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Abstract:
This text provides a financial survey of a small sample of Czech photovoltaic (PV) plants. To evaluate the extent of market losses, we calculate the shadow market price of solar electricity. From the profit and loss accounts of the PV plants and the shadow market price we estimate the total economic loss generated by PV electricity sector in the Czech Republic.

The presented microeconomic approach has two main advantages: Firstly, we work with real observed data, which offsets the drawback of a limited sample. Secondly, the profit accounting calculation enables sensitivity analysis with respect to key variables of the plants.

We show that every million invested in PV plants would generate an annual loss of 11%. Given the estimated solar assets of CZK 127.4 billion (EUR 560 million) as of December 2010, this translates in at least CZK 14 billion lost in the Czech solar sector in 2011.

About 42% of this loss is due to high technology costs and corresponds to pure dead weight loss, while the remaining 58% constitute the redistributive profit component of subsidies. Finally, we calculate that unless electricity prices increase or technology costs decrease approximately tenfold, PV plants will remain loss making.

1. Introduction

Anthropogenic global warming (also referred to as climate change) and its extent are becoming more disputed among scientists. Meanwhile goverments around the world have adopted various energy policy measures with significant financial impact on public budgets. The most widespread measures include subsidies of renewable sources of energy, especially photovoltaic (PV) electricity generation.

Several affairs of the PV sector recently caught negative attention in the media: (1) Generation of subsidized green electricity at night using diesel aggregates in Spain.[1] (2) Bankruptcies of several large PV companies, including PV panel producers Evergreen Solar and Solyndra.[2] (3) Electricity price increase of up to 20% for Czech customers due to PV energy subsidies, which was under pressure reduced to 5%.

This study concentrates on the last case. We provide a survey of PV plants in the Czech Republic, where we focus on large greenfield projects. We analyze their profitability and decompose their cost structure. We calculate alternative revenue scenario based on market prices, which allows us to calculate the real revenue gap needed to be covered by subsidies. This follows the approach of Borenstein [2], who employs this procedure to determine the market value and cost of PV electricity in the U.S.

Dusonchet and Telaretti [3, table 11] show that Czech Republic, along with Slovakia and Bulgaria, are among the three Central and Eastern EU member states with the most generous PV subsidy programmes. However most western EU countries have still more profitable PV subsidies, as documented in Dusonchet and Telaretti [4, table 20]. Šúri *et al.* [15, p. 1298] name Czech Republic along with Germany as an example where "policy has stimulated PV

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[1]This particular case received extensive international coverage, see Bloomberg, July 29, 2010, accessed at http://www.bloomberg.com/news/2010-07-29/spain-to-investigate-solar-plant-irregularities-government-official-says.html.

[2]Solyndra even received $535 million of US federal government guaranteed debt to finance its expansion. The company reported assets of $859 million and debt of $749 million, see Bloomberg, October 17, 2011, retrieved at http://www.bloomberg.com/news/2011-10-17/solyndra-judge-denies-u-s-request-to-put-trustee-in-charge-of-bankruptcy.html.

When Evergreen Solar filed for bankruptcy, it owed its creditors $485.6 million while listing assets of $424.5 million. See Bloomberg, August 15, 2011, accessed at http://www.bloomberg.com/news/2011-08-15/evergreen-solar-seeks-bankruptcy-protection-with-debt-of-486-5-million.html.

German PV panel producer Solon SE filed for insolvency in December 2011, with debt of EUR 570m and assets of EUR 466m as of September 2011. See Bloomberg, December 14, 2011, retrieved at http://www.bloomberg.com/news/2011-12-14/german-solar-stock-pioneer-solon-plummets-on-insolvency-filing.html.

Note that this is only a selection of the most dramatic cases of destruction of shareholder and creditor value in the PV sector.

growth even in regions with moderate solar energy resource". Thus Czech Republic is a Central and Eastern European country which joined rich western EU countries in their generous PV support.

