariff itself. The tax amounted to 26 % and was applied between 2011 and 2013. From 2014, the tax was decreased to 10 % and is imposed only on the stations built in 2010 with output greater than 30 kW. (Janda, Krška, & Průša (2014) state that the implementation of the tax saved approximately 5 billion CZK a year from 2011 and 2013.

4. Methodology

4.1. Estimation of merit-order effect

4.1.1. Data

Data in this thesis are taken from two sources. The data come from OTE, a.s., the Czech electricity and gas market operator (OTE) and ČEPS, a.s., the sole Czech electricity transmitter (CEPS).

OTE organizes the spot electricity market. The spot market is closed a day before at 11:00 so the market participants does not know the amount of consumed electricity for the future.

Explanatory variables are spot (day-ahead) prices or their indices, whereas energy or power delivered are actual data for respective days or hours. This means that prices are set in advance before we know the actual amount of energy produced or cross-border flows. So we have to use simplifying assumption that market agents are able to predict actual values, when they are acting on a day-ahead market. However, this practice of combining day-ahead data is common in the literature e.g. (Cludius, Hermann, Matthes, & Graichen, 2014).

OTE publishes three types of indexes base load, peak load and off-peak load. The base load index takes into account all hours within a day, whereas peak load index averages only twelve hours between 8:00 and 20:00. The off peak index is the average of the other twelve hours within a day.

Wind and PV outputs, load and cross-border flows are obtained from the CEPS website.

4.1.2. Econometric models

Increasing supply of the electricity results in the decrease of the wholesale price. Intermittent sources, whose production is not absolutely predictable, can have significant effect on the price. The purpose of merit-ordering (using the source with the lowest marginal costs) is to provide customers with the cheapest electricity.

Renewables sources such as solar and wind plants have zero marginal costs so in case their production is abundant the wholesale price can be driven to zero or even below it. Negative prices can happen, when the producers using standard means such as coal or nuclear energy want to get rid of their production and pay the buyer for accepting their production.

We will use two types of prices. The merit-order effect will be examined on daily price indexes and then on hourly spot (day-ahead) prices. The daily prices were used by Wurzburg, et al. (2013) and spot prices were used in the research done by Cludius, et al. (2014). Both papers were focused on the German market and both methods included a multivariate regression model. We will use analogous methodologies but we will use data from the Czech electricity market.

4.1.2.1. Model including daily data

The basic framework for the regression can be seen in the Equation 0.1. The explained variable is price index of the electricity and explanatory variables are load, the production from wind and solar power plants, prices of gas and the balance of imports and exports with adjacent countries.

$$\boldsymbol{P_{elec,t} = \beta_0 + \beta_1 Load_t + \beta_2 Wind_t + \beta_3 PV_t + \beta_4 P_{gas,t} + \sum_{i=1}^{5} \beta_{4+i} ImEx_{i,t} + \sum_{l=1}^{6} \gamma_l d_{lt} + \sum_{j=1}^{11} \delta_j m_{jt} + u_t}$$

Equation 0.1

The rationale for using these variables is following. The load should influence the price through a supply curve, i.e., the higher consumption the more expensive sources have to be used. The wind and photovoltaic production should drive the price down because of their zero marginal costs. The gas is used as fuel in some power plants so its price should influence the price of electricity as well.

Dummies comprise of weekdays, months and years. Monday-Saturday are included because the consumption is lower for example at the weekend. It is the same for some month, e.g., heating or air-conditioning is used, which yields different consumption patterns. Year dummies are included to avoid possible issues with omitted variables.

4.1.2.2. Model including hourly data

To determine the merit-order effect we will use similar methodology as in case of daily data. The method we use is analogous to Cludius, et al. (2014), whose foundation is a multivariate regression.

The underlying regression is displayed in the **Equation 0.2**. The dependent variable is day-ahead price of the electricity and explanatory variables are load, wind and PV output, cross-border flows and time dummies. Unlike the case of daily data, we do not include the price of gas.

$$\boldsymbol{P_{elec,t} = \beta_0 + \beta_1 Load_t + \beta_2 Wind_t + \beta_3 PV_t + \sum_{i=1}^{5} \beta_{3+i}\, ImEx_{i,t} + \sum_{i=1}^{23} \theta_i h_{it} + \sum_{l=1}^{6} \gamma_l d_{lt} + \sum_{j=1}^{11} \delta_j m_{jt} + u_t}$$

Equation 0.2

There are two reasons for not including the price of gas. The first one is low liquidity of the Czech market and the second one is that gas prices are available only on a daily basis as the gas is storable.

The fundamental condition for leas-squares estimation to be valid is the exogeneity of variables. We assume in line with Cludius, et al. (2014) that demand for electricity in inelastic in the short-term. This means that consumers end consumers do not decide about their consumption on day-to-day basis based on the wholesale price. Secondly, most of end consumers pay fixed tariff and the risk in the price volatility is borne to a supplier.

In case of daily data, we estimate only specific merit-order effects but using hourly data we compute total average merit-order effect. Its computation is shown in the **Equation 0.3**. Beta coefficients are those ones estimated in the **Equation 0.2**. These specific effects are then multiplied by load-weighted PV and wind output (feed-in)

$$\boldsymbol{Merit\ order\ effect = \beta_2 load - weighted\ wind\ average\ in - feed +}$$
$$\boldsymbol{+\beta_3 load - weighted\ PV\ average\ in - feed}$$

Equation 0.3

However, pure estimation of the merit-order effect is not the only goal of this part. We would like to project merit-order effect to the future. We will develop three scenarios of possible future deployment of new solar power plants to determine possible effect on the wholesale prices and possible profitability of new projects.

In order to do so, the relation between residual load and spot price is estimated. Residual load is defined as the load without the production from renewables.

The Equation 0.3 displays how the relation is to be estimated. We will use data from 2014 for that purposes. We will estimate the regression for several brackets to determine the price curve as price curve may have different slope for different levels of residual load.

$$\boldsymbol{Spot_t = \beta_1 residual\ load_t + \sum_{i=1}^{23} \theta_i h_{it} + \sum_{l=1}^{6} \gamma_l d_{lt} + \sum_{j=1}^{11} \delta_j m_{jt} + u_t}$$

Equation 0.4

Then based on the scenarios, we compute levels of residual load. Scenarios will differ in capacity installed and energy efficiency. The production from PV and wind sources and load will be scaled proportionally to year 2014. We assume the same industry structure across the forecasted period and we also assume that customers' demand is inelastic in the short-term.

The simulation is done for 2015-2018 horizon during which we adhere to the assumption of unchanged structural features of the Czech electricity market. Only structural changes are these captured by scenarios.

Modelled load and productions are then use to compute residual load for every hour. The calculate load is than fitted to determine the spot price, which is subsequently used to estimated the specific-merit order effect.

Ultimately, we will determine total average merit-order effect for each year in 2015-2018 horizon and each scenario.

The predicted prices will be used for comparison with the costs of the electricity so called LCOE. LCOE figures will be taken over from other researches.

5. Estimation of merit-order effect

5.1. Methodology

We use to two approaches to measure merit-order effect in the Czech electricity market. The difference between them is the frequency of data used. Firstly we construct a model based on daily observances analogously to Wurzburg, et al. (2013). Then we use hourly data as Cludius, et al. (2014). Both papers were created using data from the German electricity market.

