Macroeconomic Costs of the Energy Transition in the Czech Republic

LUBOMIR LIZAL, JAN HORACEK, VACLAV SEDMIDUBSKY

Abstract

Background: Carbon neutrality and the entire energy transformation, especially of electricity supplies, lead to a change in the current energy paradigms. The past modelling approaches can lead to errors if not modified properly.

Aim: In this article we estimate the lower-bound of direct macroeconomic costs of the proposed electric energy mix change in the Czech Republic.

Methods: We augment the physical electric energy balance model with seasonally (monthly adjusted) estimated hourly average electric prices to show the economic difference between the yearly energy balance and import costs due to seasonal price patterns. This simple economic model is then applied on proposed future energy mix stemming from State Energy Policy (SEK) that does not consider the seasonal price patterns at all, and the paper goal is to provide the approximate magnitude of such an error. Our backward simulation imposing past prices and seasonal patterns on future energy mix is conservative, i.e., provides lower-bound estimate of the economic effect but also allows us to avoid future price and future consumption prediction errors.

Results: We show that the envisaged change in production mix leads to a direct increase in net imports that are comparable to the value above 0.5% GDP. When considering the fiscal multiplier, the total negative impact shall be around 1% GDP, annually. As the Czech economic growth is not stellar, the implied GDP decrease can further worse economic prospects.

Practical relevance/social implications: Models used by the state underestimate total costs and potential social impact of economic shrinkage.

Value: State energy policy shall be revised considering substantial effect of seasonal price variations leading to fiscal imbalances.

Keywords

Energy transformation, Czech Republic, Import dependency, Trade balance, Transition costs

JEL Codes

Q41, Q43, Q47, Q48, F17, F47, E17

DOI
http://dx.doi.org/10.37355/acta-2025/2-04

Introduction

Carbon neutrality and the entire energy transformation, especially of electricity supplies, lead to a change in the current energy paradigms. In addition, the changed geopolitical situation has reminded us of the energy security issues of the oil crisis. For example, Stegen (2011) deals with strategic use of energy and security issues while Guarascio et al. (2025) evaluate recent energy vulnerability and resilience in the EU regarding the imported energy inputs (mainly oil and gas). While energy generally includes the production of heat, cold and electricity, in this article we will focus on the latter part. In addition to the intended primary objectives, i.e., the transition from fossil fuels, the transition strategy has a few side effects in the electricity sector that must be dealt with.

The electricity sector is perceived either as the primary target of the transformation or as a source of a new, carbon-free electricity energy that will replace fossil fuels in other areas, especially industry and heating. Such a dichotomy unfortunately fuels biased partial views on the electricity industry and thus leads to distorted conclusions due to the unrealistic assumptions, and neglected impacts of regulation and omitted fundamentals.

The rapid ultimate change in the production mix means that old time-proved models of energy sectors are no longer suitable, as some long-standing (and therefore often silent and overlooked) assumptions cease to apply – as we will show later. Unfortunately, these facts are not given due attention both in policymaking and in the analysis of possible first-round or second-round effects.

It is worth pointing out the prerequisites for the liberalization of network industries. A key moment in European policies at the end of the last century was the separation and preservation of the network infrastructure with the character of a natural monopoly, which is the cheapest solution from a social point of view, and the enabling of equal competition of services or products on this infrastructure (the initial situation in the Czech Republic and the EU is described in Lizal, 2000).

From today's point of view, the policy of liberalization applied to telecommunications has led to an improvement in services. The energy sector, especially because of the original natural national diversification of production mixes and excess existing capacities, did not look like a problem after successfully coping with the emission limits of pollutants. However, the principle of neutrality has been violated by the gradual regulatory preferential inclusion of new (so-called emission-free) intermittent sources (RES). The growing problem of new inequality (subsidies, regulatory preference over other sources) has been de facto legislatively implemented as a new type of market (or rather regulatory) failure, which is now emerging to the surface in the form of (surprising) rapid price changes, volatility, and investment havoc in transmission and distribution networks. The electricity industry, for a long time being an industry where a long-term perspective worked perfectly, has become a highly volatile and risk-unpredictable part of the economy. Recently, however, so far theoretical risks of endangering the stability of networks have materialized in the form of an April 2025 blackout in Spain affecting 50 million people for nearly a day or a large outage in July in the Czech Republic affecting 3 million people for a few hours.

In the following sections of our article, we first explain common misconceptions and show why common price patterns emerge, and then we use these patterns in our simulation model to show that yearly physical balance of electricity generation and consumption can be associated with huge macroeconomic fiscal imbalance. The quantitative goal of the article is to quantify the omitted direct macroeconomic costs of the energy mix change in the proposed Czech State Energy Policy proposal.