This calls for a detailed analysis of impacts of the supportive PV policy. Hitherto evaluations of Czech PV subsidies (including Dusonchet and Telaretti, c.f.) are based on a top-down approach calculating merely with the value of feed in tariffs (hereinafter FIT, defined in the next section). However our approach has the benefit that we look at the single plant level to build a comprehensive view of their microeconomics and how efficiently these plants turn the subsidies into profits. When compared with estimated market value of PV generated electricity, as a result we provide a thorough estimation of the dead weight loss which was caused by Czech PV subsidies.

There is a growing amount of literature devoted to economic analysis of PV plants. The U.S. market was analyzed in great detail e.g. by Wiser *et al.* [16] and Borenstein [1]. The former paper tracks the cost of PV plants in terms of assets that were built, while the latter models complex U.S. subsidy schemes, so called time-of-use rates. The Czech case was most recently described by Smrčka [11], who argues against the efficiency of PV subsidies in terms of theoretical political economy. To the best of our knowledge our microeconomic survey is completely novel in the field.

The rest of the paper is organized as follows: In section 2 we introduce general theoretical considerations on PV subsidies along with the legislation background. In section 3 we present the core microeconomic survey of selected PV plants. Figures from this survey enter our calculation of dead weight loss in section 4. Section 5 concludes.

2. Theoretical Considerations

2.1. Understanding PV Costs

It goes without saying that without subsidies PV plants would generate losses, otherwise subsidies would not be needed in the first place. These losses stem above all from significant requirements for capital investment into plant equipment. Not only are solar panels produced by expensive technology. The panels also use costly materials and are relatively fragile, which shortens their expected lifetime.

The situation was made worse by the subsidies themselves, because the governments in fact generated a perfect PV bubble. Polysilicon, the major component of solar panels, illustrates the case:

> Polysilicon has been used as a semiconductor in computer microchips for decades. Supplies only became scarce from 2004, when European nations began introducing subsidies for clean energy. The price

soared to \$475 [per kilo] in March 2008 from about \$30 in 2003. New capacity began to come on stream in 2008.[3]

As of 2011 year-end the price has fallen back to \$33 due to massive jump in capacity and fall in demand. At this price however, some producers are making big losses and will have to close down. On this example we see the size of the shock that is imposed on the economy because of one simple policy.
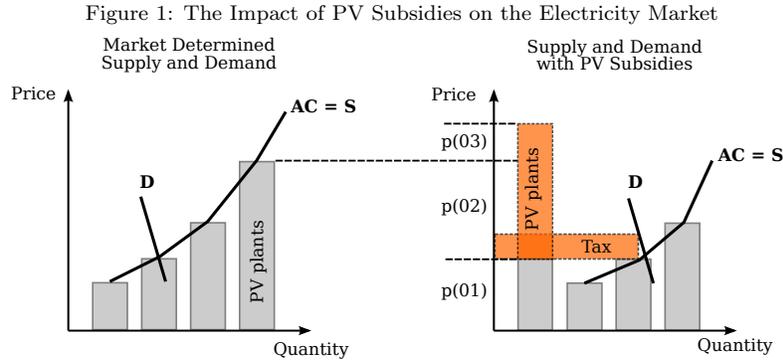
In the Czech Republic we will evaluate the size of this shock in more detail. We will analyze the case of feed-in tariffs, which is a common way to subsidize electricity from PV plants. An excellent overview of other options to support PV plants is provided by Timilsina *et al.* [13, sec. 5].

FIT are defined as a scheme in which producers of PV electricity are paid for each unit certain guaranteed fixed price above market price. Such subsidies of course do not lower costs of PV electricity. Instead, customers are charged more for electricity than their original willingness to pay. In the Czech case it is the regional electricity distribution companies who are forced to pay artificially high price to PV producers. Distribution companies are then allowed to pass this additional cost onto end consumers. This PV surcharge is spread over all units of electricity sold, so that end customers end up paying higher average electricity price.

The subsidized price can be decomposed into three parts. The first part of the price p_{01} covers the average cost of electricity in the grid produced by standard plants. Price p_{01} approximately corresponds to the market price at which electricity is traded on the commodity exchange. To the extent that average cost of PV plants is higher than average cost of the remaining sources, there is *dead weight loss* in the economy induced by the subsidies. The difference between PV average cost and p_{01} is the second subsidized price component p_{02}, which we call the pure DWL component. Finally the third component p_{03} is the amount above PV average cost which constitutes profits of PV plant owners. As we shall see below a significant part of the subsidies goes to this profit component.