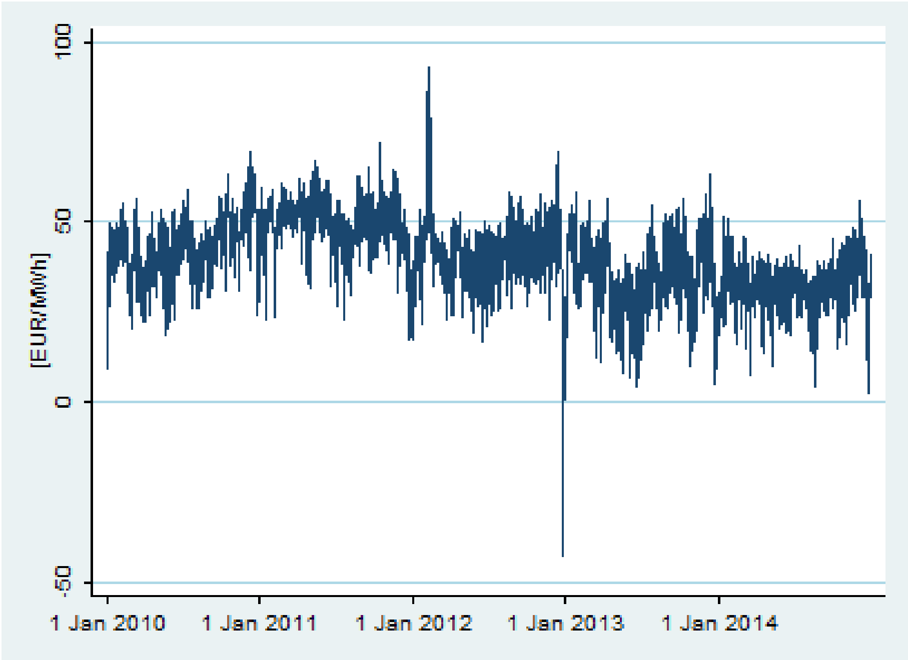
5.2. Merit-order effect on daily data

In this part we will examine the merit-order effect on daily data. Dependant variables are electricity indices (base load, peak load and off-peak load). Explanatory variables are average solar and wind output, load and cross-border flows.

Graphs below and the **Table 0.4** summarize the development of all three indexes, which we examine. The peak load index exhibits higher mean and median values than other two indexes, which is not surprising due to higher demand in peak hours. On the other hand the Off-index shows lower values than other two. This can be explained by lower demand and mostly unchanged supply by conventional sources. The values for the Base load index lie in-between.

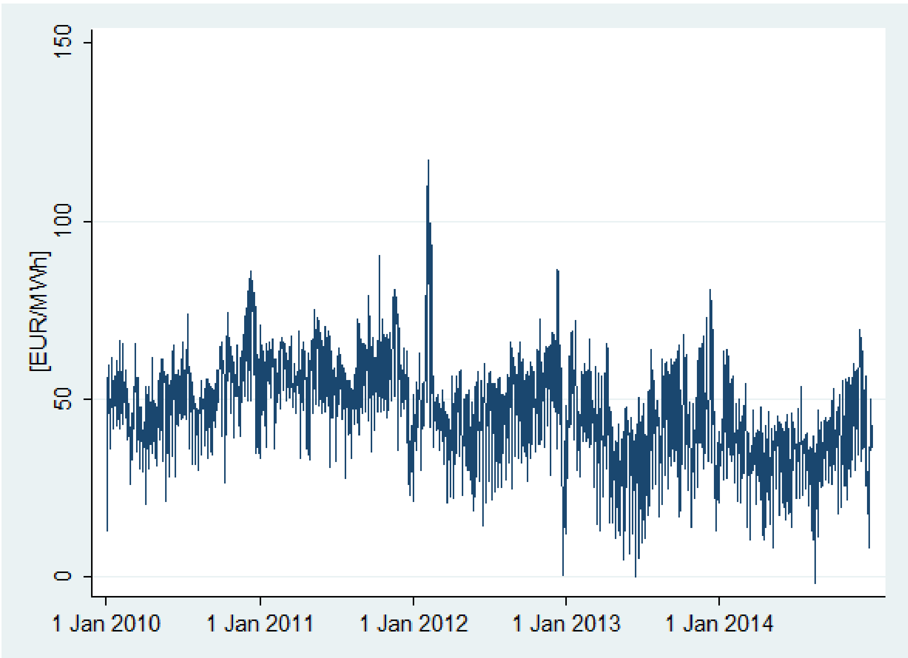
The same case applies to extreme values. The peak load index reached the highest maximal value and the lowest minimal value from three indices concerned. The opposite is true for the off-peak index. The extreme values for the base load index are in between.

Figure 0.8: Czech Spot Market Base Load Index



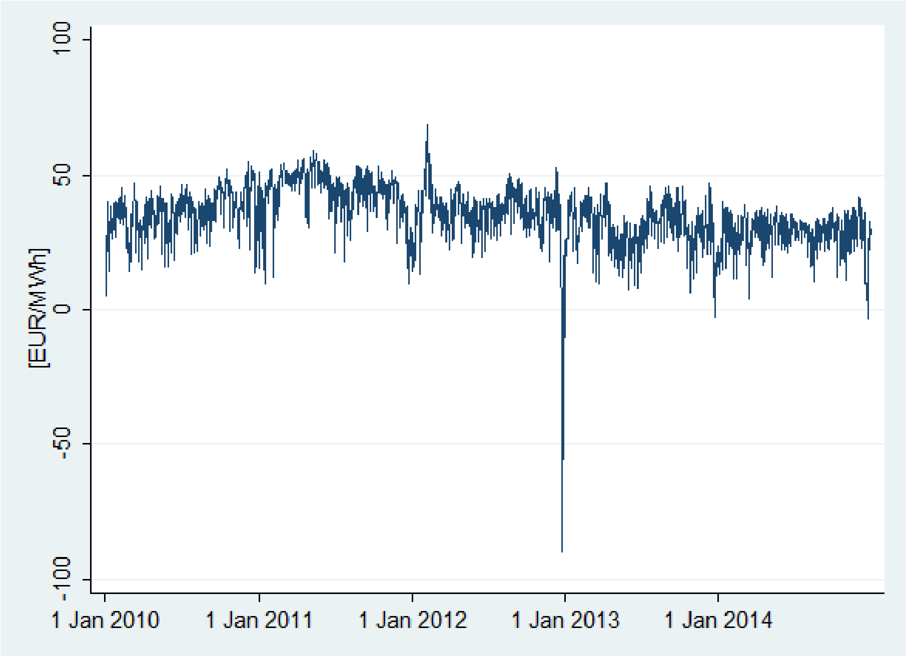
Source: OTE

Figure 0.9: Czech Spot Market Peak Load Index



Source: OTE

Figure 0.10: Czech Spot Market Off-peak Load Index



Source: OTE

Table 0.4: Spot Indexes 2010-2014

CZK/MWh	Base load	Peak load	Off-peak load
Mean	41.3	47.3	35.2
Median	41.8	48	35.8
Sample standard deviation	11.7	14.1	10.4
Minimum	-42.7	-1.6	-90.1
Maximum	92.9	117	68.7

Source: OTE

Table 0.5 shows three explanatory variables and their descriptive statistics.

Table 0.5: Daily averages of load and solar and wind output 2010-2014

MW	Load	PV	Wind
Mean	7 607.9	182.6	35.7

Median	7 471.3	130.6	26.7
Sample standard deviation	1 017.1	162.3	30.6
Minimum	5 438.5	0.0	0.0
Maximum	10 482.1	550.8	550.8

Source: OTE

Original model designed by Wurzburg, et al. (2013) takes into account cross-border flows from joint German and Austrian electricity market. Since cross-border flows data are available for all five years, we will use separately the flows between CEPS and its five neighboring transmitters (Poland, Slovakia, Austria and two transmitters in Germany).