1 The Emergence of Non-Market Competition: Market Separation

Perhaps the best and most important example of a change that documents both the confusion of concepts in the public space and regulatory failures is the approach to uncontrollable electricity production sources (RES) and the policy of emission allowances (ETS).

For a long time, the energy sector in the EU has not been developing according to competition on the market, but according to the impact of state interventions, as the price of emission permits depends directly on political decisions. The fact that permits are traded does not mean that the price is not a direct consequence of the political decision on how many of them were or should be available. The inconsistency of policies over time and permanent revisions act as an investment repellent: if there is a periodic tightening that changes the original political objectives, then the new goals are also implausible from the point of view of risk management of classic investment plans, and the area becomes the domain of speculative investments. The public interest is then solved by new subsidies that further distort the investment environment, and we begin to move in a vicious circle. While the investment decisions and the effects of ETS are subject to scholarly exercises often, our contribution focuses on a different direction.

Unfortunately, the total impact of regulations is also determined by the degree of misunderstanding of how the energy industry works in the real world. There are **less visible but equally serious impacts than the allowances described**. In the following short exposition, we start with Lizal (2025). The price of electricity for consumers is de facto created as a combination of results on two "markets" that are recently, due to regulatory policy-induced changes, moving apart in terms of price while originally these markets were almost identical. In addition, typically prices from only one of these two markets are presented – the wholesale commodity price.

Electricity is the only product that **we cannot store cheaply and massively**. Production adapts to demand at every moment to maintain a **physical (electric) balance between demand (consumption) and supply (production)**. However, the massive involvement of uncontrollable sources leads to a change in the quality (characteristics) of the distribution network. Previously, all sources were controllable, and it was possible to increase and decrease their output (very cheaply) as needed. As a result, there was no big difference between the price of electricity and electricity for power and stability regulation. As all sources operated close to their economic optimum the downward or upward deviation led to only a minimal increase in costs (or decrease in efficiency). Therefore, the prices of regulatory and basic energy were highly correlated, and regulation has been with a minimal surcharge.

Now, the RES (renewable energy sources) that are in the network system have a priority (which is given regulatory) and require other sources to adapt to their production. That is why there is a growing price difference between the power electricity for the so-called base load and the electricity needed for stability and **grid regulation**. However, the more RES, the greater the volatility of the regulatory component needed, and the greater the costs for providing it. That can only result in a growing difference between the baseload and balancing energy component prices. The baseload and balancing electricity markets have not only separated but are still diverging from each other. Increasingly more balancing electricity is needed, and at the same time there are fewer sources available that were used to provide it cheaply. In addition, these sources (formerly coal, today typically steam-gas) are further burdened with ever increasing price of CO_2 permits in ETS. Both permit price growth and increased scarcity of the balancing resources do work in the same direction to increase total balancing costs.

Electricity, as a baseload, may thus become cheaper, but as we document in the following section, due to the need for balancing electricity for the functioning of the network and other distribution costs, the total final consumer cost increases. In addition, expensive new sources (steam-gas) shall be added to make it possible to manage the network. Therefore, economic impact modelling must account for these specificities of influencing prices.

2 Regulatory Failure: Investor vs. National Economic Perspective

These issues mentioned are not new, see Ueckert et al. (2012), Idel (2023) or BoA(2022). The usual argument that RES saves conventional fuels and therefore their increasing share will lead to cheaper electricity has limited validity both due to the size of the share of RES in the energy mix and the composition of the mix itself, as will be shown in the following exposure. The "cheap" benefit applies only to a small share of RES typically up to a few percent. With the growing share of RES, they are already displacing other cheap sources, such as nuclear or water, or even cannibalizing themselves if employed massively. It is more difficult and costlier to maintain the stability of the grid and consequently the final total price of electricity is rising. For example, the simple earlier estimates, e.g., Eschenbach (2015), have claimed the residential costs of electricity shall rise by 0.02cents per each additional kW of RES capacity.[1] While these earlier academic papers and calculations have not received much attention so far and have been largely ignored in policymaking,