This decomposition is schematically shown in figure 1. The shaded rectangles indicate various sources of electricity, typically these would be nuclear, lignite/coal and natural gas plants. Note that the costs depicted here include the interest accrued to creditors and shereholders. PV plants are at the right end because their market cost is too high. The figure on the right shows how the situation changes after PV subsidies are introduced. The supply curve is distorted, as suddenly PV plants are shifted to the left. A green tax is introduced

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Figure 1: The Impact of PV Subsidies on the Electricity Market

Note: Proportions in this figure do not correspond to real values.

which is paid by all consumers, driving the price above the natural market price. The proceeds are distributed to PV plants to cover their excessive costs (p_{02}) and any additional profits made by PV plant operators (p_{03}). Hence the two dotted (orange) rectangles have an equal area.

In reality the subsidies can be financed from other sources than just a price increase. In the Czech Republic, for example, the sum of subsidies granted to PV operators was covered by three sources: (1) the green tax on electricity price, (2) the proceeds from the sale of CO2 permits to companies, and (3) a special tax on profit of PV plants operators.

The empirical counterpart to the left chart in figure 1 is depicted in figure 2. Figure 2 shows estimated unit electricity costs according to the Boston Consulting Group, along with the approximate breakdown of the total price into the main components: capital expenditures required (fixed costs), operating expenditures excl. fuel (variable costs), fuel costs and CO2 emission permits.

Additionally, for onshore wind energy and for PV plants the figure also shows estimates of costs of grid balancing which are not paid by the producer but by the grid operator. The balancing costs arise because electricity generation by these sources depends on weather conditions that cannot be influenced and that are independent of demand. This so called intermittency problem was analyzed in great detail by e.g. Gowrisankaran *et al.* [5]. Currently grid operators have to devote significant resources to balancing when these sources are suddenly start or stop producing electricity. Even though the costs indicated in figure 2 are rough estimates and would in practice vary across countries, we include the figure to provide a reality check for figure 1.

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Figure 2: Estimated unit electricity costs in EUR/MWh according to BCG [12].

■ Capital expenditures ■ Operations and maintenance ■ Fuel ■ CO2 permits ☐ Grid balancing
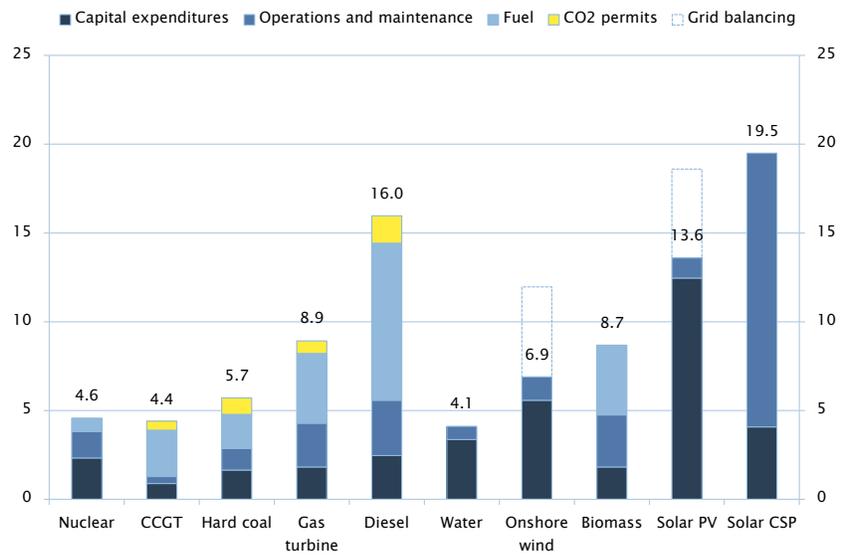
Note: CCGT = Combined cycle gas turbine. CSP = Concentrated solar power.
Assumptions: CO2 price 20 EUR/t, gas price 25 EUR/MWh, oil price 80 USD/bbl.