Table 0.6: Daily averages of cross-border flows 2010-2014

MW	CEPS	Poland	Slovakia	Austria	Germany South	Germany North
Mean	1 936.2	-767.7	874.3	1 109.8	798.2	-78.4
Median	1 941.6	-772.6	889.0	1 089.5	829.0	-59.6
Sample standard deviation	631.3	347.7	455.9	445.2	367.3	473.6
Minimum	-585.6	-1 844.6	-541.4	-260.7	-339.0	-1 650.8
Maximum	3 819.3	501.8	2 304.4	2 386.0	1 672.7	1 232.8

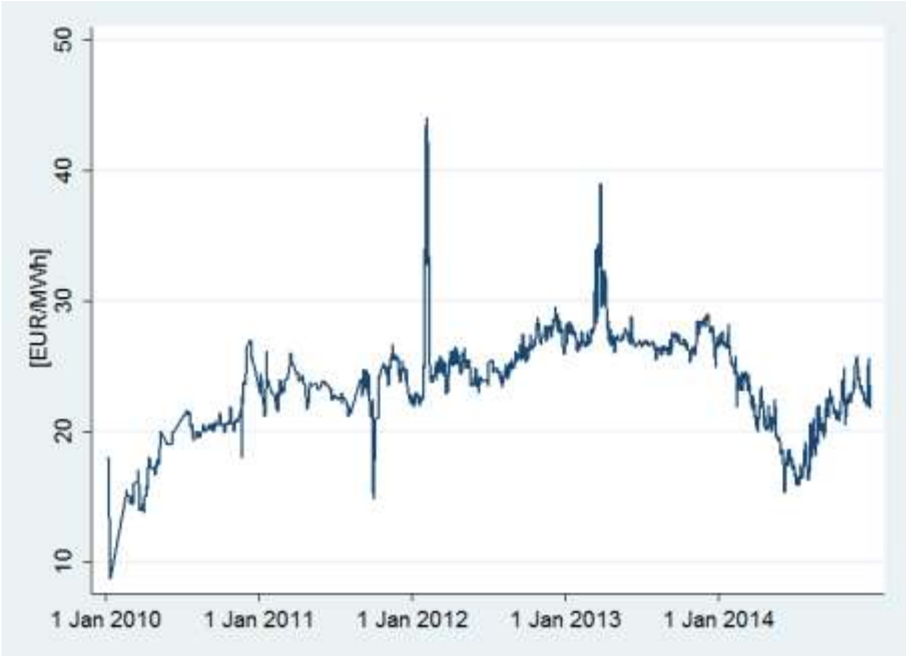
Source: CEPS

The **Table 0.6** presents average cross-border flows between 2010 and 2014. Numbers in CEPS column represent overall flow balance between the Czech Republic and surrounding countries. The positive number in the CEPS column means that the Czech Republic was a net exporter of electricity. Positive numbers in other columns mean that the Czech Republic was exporting more than importing to the respective network.

It is evident that the Czech Republic is overall net exporter of electricity but it is the net importer vis-a-vis Poland. As far as Austria and Germany are concerned, CEPS' exports electricity to Austria and Southern Germany, where it is net import from Northern Germany. Moreover, the Northern German flow has the highest standard deviation of all five connections. It suggests that the flow is very volatile. We suspect that this is caused by capricious production of wind farms in Northern Germany.

The electricity price indexes and gas prices were obtained from OTE database. For gas prices we use day-head values, only for 2010 we use the combination of values from intra-day and day-ahead market, where both are available for the same day we use day-ahead price. Unfortunately, the Czech gas spot market was not liquid enough so in some days in examined five-year period no gas was purchased on the spot market. The development of gas prices is depicted in the **Figure 0.11**.

Figure 0.11: Czech Gas Prices 2010-2014



Source: OTE

All variables used in multivariate regression models are I(0). We used Augmented Dickey-Fuller test to determine the order of lag specification was chosen based on Akaike information criteria (AIC).

5.2.1. Results

Unlike the original, where authors found that variables are I(1) and so they used first differences, in our case all variables are integrated of order zero. This is better because we do not lose any information by differencing the data. The dependent variable is the electricity price (price index). We will run regressions for all three indexes we have, which might yield interesting results because the solar production might mostly influence the peak load index, whereas for the off-peak load index the effect should be statistically insignificant.

Table 0.7: Regression results on daily data

	Model 1	Model 2	Model 3	Model 4	Model 5
	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$
$Load_t$		-0.001		-0.001	
		(0.001)		(0.001)	
$Wind_t$			-0.079***	-0.079***	-0.083***
			(0.012)	(0.011)	(0.012)
PV_t			-0.006	-0.006	-0.004
			(0.004)	(0.004)	(0.004)
$ImEx_t$					-0.003***
					(0.001)
Daily dummies	Yes	Yes	Yes	Yes	Yes
Monthly dummies	Yes	Yes	Yes	Yes	Yes
Yearly dummies	Yes	Yes	Yes	Yes	Yes
Observations	1 826	1 826	1 826	1 826	1 826
R^2	0.53	0.53	0.56	0.57	0.58

Note: Standard errors reported in parenthesis. Newey-West errors robust to serial correlation and heteroscedasticity are used. *(p < 0.1) **(p < 0.05) ***(p < 0.01).

The first set of regression is in the **Table 0.7**. It shows no significant influence of power of solar power plants on the base load price index. Load is not significant as well. Wind plants average power and the overall cross-border balance (in this set of regressions we use overall balance instead of individual flows) are only two significant variables.

Table 0.8: Regression results on daily data with cross-border flows

	Model CB1	Model CB2	Model CB3	Model CB4	Model CB5	Model CB6
	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$	$P_{base,t}$
	2010-14	2010	2011	2012	2013	2014
$Wind_t$	-0.083***	-0.066***	-0.077***	-0.139***	-0.153***	-0.097***
	(0.011)	(0.017)	(0.012)	(0.042)	(0.030)	(0.014)
PV_t	-0.001	0.009	0.005	-0.002	-0.011***	-0.007**
	(0.004)	(0.036)	(0.004)	(0.006)	(0.003)	(0.003)
$Poland_t$	-0.016***	-0.013***	-0.009**	-0.027***	-0.013***	-0.009**
	(0.003)	(0.005)	(0.004)	(0.008)	(0.004)	(0.004)
$Slovakia_t$	-0.002	0.009***	0.001	-0.014***	-0.001	0.000
	(0.002)	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)
$Austria_t$	-0.008***	-0.012***	-0.010***	-0.011*	-0.011***	-0.007***
	(0.002)	(0.003)	(0.002)	(0.005)	(0.004)	(0.002)
Germany $South_t$	0.003	0.005*	0.000	0.003	0.007**	0.004**

	(0.002)	(0.003)	(0.002)	(0.005)	(0.003)	(0.002)
Germany North$_t$	0.003**	0.003*	-0.000	0.006**	-0.001	0.004**
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.002)
Daily dummies	Yes	Yes	Yes	Yes	Yes	Yes
Monthly dummies	Yes	Yes	Yes	Yes	Yes	Yes
Yearly dummies	Yes	No	No	No	No	No
Observations	1 826	365	365	366	365	365
R^2	0.65	0.66	0.70	0.62	0.72	0.74

Note: Standard errors reported in parenthesis. Newey-West errors robust to serial correlation and heteroscedasticity are used. *(p < 0.1) **(p < 0.05) ***(p < 0.01).

Further, we included specifically cross-border flows for all neighbouring countries` transmission networks. We ran the regression on the sample containing all five examined years and then also for each years separately. The Table 0.8 concludes the results. In all years there is apparent merit-order effect from wind generation but the merit-order effect for photovoltaic power plants is significant only for last two examined years. Therefore based on these results, we can conclude that merit-order effect from PV plants was not present in 2010, 2011 and 2012 but was present in 2013 and 2014, i.e., the additional production from PV plants caused the decrease in the index price of the electricity.

We can also observe significance of cross-border flows and that the whole model can explain in some cases more than 70 % of variation in a dependent variable so we can consider the model to be well specified. However, examining specific effects of cross-border flows and their variations across years is beyond the scope of this text.

5.2.1.1. Peak load and Off-peak load

Subsequently, we ran the regression analysis with dependent peak load and off-peak load indices. In the specification with the off-peak load we ran only one regression for the whole sample between 2010 and 2014 because there is only little of sunshine during off-peak hours. As expected, the results given by the model PL2 do not yield significant merit-order effect from PV plants.