It is crucial to distinguish between the above listed components of subsidized price of PV electricity. The pure DWL component is a net loss to the economy, because it captures the extent of inefficient electricity production. p_{02} is equivalent to artificial cost which would not exist were it not for the subsidies. It is equivalent to a certain sum of goods which could have been produced instead and which would have increased consumer utility. As this wealth cost trickles through all segments of the economy in a multiplicating way, we certainly know that this cost is carried by all citizens, even those who otherwise participate in financial benefits from PV subsidies. Other than that we cannot say much about exact proportions in which different groups of consumers will bear this cost.

The profit component p_{03} is different: It is in fact a pure redistributive tax. Just as any other sales tax, p_{03} increases price of the good (electricity) and the proceeds are redistributed, in this case to PV plant owners. Taxes induce inefficiencies of their own, which we leave aside at this point. However we can determine the effect of this quasi-tax on consumers. The demand for electricity is highly inelastic, and electricity bills take a higher share of living cost for the poor than for the rich. Moreover this profit goes directly to capitalist investors in the PV sector. From these three points we therefore derive that the profit component p_{03} is tax regressive.

It is worth noting that a carbon tax has the same effect. Due to low elasticity of demand, producers of electricity can pass this additional cost on consumers, and the tax is again born by all citizens. This is why we conclude that the effect of a carbon tax is regressive as well.

2.3. Czech Legislation

The subsidies of PV electricity in the Czech Republic were introduced due to the legally binding *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources*. Following this directive the Czech Ministry of Industry prepared the *National Renewable Energy Action Plan* dated July 2010 (NREAP[4]), which outlines targeted shares of each energy source on total consumption until 2020.

Even though the NREAP proposes to increase the share of renewables on total energy consumption from 8.3% in 2010 to 13.5% in 2020, it does not even touch the topic of costs of this plan. The evaluation of costs and benefits of renewable subsidies is not a mandatory part of the NREAP, therefore this part was left empty in the Czech NREAP (p. 75).

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[4]See the National Action Plan, retrieved at http://www.mpo.cz/dokument79564.html

Specifically the NREAP defines the target for PV electricity to be 1,695 MW of installed capacity as of 2020, gradually increasing from 1,650 MW that were to be reached in 2010 (p. 80). However this plan was exceeded already in 2010 by 170 MW (+10%) and in 2011 by 311 MW (+19%, see below table 6). This suggests that the subsidies for PV plants, and accordingly the costs for Czech consumers, were set quite high. We now turn to a rigorous examination of these costs.

3. Czech PV Plants

3.1. Summary of Surveyed Plants

This part surveys the segment of photovoltaic power plants in the Czech Republic. We depart from microeconomic analysis of individual companies operating the largest Czech PV plants. The Czech *Energy Regulatory Office* (ERU) published the regular survey of electricity market for 2010 (see Lukáš [9]) with a complete list of PV plants whose capacity is larger than 5 MW. As a relevant sample of these plants, we select those which started production in 2009, so that they already went through a full year of operation in 2010.

Table 1: Summary of sample PV plants.

	Legal form	Financials	Total assets	Fixed assets
		Year	*CZK mil.*	*CZK mil.*
REN POWER II	s.r.o.	2010	521.1	464.3
Solar Stribro	s.r.o.	2010	1,762.1	1,588.3
BS Park I	s.r.o.	2009	196.5	128.1
FVE Czech	a.s.	2009	621.2	574.2
Papeno	s.r.o.	2009	603.6	519.4
CEZ OZ	s.r.o.	2010	4,669.7	4,316.3

Note: s.r.o. = limited liability company, a.s. = joint stock company.
Source: Czech Business Register.

There are six such companies: BS Park I, CEZ Obnovitelne zdroje, FVE Czech, Papeno, REN Power CZ II and Solar Stribro. We obtained financial data of these companies from the publicly available business register. The latest annual report which was available is shown in table 1.

Table 2 shows production of sample plants in 2010 compared to their capacity. Capacity usage in the third column is computed as the ratio of production to capacity in MWh/MW_e (i.e. in hours). Dividing this by the total number of hours in the year (8,760) we get the percentage usage of the plants. Average usage of the plants was 734 hours (8.38%). This is in line with the results of Šúri *et al.* [15, p. 1298] who calculate theoretical usage of plants based on insolation taken from the Solar radiation database. They show on the map that Czech Republic lies mostly in the area with potential usage of 700-800 hours.