Table 0.9: Regression results on daily data – Peak load/Off-peak load

	Model PL1	Model PL2	Model PL3	Model PL4	Model PL5	Model PL6	Model PL7
	$P_{peak,t}$	$P_{off\text{-}peak,t}$	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$
	2010-14	2010-14	2010	2011	2012	2013	2014

$Load_{(off)peak,t}$	-0.001	-0.000					
	(0.001)	(0.001)					
$Wind_{(off)peak,t}$	-0.085***	-0.078***	-0.037*	-0.072***	-0.150***	-0.178***	-0.114***
	(0.012)	(0.011)	(0.012)	(0.014)	(0.052)	(0.034)	(0.017)
$PV_{(off)peak,t}$	-0.010**	-0.003	-0.009	-0.001	-0.011***	-0.030***	-0.020***
	(0.004)	(0.003)	(0.054)	(0.006)	(0.004)	(0.004)	0.004
$ImEx_{(off)peak,t}$	0.003***	0.002	0.004**	0.006*	0.002	0.000	0.000
	(0.001)	(0.001)	(0.002)	(0.003)	(0.001)	(0.001)	(0.001)
Daily dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monthly dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yearly dummies	Yes	Yes	No	No	No	No	No
Observations	1 826	365	365	366	365	365	365
R^2	0.65	0.66	0.70	0.62	0.72	0.74	0.71

Note: Standard errors reported in parenthesis. Newey-West errors robust to serial correlation and heteroskedasticity are used. *(p < 0.1) **(p < 0.05) ***(p < 0.01).

As far as the effect on the peak load index is concerned, there is significant evidence of the merit-order effect for the whole sample and in 2012, 2013 and 2014. Furthermore the effect is higher than on the base load index. Additional MW of PV production resulted in the discount of 0.007 EUR/MWh of the base index in 2014 and 0.011 EUR/MWh in 2013, whereas the discount of the peak load index was 0.020 EUR/MWh in 2014 and 0.030 EUR/MWh in 2013. This is not very surprising if we take into account non-existent merit-order effect during off-peak load hours.

5.2.1.2. Gas prices included

In the last specification, we add gas prices as the explanatory variables. Its inclusion is reasonable because gas is used as fuel in some power plants. The issue that prevents us from including gas in other regression is low liquidity of the Czech spot gas market and unavailability of data for some days, when no trade was made on a spot market.

The price of gas is significant explanatory variable for the whole sample and also for all five years except 2013. The inclusion of gas causes that the magnitude of merit-order effect changed, which suggests that the price og gas was an omitted variable.

To conclude average merit-order effect between 2010 and 2014 was 0.010 EUR/MWh for each extra MW of solar power produced. The presence of the merit-order effect was also individually significant for years 2012, 2013 and 2014. The effect on the peak load index ranged between 0.012 EUR/MWh and 0.029 EUR/MWh for each additional MW of solar energy produced during peak hours. In the original paper by Wurzburg, et al. (2013) the effect on the German price was decrease 0.001 EUR/MWh per additional MW. This is in line with the conclusions of authors, who claim that merit-order effects are smaller in larger markets.

Table 0.10: Regression results on daily data with cross-border flows

	Model G1	Model G2	Model G3	Model G4	Model G5	Model G6
	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$	$P_{peak,t}$
	2010-14	2010	2011	2012	2013	2014
$Load_{peak,t}$	-0.000					
	(0.001)					
$Wind_{peak,t}$	-0.092***	-0.039*	-0.080***	-0.132***	-0.189***	-0.113***
	(0.014)	(0.021)	(0.014)	(0.050)	(0.036)	(0.016)
$PV_{peak,t}$	-0.010***	-0.088	0.000	-0.012***	-0.029***	-0.018***
	(0.003)	(0.055)	(0.001)	(0.004)	(0.004)	(0.004)
$ImEx_{peak,t}$	0.003***	-0.001	0.003	0.004**	0.002	0.001
	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)
$P_{gas,t}$	1.305***	2.756***	2.150***	2.330***	1.189	0.814**
	(0.294)	(0.538)	(0.427)	(0.300)	(0.887)	(0.323)
Daily dummies	Yes	Yes	Yes	Yes	Yes	Yes
Monthly dummies	Yes	Yes	Yes	Yes	Yes	Yes
Yearly dummies	Yes	No	No	No	No	No
Observations	1 351	175	190	315	320	351
R^2	0.68	0.73	0.69	0.69	0.67	0.71

Note: Standard errors reported in parenthesis. Newey-West errors robust to serial correlation and heteroscedasticity are used. *(p < 0.1) **(p < 0.05) ***(p < 0.01).

The obvious disadvantage of use of daily data is the fact that variables are results of averaging. The dependent variables are weighted averages of hourly day-ahead prices and also independent variables are only average powers across 12 or 24 hours. This averaging might obfuscate some relations among variables, so we will do more elaborate simulations on hourly data.

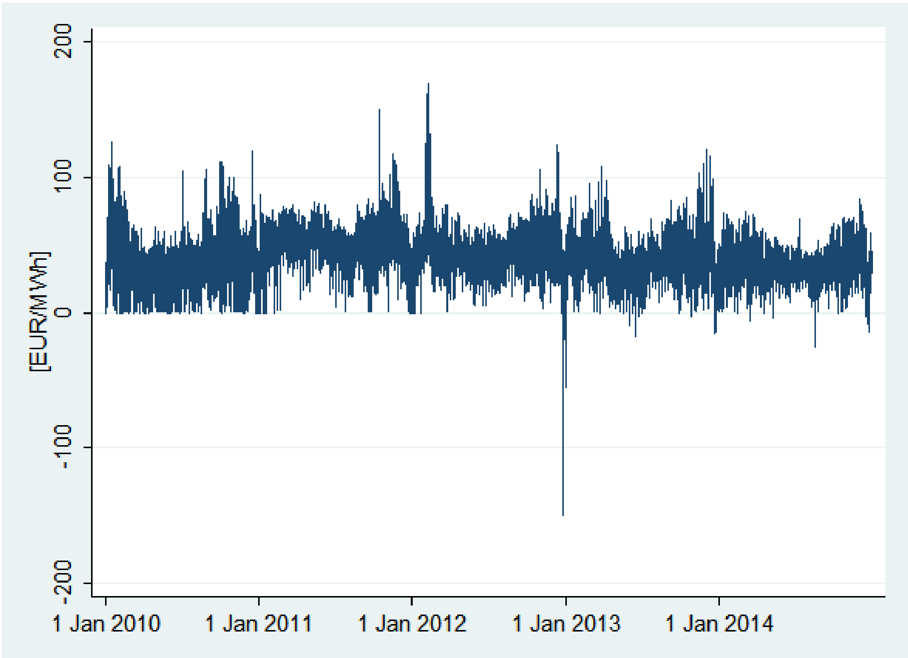
5.3. Merit-order effect on hourly data

In this section we will estimate the merit-order effect on hourly data with similar methodology to (Cludius, Hermann, Matthes, & Graichen, 2014). Our sample spans again over five years between 2010 and 2014.

The model using hourly data is very similar to the one that was used on daily data. Only significant difference is absence of gas because gas does not have hourly prices because it can be stored. Dependent variable is the spot (day-ahead) price of electricity. Explanatory variables are again load, wind and PV production and cross-border flows. Hourly, daily, monthly and yearly dummies are included as well.

Figure 0.12 shows the development of the spot price (day-ahead market) and the **Table 0.11** provides descriptive statistics. We observe several spikes. Since these outliers proved to be influential, we censor the sample based on studentized residuals. We censor the sample and set all values between -50 EUR/MWh and 150 EUR/MWh. Values, which are below lower or above upper threshold are set to the lower or upper threshold.