Table 2: Production of sample PV plants in 2010.

	Capacity	Production	Capacity usage	
	MW_e	MWh net	MWh/MW_e	%
REN POWER II	7.3	5,130	706	8.06%
Solar Stribro	13.6	13,056	959	10.95%
BS Park I	8.1	2,637	325	3.71%
FVE Czech	6.1	6,372	1,047	11.95%
Papeno	8.4	5,222	618	7.06%
CEZ OZ	21.3	15,911	747	8.53%
All plants	64.8	48,328	734	8.38%

Source: Energy Regulatory Office, own calculation.

3.2. Balance Sheet Indicators

From available financials we calculate the most important balance sheet indicators. We exclude CEZ in this evaluation because their portfolio includes water and wind power plants.

The *equity to assets* ratio shows sources of financing for PV plants. In our sample this ratio averages mere 8.1%. This means that for every million of shareholders' equity there must be more than 11 million of liabilities, which in turn are mostly represented by bank debt. PV plants are highly leveraged projects where banks are the dominant stakeholders.

Table 3: Balance Sheet Indicators for Sample PV Plants.

	Equity to Assets	PPE to MW_e	Liabilities to MW_e
	%	CZK mil.	CZK mil.
REN POWER II	3.52%	63.9	68.9
Solar Stribro	23.28%	116.7	99.3
BS Park I	-0.20%	15.8	24.3
FVE Czech	4.56%	94.4	97.4
Papeno	9.22%	61.5	64.9
Average	8.08%	70.5	70.9

Source: Czech Business Register, own calculation.

The second indicator captures investment costs required per MW_e, by taking fixed assets (called property, plant and equipment, or PPE) and dividing PPE by generating capacity. The *PPE to capacity* ratio is of crucial importance, as it will help us evaluate total investments in Czech PV plants. This ratio can also be seen as cost per unit MW_e of generating capacity. As can be seen from the data, average cost of 1 MW_e amounts to CZK 70 million (approx. EUR[5]

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[5]Throughout the text we use the approximate exchange rate of CZK 25 per EUR.

2.8m).[6] There are also significant differences across single plants. BS Park cost per MW_e is mere CZK 16m, which can be explained by the fact that most of the production capacity was installed in 2010, while the financials are from 2009. Average cost of the remaining four plants is then CZK 84m per MW_e. Variation at the upper end can be explained by differences in location (cost of land) and in cost of technology.

Lastly we turn back to financing and evaluate the amount of liabilites (both current and long term) per MW_e of capacity. For the sample plants the *liabilities to capacity* ratio is CZK 71 million. This simply means that all PPE investments are debt financed and underlines once again the important role of creditors, especially banks, in the Czech PV sector, which will prove important in further discussion.

3.3. Income Statement Indicators

For two PV plants we were able to look at the complete income statement. The remaining plants did not publish 2010 financial reports yet, and 2009 income statement was not relevant as the plants were still under construction and did not produce significant amount of energy. Annual report of CEZ OZ does not distinguish between PV power and other renewable sources.

Table 4 shows selected figures from the income statement. It can be seen that *EBITDA margin* (the ratio of EBITDA to revenue) is very high, averaging 89.4%. PV plants do not require any full-time employees. Maintenance and servicing costs are recorded as cost of services. EBITDA then covers two major cost items: depreciation and interest payments. After accounting for these, the listed plants were able to cash in net profits of CZK 2,619 per MWh, which is equivalent to over EUR 100 per MWh. This is equivalent to a *profit margin* of 18%. Note that the profit itself is higher than average price of traded electricity in 2010.

Table 4: Cost Decomposition for Sample PV Plants.

	Revenue CZK/MWh	EBITDA CZK/MWh	Depreciation CZK/MWh	Interest CZK/MWh
REN POWER II	15,444	15,079	5,497	4,068
Solar Stribro	13,125	10,403	4,645	6,033
Average	14,284	12,741	5,071	5,051

Source: Czech Business Register, own calculation.

Table 5 relates income statement indicators to the respective balance sheet

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[6]Developers offer PV projects to prospective investors such as CEZ at a price of EUR 200-250 thousand, i.e. CZK 5 to 6.25 million.

figures. *EBITDA to assets* ratio indicates how asset intensive the business is. The 11% will enter our evaluation of total cost of subsidies in the next section.

We show that *depreciation* is at the expected level of 5%, meaning that the plant will be completely written off after 20 years. *Interest rate* on debt stood at 6.4%, reflecting the perceived predictability of returns at the time of construction.

Table 5: Income Statement to Balance Sheet Ratios for Sample PV Plants.

	EBITDA/Assets	Depreciation/PPE	Interest/Debt
REN POWER II	14.8%	6.5%	6.5%
Solar Stribro	7.7%	3.8%	6.3%
Average	11.3%	5.1%	6.4%

Source: Czech Business Register, own calculation.

3.4. Market Value of PV Electricity

To calculate PV costs, we need to estimate the shadow market price of PV electricity. We started with market prices from OTE. OTE is a Czech company which organizes short-term market with electricity and natural gas delivered at the Czech virtual trading point. Participants trade mostly with day-ahead or intra-day electricity, and moreover they are allowed to trade with their distribution network imbalances. Market data is publicly available at the website of OTE.[7] These prices can be viewed as marginal electricity prices for the given hour of the year. The average market price in 2010 from these data is 1,087 CZK/MWh.

However, to obtain the shadow PV price, we need to weight these prices by hourly electricity production of PV plants. Such data are not publicly available. ČEPS, the operator of the electricity distribution network, kindly provided us with unique data on hourly production of Czech PV plants in 2010. To the best of our knowledge this is therefore the first attempt to calculate shadow PV price directly from PV plant production.

To each hourly production we then assigned the market price from hourly trading data from OTE. PV plants only produce electricity when there is sunlight, and for majority of the hours we had the corresponding hourly price available. There were some missing prices however, because for some hours there were no recorded trades at OTE exchange.

We wanted to assign a price to non-zero hourly production even if no recorded trade was available in that hour. For each hour of the day (from 1 to 24) we calculated yearly average trading price in that hour. Thus we arrived at 24

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[7]See www.ote-cr.cz.

average hourly prices. If PV plants produced 17 MWh of electricity in the 9th hour on January 1st 2010, but there was no price at OTE exchange, we used the average price for the 9th hour of all days in 2010.

PV plants had non-zero production in 5,005 hours of the year, and for 1,379 hours (27.6%) we had to use the hourly average price. The computation yields the shadow market price of PV electricity of **1,091.5 CZK/MWh** (43.7 EUR/MWh). We will use this result in the section 4 to estimate PV costs in the Czech Republic.

4. Cost of PV Subsidies

4.1. Income Method

One method to calculate cost of PV subsidies is to evaluate the sum of feed-in tariffs above market price. This way we can get a simple approximation of how much money must be extracted from the rest of the economy and shifted to the PV business. Table 6 shows Czech feed-in tariffs as they are set by the Energy Regulatory Office.

Table 6: Feed-in Tariffs and Installed Capacity

CZK/kWh	**Plant Capacity**			**Installed Capacity**
Year of Construction	**< 30 kW**	**30-100 kW**	**> 100 kW**	*MW, year end*
2011	7,500	5,900	5,500	1,971.0
2010	12,500	12,400		1,820.0
2009	13,420	13,320		464.4
2008		14,300		39.5
2006, 2007		14,660		3.6
< 2006		6,990		0

Source: Energy Regulatory Office, price regulation no. 2/2010.

In table 7 we estimate the cost from the difference between average feed-in tariffs and average market prices. We weighted average feed-in tariff by newly installed capacity in the given year. The market price is the weighted average of hourly settlement prices from the Czech short-term electricity market operated by OTE for 2009 and 2010. In addition, we also use the shadow PV price calculated in section 3.4 for 2010.

Note that the market price of electricity corresponds only to the price of commodity. Electricity price paid by end users is composed from other components such as distribution fees or contribution to renewable resources, so that the final price might be up to four times higher.