Figure 0.12: Czech Spot Price



Source: OTE

Table 0.11: Descriptive statistics of spot price 2010-2014

EUR/MWh	2010	2011	2012	2013	2014
Mean	37.8	50.5	42.3	36.7	32.9
Median	37.5	51.2	42.2	35.6	32.2

Sample standard deviation	17.7	13.9	17.1	16.2	12.4
Minimum	0.0	0.0	-150.0	-55.0	-25.6
Maximum	125.9	150.0	170.0	120.9	83.6

Source: OTE and Authors computations

The **Table 0.12** and the **Table 0.13** summarize values of dependent variables. We can see that solar output values can vary a lot among different hours. In our sample there are hours, when no solar energy was produced. On the contrary, in some hours the output exceeds 1 500 MW.

Table 0.12: Hourly values of load and solar and wind output 2010-2014

MW	Load	Solar output	Wind output
Mean	7 608.4	182.6	35.7
Median	7 601.8	3.8	25.0
Sample standard deviation	1 267.2	335.5	34.0
Minimum	4 401.1	0.0	0.0
Maximum	13 606.4	1 656.4	239.6

Source: CEPS and Authors computations

Table 0.13: Hourly values of cross-border flows 2010-2014

MW	CEPS	Poland	Slovakia	Austria	Germany South	Germany North
Mean	1 936.3	-767.7	873.8	1 109.4	798.2	-77.9
Median	1 958.9	-772.6	888.1	1 095.2	822.4	-47.9

Sample standard deviation	709.7	400.4	512.1	482.4	406.0	517.1
Minimum	-1 114.7	-2 422.8	-802.6	-733.1	-714.8	-1 938.1
Maximum	4 604.3	797.4	2 508.5	2 607.8	2 040.0	1 603.3

Source: CEPS and Authors computations

The multivariate regression is conducted as described in the methodological part and is shown again in the **Equation 0.5**.

$$P_{elec,t} = \beta_0 + \beta_1 Load_t + \beta_2 Wind_t + \beta_3 PV_t + \sum_{i=1}^{5} \beta_{3+i} ImEx_{i,t} + \sum_{i=1}^{23} \theta_i h_{it} + \sum_{l=1}^{6} \gamma_l d_{lt} + \sum_{j=1}^{11} \delta_j m_{jt} + u_t$$

Equation 0.5

The **Table 0.14** includes results of the multivariate regression over the whole sample and also for all years. In all specifications, except for one, wind and PV productions have negative signs as expected by the theory. Only in 2010 the sign of the PV production is positive and the wind production is insignificant. This is the same case as with the daily data in the previous section.

The higher the load, the higher the price of electricity in for the whole five-year sample and all individual years, which is in line with the assumed upward sloping supply curve. Renewable resources have overall and for all five years expected negative effect on the price except for 2010. The merit-order effect for the solar production ranges between 0.002 EUR/MWh and 0.010 EUR/MWh for every additional MW produced by solar power plants. The results are comparable with values obtained with the analysis conducted on daily data.

Table 0.14: Regression results on hourly data

	Model H1	Model H2	Model H3	Model H4	Model H5	Model H6
	P_t	P_t	P_t	P_t	P_t	P_t
	2010-14	2010	2011	2012	2013	2014
$Load_t$	0.005***	0.008***	0.012***	0.015***	0.012***	0.009***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.006)	(0.000)
$Wind_t$	-0.079***	0.013	-0.051***	-0.085***	-0.083***	-0.072***
	(0.006)	(0.011)	(0.006)	(0.015)	(0.012)	(0.006)
PV_t	-0.009***	0.024***	-0.002***	-0.007***	-0.010***	-0.010***
	(0.001)	(0.008)	(0.001)	(0.001)	(0.001)	(0.001)
$Poland_t$	0.005***	0.003	0.001	0.002**	0.001	0.000
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
$Slovakia_t$	0.003***	0.000	0.001	0.002**	0.001	0.000
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
$Austria_t$	0.002***	-0.001	-0.001	-0.001	-0.000	0.002*
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Germany $South_t$	0.004***	0.002	0.002	-0.000	-0.002*	-0.000
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Germany $North_t$	-0.002**	-0.001	-0.004***	-0.004***	-0.003***	-0.001
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Daily dummies	Yes	Yes	Yes	Yes	Yes	Yes
Monthly dummies	Yes	Yes	Yes	Yes	Yes	Yes
Yearly dummies	Yes	No	No	No	No	No
Observations	43 824	8 760	8 760	8 784	8 760	8 760
R^2	0.66	0.73	0.78	0.78	0.78	0.80

Note: Standard errors reported in parenthesis. Newey-West errors robust to serial correlation and heteroscedasticity are used. *(p < 0.1) **(p < 0.05) ***(p < 0.01).

5.4. Total merit-order effect

So far, we spoke about the specific merit-order effect, i.e. how much additional MW of power influences the wholesale price. In this section we will determine so called total average merit-order effect. Total average merit-order effect represents the total amount of price decrease caused by the sources. The total effect will be computed using the results from analysis with the hourly data because they control for differences throughout a day.

The computation can be seen in the **Equation 0.6**. This computation is in line with Cludius, et al. (2014). Coefficients β_2 and β_3 are specific merit-order effect estimated in the **Equation 0.5**.

$$\boldsymbol{Merit\ order\ effect = \beta_2 load - weighted\ wind\ average\ in - feed +}$$
$$\boldsymbol{+ \beta_3 load - weighted\ PV\ average\ in - feed}$$

Equation 0.6

Table 0.15: Total merit-order effect

	2010-14	2010	2011	2012	2013	2014
Wind specific effect [EUR/MWh^2]	-0.079	0.013	-0.051	-0.085	-0.083	-0.072
Load-weighted average wind output [MW]	35.783	30.233	39.291	26.395	36.308	46.951
Wind total effect [EUR/MWh]	**-2.812**	**0.388**	**-2.018**	**-2.245**	**-3.020**	**-3.370**
PV specific effect [EUR/MWh]	-0.009	0.024	-0.002	-0.007	-0.010	-0.010
Load-weighted average PV output [MW]	186.263	18.895	200.886	245.582	229.231	243.902
PV total effect [EUR/MWh]	**-1.732**	**0.454**	**-0.463**	**-1.842**	**-2.271**	**-2.370**
Total merit-order effect [EUR/MWh]	**-4.544**	**0.842**	**-2.481**	**-4.087**	**-5.291**	**-5.740**

The results of total average merit-order effect can be found in the Table 0.15. It clearly demonstrates the negative effect of the production from intermittent sources on the wholesale price of the electricity.

Two things are noteworthy. The first one is that total average merit order is increasing year by year. It could have been expected as the production from renewables increased as well year by year.

The second thing is that merit order effect of wind is absolutely higher than PV despite the fact that production from wind is smaller. Possible explanation of this fact could be that the price is more sensitive during the night to additional production from wind farms. This issue requires further research but since our major focus is the solar energy it is not investigated in this paper.

To conclude, the production of renewable resources production caused the price to drop by 4.5 EUR/MWh if we examine the whole sample between 2010 and 2014. If the years are investigated separately the decrease of the wholesale price of electricity is lowest in 2011 (besides 2010) and stands at 2.5 EUR/MWh. The highest effect was found in 2014 amounting to 5.7 EUR/MWh out of which 2.4 EUR/MWh is attributable to the solar output. In the original paper, which was estimated on data from 2008 to 2012, the total-merit order effect lied between 6 EUR/MWh and 10 EUR/MWh.

5.5. Projection of the merit-order effect 2015-2018

In this part we will project the merit order effect for four years that followed the sample used for previous analysis. We create three theoretical scenarios regarding the increase in the production of PV plants and energy efficiency. These scenarios are proposed by the author and should serve as an example of possible tools to achieving national energy goals.

(Ministry of Industry and Trade of the Czech Republic, 2014) published the updated national energy concept. The document states that share of production from renewables (wind, solar and hydro energy) should reach 18%. Their share in 2014 was only 7%.

Load and production of renewables is projected separately for every hour, where we assume that the load and wind and photovoltaic production have the same patterns as they had in 2014. It means that the change in capacity will affect every hour in the same proportion or the decrease in load will affect all hours. For example if we decrease the load by 1 %, the load will decrease by 1 % in every hour. We also assume that cross border flews will remain the same as in 2014.

Table 0.16: Scenarios – installed PV capacities

MW	Scenario 1	Scenario 2	Scenario 3
2012	2 086	2 086	2 086
2013	2 132	2 132	2 132
2014	2 067	2 067	2 067
2015	2 459	2 067	3 091
2016	2 924	2 067	4 623
2017	3 477	2 067	6 913
2018	4 135	2 067	10 337

Source: OTE and Authors computations

The first scenario simulates the case that the installed capacity of PV plants will increase two-fold between 2015 and 2018 so in 2018 photovoltaic power will cover 6:5% of the overall consumption. Overall load and wind production stay same as in 2014 for the whole projected period.

Table 0.17: Scenario 1 – Load and RES production

GWh	Load	Wind	PV
2012	66 302	223	2 085
2013	64 995	322	2 132
2014	65 630	411	2 050
2015	65 630	411	2 530
2016	65 630	411	3 017
2017	65 630	411	3 578
2018	65 630	411	4 255

Source: CEPS and Authors computations

The second scenario does not count with the increase in the installed PV capacity. This scenario is designed in the way that achieved residual load is the same as in the scenario number 1 but this not achieved by the production of renewable sources but by the increase in energy efficiency, i.e., decrease in overall load. Wind and solar production stay the same as in 2014 for all projected period.

Table 0.18: Scenario 2 – Load and RES production

GWh	Load	Wind	PV
2012	66 302	223	2 085
2013	64 995	322	1 966
2014	65 630	411	2 050
2015	65 150	411	2 050
2016	64 663	411	2 050
2017	64 102	411	2 050
2018	63 425	411	2 050

Source: CEPS and Authors computations

The third scenario presents the case of more rapid PV plants development than in the first case. This scenario expects that installed PV capacity would increase five times between 2015 and

2018. Overall the production from photovoltaic power plants would represent 16:2% of overall load. In this scenario the load and wind production would remain the same as in 2014.

Table 0.19: Scenario 3 – Load and RES production

GWh	Load	Wind	PV
2012	66 302	223	2 085
2013	64 995	322	1 966
2014	65 630	411	2 050
2015	65 630	411	3 182
2016	65 630	411	4 771
2017	65 630	411	7 114
2018	65 630	411	10 638

Source: CEPS and Authors computations

To proceed further with our research, the relationship between residual load (defined as load minus production from PV and wind plants) and the spot price. This price curve will be used to derive the spot price for our scenario analysis. We assume that the estimated price curve has the same shape in all years, for which we project the merit-order effect. This is analogous to the assumption of the unchanged industry structure beyond the adjustments in scenarios. We do not take into account possible closures of thermal power plants.

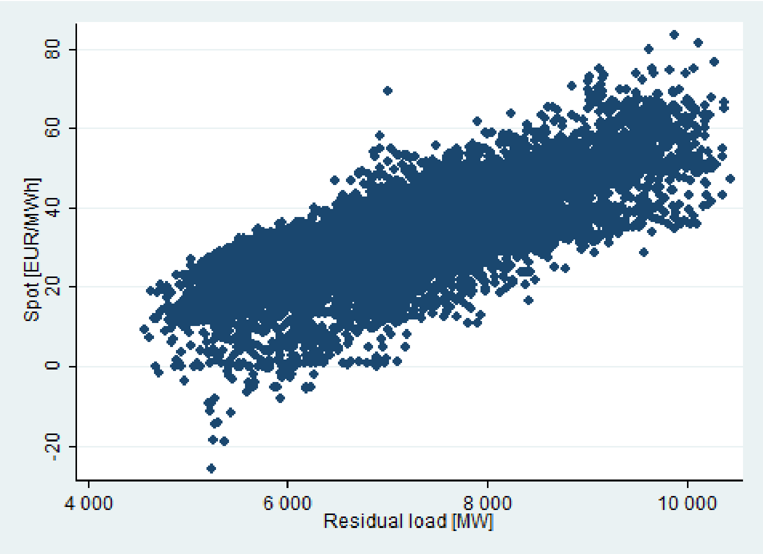
Figure 0.13 contains the scatter plot of the residual load and the spot price in 2014. The relationship between these two variables looks to be linear but given the theoretic assumption, that electric sources with lower marginal costs are used, the slope will be estimated in the intervals.

Bins for the estimation are following: below 6 GW, 6-7 GW, 7-8 GW, 8-9 GW and over 9 GW. **Equation 0.7** shows the method of estimation. Linear regression with corrected residuals is used. The residual load is regressed on the spot price. Moreover the equation also includes dummies for hours, days and months to deal with the daily, weekly and seasonal patterns.

$$\boldsymbol{Spot_t = \beta_1 residual\ load_t + \sum_{i=1}^{23} \beta_{i+1} h_{it} + \sum_{l=1}^{6} \beta_{l+1} d_{lt} + \sum_{j=1}^{11} \beta_{j+1} m_{jt} + u_t}$$

Equation 0.7

Figure 0.13: Residual load and Spot price scatter plot 2014



Source: OTE, CEPS

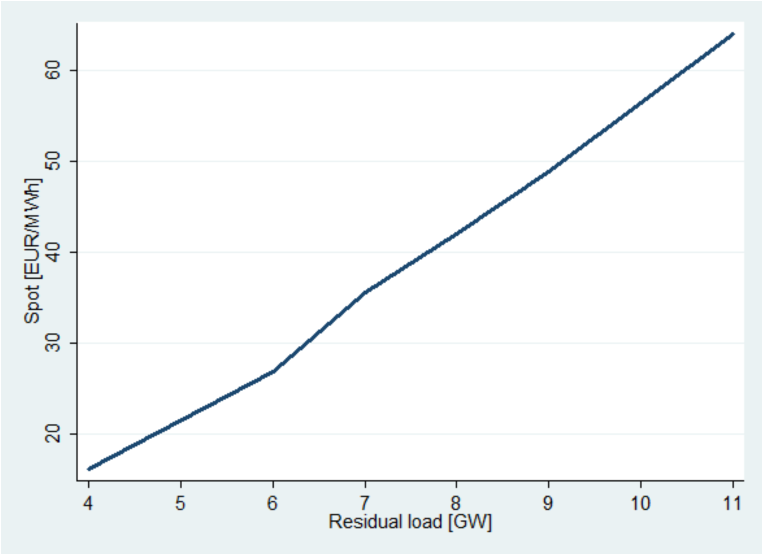
The results of estimation can be found in the **Table 0.20**. Below 6 GW the curve is the flattest than it becomes steeper between 6 and 7 GW. Brackets between 7- 8 GW and 8-9 GW have a similar slope the curve becomes steeper in the last bin, where the most expensive sources are used. The curve is depicted in the **Figure 0.14**.