In 2009 the average final electricity price was 4,128 CZK/MWh for households and 4,487 CZK/MWh for companies, including value added tax of 19% (see the ERU report [9, part 6, p. 2]). Table 7 shows that average feed-in tariff is

Table 7: Cost of PV Subsidies: Income Method

Year	Production MWh	Feed-in tariff avg., CZK/MWh	Market price avg., CZK/MWh	Cost CZK mil.
2010 (A)	615,700	12,717	1,087	7,161
2010 (B)	615,700	12,717	1,092	7,158
2009	88,800	13,498	1,026	1,107

Source: Energy Regulatory Office, OTE, own calculation.

about twelve times higher than the market price, and almost three times higher than final consumer price of electricity. In computation (A) for 2010 the market price is employed, and in computation (B) the shadow PV price is employed.

The total cost of PV subsidies in 2010 amounted to approximately **CZK 7.2 billion**, or EUR 288 million. As we discussed in section 2, this is equal to both the DWL (p_{02}) and the profit (p_{03}) component of the subsidies. Because the market price and the shadow PV price do not differ significantly, the presented result is robust with respect to the base price used.

4.2. Tied-up Resources

The method which we described in the previous section does not completely account for resources which are tied up in PV plants over the period of their lifetime. Construction of solar plants requires significant investments in fixed assets, including land plots and PV panels. Solar panels are not versatile and cannot be employed elsewhere except for electricity generation. Ecological liquidation or recycling of materials used in the panels is questionable and costly.

As such fixed assets sunk in the PV sector represent resources which are missing in other sectors of the economy. Normally PPE costs (depreciation and foregone land rent) are covered by company earnings, however given that PV plants are loss making on a market basis, these resources could have been invested in a more efficient way, generating higher economic value added and increasing general wealth. To analyze the one-off loss to the economy represented by PV assets, we estimate the sum of PPE which are committed to PV plants for a period of their depreciation.

In table 3 we calculate that each MW_e of generation capacity requires roughly CZK 70 million in PPE. Multiplying this by installed capacity of 1,820 MW_e as of 2010, this yields total resources amounting to CZK 127.4 billion which were taken from other sectors. We show in table 5 that average depreciation for the surveyed plants equals 5%, which corresponds to 20-year depreciation period. We can sum up that as a result of PV subsidies the economy has to withstand a shock of about **CZK 6.4 billion** (EUR 256m) annually for 20 years — these are capital expenditures that have to be directed from other

sectors to PV plant building. Since this calculation does not capture foregone land rent, it represents a low-end estimate of the costs of PV subsidies.

This number does not directly estimate losses, as there will be electricity production on one hand and further variable costs on the other hand. However it illustrates the magnitude of adjustments that are needed as a result of PV subsidies and that increase the volatility of doing business in the Czech Republic.

4.3. Profit Accounting Method

Finally, profits or losses stemming from PV subsidies can be estimated from microeconomic data based on average profit or loss margin of PV plants. We can formalize this idea as

$$PL = \text{Profitability} \times \text{PPE} \ ,$$

where PL are costs of subsidies to the economy.

To derive the profitability we can start from standard profit accounting:

$$
\begin{aligned}
PL &= \text{Revenues} - \text{Costs} \\
&= \text{capacity} \times \text{usage} \times \text{electricity price} - \text{depreciation} - \text{interest} \\
&= \frac{\text{PPE}}{\text{cost per MW}} \times \text{usage} \times \text{electricity price} - \\
&\quad -\text{PPE} \times \text{depreciation rate} - \text{PPE} \times \frac{\text{debt}}{\text{PPE}} \times \text{interest rate}
\end{aligned}
$$

We used the fact that PPE is a multiple of capacity and unit cost of MW_e. Denoting depreciation δ, leverage $\lambda = \frac{\text{debt}}{\text{PPE}}$ and interest rate i we finally derive:

$$
\begin{aligned}
PL &= \text{PPE} \times \left[\frac{\text{usage} \times \text{electricity price}}{\text{cost per MW}} - \delta - \lambda \times i \right] \quad (1) \\
&= [\text{CZK}] \times \left\{ \frac{[\text{h}] \times [\text{CZK/MWh}]}{[\text{CZK/MW}]} - [\%] - [\%] \times [\%] \right\} = [\text{CZK}]
\end{aligned}
$$

The last line indicates units of each of the variables.