Table 0.20: Spot and load regression coefficients

<6 GW	6-7 GW	7-8 GW	8-9 GW	9 GW<
5.37	8.75	6.39	6.81	7.58

Source: CEPS and Authors computations

Figure 0.14: Estimated price curve 2014



Source: Authors computations

Table 0.21 contains the projections for the merit-order effect under the first scenario, when the capacity is doubled during the next four years. As set by the scenario itself the merit-order effect for the wind power plants is almost unchanged. As far as the merit-order caused by PV power plants concerned, there is no significant change in the specific merit-order effect but the total effect is projected to increase up to 3.473 EUR/MWh

Table 0.21: Projection of merit-order effect – Scenario 1

	2015	2016	2017	2018
Wind specific effect [EUR/MWh^2]	-0.073	-0.072	-0.071	-0.070
Load-weighted average wind output [MW]	46.951	46.951	46.951	46.951
Wind total effect [EUR/MWh]	**-3.410**	**-3.392**	**-3.344**	**-3.299**
PV specific effect [EUR/MWh]	-0.007	-0.007	-0.007	-0.007
Load-weighted average PV output [MW]	300.305	359.756	426.829	507.622
PV total effect [EUR/MWh]	**-2.064**	**-2.511**	**-2.982**	**-3.473**
Total merit-order effect [EUR/MWh]	**-5.472**	**-5.903**	**-6.326**	**-6.771**

The results for the second scenario are displayed in the **Table 0.22**. This scenario has same renewable capacities as there were in 2014 but has the same values for residual capacities as the first scenario. This achieved through the decrease of overall load thus this could be perceived as an improvement in the energy efficiency. We can see that specific effects remain unchanged but total effects decrease. The drop in total merit-order effect is caused by the method of averaging. It can be concluded that the improvement in the energy efficiency would not substantially change the merit-order effect given the fact that structure of the energy industry remained the same.

Table 0.22: Projection of merit-order effect – Scenario 2

	2015	2016	2017	2018
Wind specific effect [EUR/MWh^2]	-0.073	-0.072	-0.071	-0.070
Load-weighted average wind output [MW]	46.799	46.494	46.189	45.884
Wind total effect [EUR/MWh]	**-3.410**	**-3.392**	**-3.344**	**-3.299**
PV specific effect [EUR/MWh]	-0.007	-0.007	-0.007	-0.007
Load-weighted average PV output [MW]	237.805	231.707	224.085	216.463
PV total effect [EUR/MWh]	**-1.621**	**-1.609**	**-1.554**	**-1.433**
Total merit-order effect [EUR/MWh]	**-5.020**	**-4.968**	**-4.844**	**-4.657**

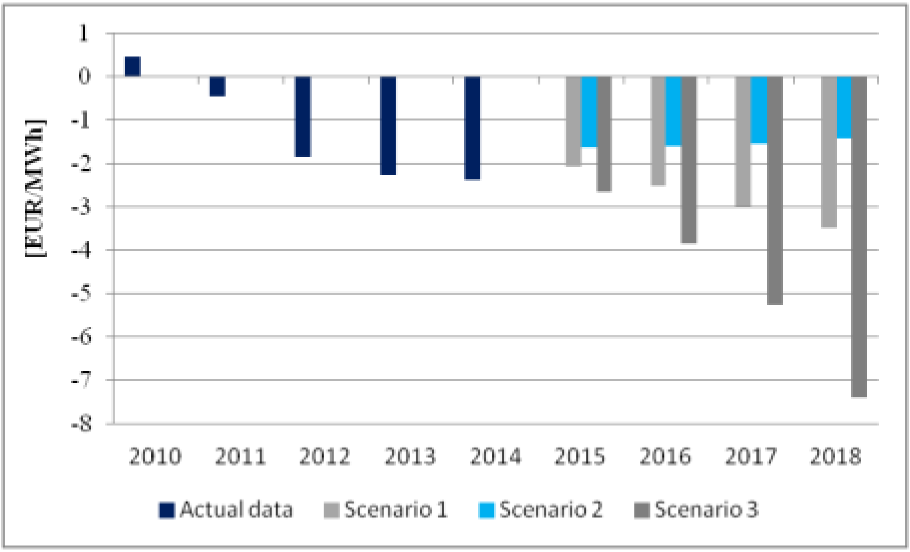
The results of the third scenario are displayed in the **Table 0.23**. The merit-order effect for the wind production remains unchanged. In the case of the merit-order effect we can observe substantial changes in comparison to previous scenarios. This scenario counts with extension of existing PV capacities five times until 2018. The peak capacity in 2018 would be more than 10 GW, which means that in case of full utilization the photovoltaic plants could cover all the consumption in the Czech Republic if there were good weather conditions.

Table 0.23: Projection of merit-order effect – Scenario 3

	2015	2016	2017	2018
Wind specific effect [EUR/MWh^2]	-0.071	-0.070	-0.071	-0.074
Load-weighted average wind output [MW]	46.951	46.951	46.951	46.951
Wind total effect [EUR/MWh]	**-3.345**	**-3.285**	**-3.320**	**-3.482**
PV specific effect [EUR/MWh]	-0.007	-0.007	-0.006	-0.006
Load-weighted average PV output [MW]	378.049	570.122	846.037	1 265.244
PV total effect [EUR/MWh]	**-2.641**	**-3.836**	**-5.268**	**-7.397**
Total merit-order effect [EUR/MWh]	**-5.020**	**-7.121**	**-8.588**	**-10.879**

The setting of this scenario results in more pronounced merit-order effect The specific merit-order effect does not change much although in 2017 and 2018 there is little drop caused probably by the flatter slope of the estimated price curve. However total PV effect increased due to increased capacity and production from photovoltaic power plants. In this scenario, average total merit-order effect caused by solar plants rose from 2.641 EUR/MWh in 2015 to 7.397 EUR/MWh in 2018.

Figure 0.15: Average total merit-order effect caused by PV plants



The Figure 0.16 summarizes merit-order effects from all scenarios. We showed that marginal effect of production does not differ among scenarios. The average effect of additional MWh produced by photovoltaic plants is 0.006 or 0.007 EUR decrease of the wholesale price in all scenarios. Still total effects differ.

The amount of solar energy produced is the main driver of total average merit-order effect. Notably, there is difference between the Scenario 1 and the Scenario 3. By the end of 2018, the solar capacity in the Scenario 3 is 2.5 times higher than in the Scenario 1 and the total average merit-order effect is 2.1 times higher in the third Scenario. Thus the total effect increased nearly proportionally to the increase of the capacity constructed.

5.6. Revenue factors

In this part we will determine revenue factors for photovoltaic power plants in the Czech. The revenue factor is ratio of average spot price received by operators of PV plants and average spot price received by all operators. The revenue factor takes into account only the wholesale price, not subsidies and other support. Future prices are derived from the estimated price curve, where we use forecasted residual load and fit the respective price on the price curve.

Table 0.24: Historical revenue factors

	2010	2011	2012	2013	2014
Load-weighted average PV in-feed per hour [MW]	18.90	200.89	245.85	229.23	243.9
Average PV spot price [EUR/MWh]	46.17	56.06	44.31	36.68	32.88
Average spot price [EUR/MWh]	39.53	51.85	44.34	38.62	34.45
Revenue factor	**117%**	**108%**	**100%**	**95%**	**95%**

Revenue factors from past five years that were used a source for our analysis and are shown in the **Table 0.24**. In first two years, when the production from PV power plants was not so high, the revenue factors were higher than one. It means that solar producers could have sold their power in the spot market above the average because they benefited from the higher demand during peak hours, which is in line with the proposition of Borenstein (2008) that economic value of solar energy is higher.

However in next three years, the average price for the production from PV plants would not have exceeded the industry average price. In 2013 and 2014 the price for the solar production was only at 95 % of overall average.

Table 0.25: Revenue factors –Scenario 1

	2015	2016	2017	2018
Load-weighted average PV in-feed per hour [MW]	300.31	359.76	426.83	507.62
Average PV spot price [EUR/MWh]	33.47	32.02	30.38	28.61
Average spot price [EUR/MWh]	37.35	36.89	36.43	35.82
Revenue factor	**90%**	**87%**	**83%**	**80%**

By Fitting prices on the residual load modelled in the first scenario we get even lower revenue factors than in 2014 and with each another year the revenue factor decreases.

The second scenario also shows the decrease in revenue factors but smaller than in the case of the first one.