We calculate this value for 2010. As described in the previous section PPE $=$ 127.4 billion CZK. We take average usage of the plants from table 2: usage $=$ 734 hours. Depreciation and interest rate are from table 5. We calculated leverage λ as the ratio of liabilities to fixed assets to get $\lambda = 1.09$.

By plugging in the numbers we get

$$
\begin{aligned}
PL &= 127.4 \times \left[\frac{734 \times 1,092}{70,000,000} - 0.051 - 1.09 \times 0.064 \right] \\
&= 127.4 \times [0.011 - 0.051 - 0.070] \\
&= 127.4 \times (-0.11) \quad (2)
\end{aligned}
$$

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These numbers indicate that investments into PV plants without government support would be making a guaranteed loss of 11% of the original committment every year. The whole investment would be written off after less than ten years and over the expected lifetime of 15 years the investors would have lost 1.5 times the upfront investment.

The reason for the loss is obvious: Market price reflecting customer demand is not sufficient to cover high investment costs for PV technology. Note that high costs have to be understood as costs per usable hour, as PV plants have very low uptimes below 10% of the year.

Given the estimated value sunk in PV plants as of December 2010, annual economic loss generated by Czech photovoltaics stood at **CZK 14 billion** (EUR 560m). This estimate is roughly double the figure shown in section 4.1 which might appear strange at first sight. However most capacity was being built during 2010 with little production. Therefore the income method underestimates annualized costs arising from total PV capacity as of December 2010. Equation (2) is more precise as it is derived straight from operating figures of the plants.

From decomposition in equation (1) we can see that δ corresponds to the pure DWL component p_{02} caused by the high cost of technology. Hence $\frac{\delta}{\delta + \lambda \times i}$ share of the loss belongs to p_{02}, which in our case is 42%, or CZK 5.9 billion. The remaining 58% constitute the redistributive profit component p_{03}, amounting to CZK 8.1 billion. The bulk of this money was cashed in by financing banks (in the form of interest payments) for whom the PV plants are steady sources of cash flow.

Finally, our calculation (2) has the advantage of enabling sensitivity analysis. Suppose that the uptime of the plants could be doubled due to higher insolation: The resulting loss on invested assets would still be -10%. The same holds for solar electricity price. Only when the price is increased about tenfold do the plants turn profitable. Equivalently, the cost of PV technology would have to go down about tenfold to guarantee profitability.

5. Conclusions

This paper derives the cost of PV plants from their microeconomic operating scheme. As a background we describe the economics of PV subsidies and show how they create a redistributive distortion equivalent to a regressive tax. The core of the text is empirical: We provide a financial survey of a small sample of Czech PV plants. To evaluate the extent of market losses, we calculate the shadow market price of solar electricity. From the profit and loss accounts of the PV plants and the shadow market price we estimate the total economic loss generated by PV electricity sector.

The presented microeconomic approach has two main advantages: Firstly, we work with real observed data, which in our view offsets the drawback of a limited sample. Secondly, the profit accounting calculation in section 4.3 enables sensitivity analysis with respect to key variables of the plants.

As the main result of our model, we show that every million invested in PV plants would generate an annual loss of 11%. Given the estimated solar assets of CZK 127.4 billion (EUR 560 million) as of December 2010, this translates in at least CZK 14 billion lost in the Czech solar sector in 2011. About 42% of this loss is due to high technology costs and corresponds to pure dead weight loss, while the remaining 58% constitute the redistributive profit component of subsidies which mostly flows to financing banks as guaranteed interest income. Finally, we calculate that unless electricity prices go up or technology costs go down about tenfold, PV plants will stay in red figures.

Besides this bottom-up model, we also estimate PV costs by means of two top-down calculations, which we call the income method and the tied-up resources method. These estimates put the annual shocks caused by PV plants in the range of CZK 6.4-7.2 billion. These are however estimates for 2010 when most capacity was still being built, so that these figures are at the lower end of true costs.

In light of these costs the question naturally arises how can we justify the massive state support of PV plants. The usual answer is in order: Namely that state policies are much more often than they are not guided by motives other than economic logic.

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