Table 0.26: Revenue factors –Scenario 2

	2015	2016	2017	2018
Load-weighted average PV in-feed per hour [MW]	237.81	231.71	224.09	216.46
Average PV spot price [EUR/MWh]	33.46	32.05	30.24	28.49
Average spot price [EUR/MWh]	37.05	36.43	35.67	34.91
Revenue factor	**90%**	**88%**	**85%**	**82%**

In the last designed scenario, we observe larger drop in prices of solar production than in previous two. This is given by the low levels of residual load in many hours. In some hours the price even reaches negative values, when the production form solar plants is really abundant. This is a realistic behaviour as seen in the past, when producers were willing to pay buyers to accept their production because otherwise they would have to pay a penalty on a regulatory market for causing the imbalance.

Scenario 3 shows that if the capacity of PV plants was to increase five times until 2018. The average price for PV output sold would less than half of overall average, which would make solar energy even less competitive.

Table 0.27: Revenue factors –Scenario 3

	2015	2016	2017	2018
Load-weighted average PV in-feed per hour [MW]	379.05	570.12	846.04	1 265.24
Average PV spot price [EUR/MWh]	31.47	27.43	21.79	13.87
Average spot price [EUR/MWh]	36.73	35.52	33.69	31.25
Revenue factor	**86%**	**77%**	**65%**	**44%**

5.7. Comparison with costs of production

In a previous part, we analyzed the development of prices, for which the electricity could be sold on the spot market. Nonetheless, the equation of profitability of a project has also a cost component. In this part, we will compare the current prices of electricity with benchmarks costs for building the power plant in the Czech Republic.

Then we will use the prices from predicted scenarios with forecasted development of prices. The method of doing so will be very straightforward. Two values for unit cost and unit price will be compared. This is done to put prices, which were estimated in the previous part, into wider framework.

As the cost benchmark we will use LCOE (levelized cost of electricity). LCOE is the present value cost of production of one unit of electricity over the lifetime of the power plant.

Felcman (2014) created an economic model of a small scale solar power plant that would be built in the Czech Republic. The estimate of LCOE was 3117 CZK/MWh (113 EUR/MWh)[1]. Fraunhofer instittut (2013) computed LCOE for German installations.

Their prices range between 80 EUR/MWh and 140 EUR/MWh depending on the type and scale of the power plant. They make also forecast up to 2030. Their lower bound estimate is 55 EUR/MWh for 2030 and 70 EUR/MWh for 2020. We consider that if the similar study were conducted on the Czech market data, its results would not be different from the German study. This assumption is based on the geographic vicinity of both countries and marketability of components for the construction of a photovoltaic plant. Thus the results of the study by (Fraunhofer instittut, 2013) are used for comparison with predicted prices.

To put the data of costs into wider context, the market research is presented. US Energy Information Administration (2015) published LCOE for US market. Its estimate for PV power plants is 125.3 USD/MWh (114 EUR/MWh). The prediction for 2020 is 83.0 USD/MWh (75.8

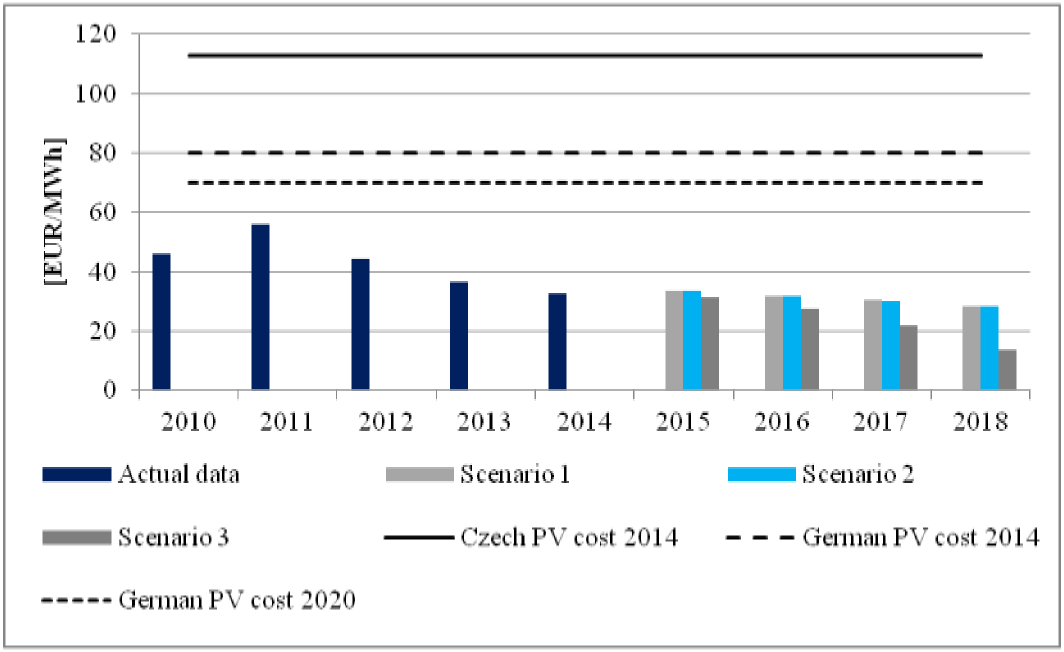
[1] Average 2014 CZK-EUR exchange rate 27.5 CZK/EUR was applied. Source: Czech National Bank.

EUR/MWh)[2]. The results of this study are in line with figures presented beforehand so this fact corroborates the use of two aforementioned studies for comparison.

The screening of LCOE from different studies yield that our computed average prices from PV sources are lower than costs to produce one MWh. Even the lowest prediction of LCOE from our short survey by (Fraunhofer instittut, 2013) for 2030 (55 EUR/MWh) is lower than current prices and prices from all scenarios.

[2] 1.0944 USD/EUR. Rate published by ECB on 1 June 2015.

Figure 0.16: Comparison of average PV spot price and LCOE



Source: Authors computation, (Felcman, 2014) *and* (Fraunhofer instittut, 2013)

The **Figure 0.16** summarizes the preceding text. The figure contains past average PV prices and forecasted prices based on three scenarios (Scenario 1 – twofold increase in the PV capacity till 2018; Scenario 2 – increase in energy efficiency; Scenario 3 – fivefold increase in the PV capacity till 2018.) and LCOEs. The past and predicted revenue per MWh is less than costs of producing regardless which LCOE we use as a benchmark.

Based on our scenarios, the solar power has hot become competitive in Central Europe despite up to 70 % drop in the price of power modules. Moreover, the more the production increased the more drops the average price of produced solar electricity and the gap between price and costs increases. So we conclude that in the current setting further increase of the solar capacities is not a reasonable choice and we did not come closer to a grid parity.

On the side note, depressed prices induced by the production of subsidised renewable energy cause capacity underinvestment in competitive electricity markets. This is phenomenon described by Milstein & Tishler (2012). The situation forces regulator to come up with new solutions to promote incentives for building new capacities. The idea of underinvestment into new capacities is corroborated in the Czech case by considered contract for difference in order to expand nuclear capacities (Ministry of Industry and Trade of the Czech Republic, 2014).

6. Conclusion

This paper provides a description of the energy, mainly photovoltaic related, situation in the Czech Republic and it quantitatively investigates future prospects of solar energy in Central Europe with focus on the Czech Republic. The merit-order effect is estimated. In last five years the wholesale price of electricity decreased on average by 0.009 EUR/MWh. The total average merit-order effect over five-year period was 4.544 EUR/MWh. The effects were more pronounced in later years.

The decrease of the price makes the solar energy less competitive on the market grounds despite the drop in construction costs. The deployment of new power plants would make the wholesale price decrease even more and so the gap between unit price and unit costs of solar electricity would increase. Thus the solar energy would be further from the grid parity.

We conclude that new solar projects are not viable without subsidies and new projects would not be able to profitable without public support. Thus solar power plants do not appear to be a reasonable choice in the Czech Republic. Nevertheless, low wholesale prices make all sources not competitive. The selection of the right energy source and its support is left for further research.

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