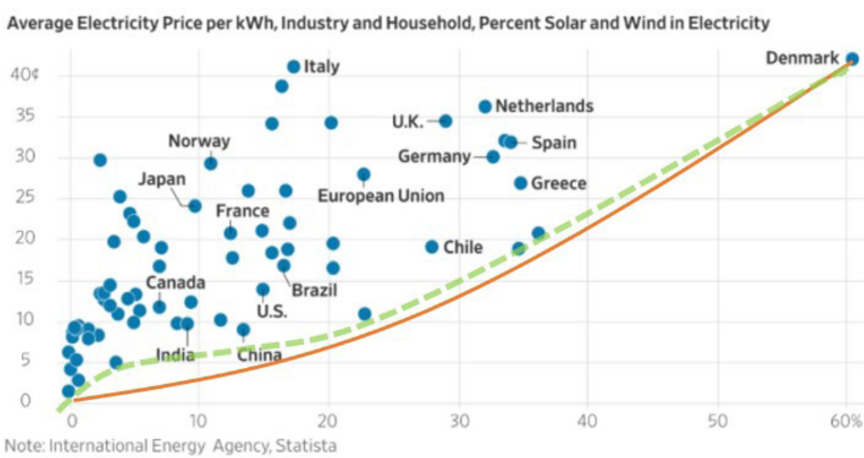
1 *https://wattsupwiththat.com/2015/08/03/obama-may-finally-succeed/*

Lomborg (2025) practical visualization of current consumer prices (see Figure 1) led to vociferous public debate.

The simple non-linear frontier estimation has an increasing pattern (orange line) while the spline (light green dotted line) shape resembles the Ueckerdt et al (2013) economy-wide costs predictions for Germany in Figure 2.

The argument of the production cheapness of electricity from wind and solar is simply not correct for consumers or from an economic (social costs) point of view. It is the investor's view of his **investment costs** (so-called LCOE, see, e.g. EIA, 2022). LCOE represents the average price of electricity sales that ensures the investor's required return (profit). But this is a price that the customer – i.e., literally speaking, the person at the electricity socket – is not interested in at all. That customer pays the total costs price that is different and higher, because it includes all the costs of maintaining the stability of the network, its development and covering the risks of non-supply.

Figure 1: Electricity Prices and RES Share



Source: Lomborg (2025), estimated frontiers: authors.

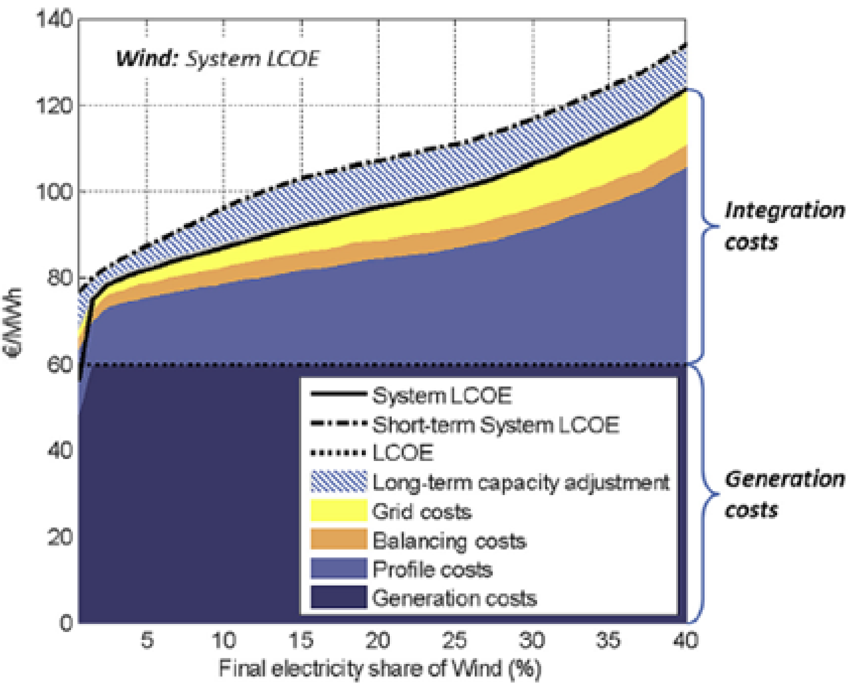
The difference between investment (LCOE) and **consumer costs** of electricity (so-called System LCOE) is growing over time. It is growing in both dimensions: as volume of RES increases and as the price of emission allowances increases. The reason is that the CO2 permit price effect is also directly reflected in the prices of grid stability services. Therefore, the price of baseload electricity may fall, but the total costs are rising, because the forced additional costs (both capital and variable) are rising faster due to the presence of two rising components. **The national economic perspective** (or social optimizer perspective) is the same as the consumer one, because it reflects the total social costs of supply (delivery) in the economy. The difference between the two approaches is in Lizal, 2025, showing LCOE is price of a commodity while consumer purchases electricity as a service.

In other words, the argument of low LCOE causing prices of the final product to decrease is the same as if the price of cheese only presents the price of milk needed for its production. No other production costs, no wages, no packaging, no transport of cheese to the store, no advertising or storage or loss of unsold expired products.

3 Regulatory market failure: the more RES, the higher the final price

The problem and its impacts are best seen on the German system, where their 12-year-old own theoretical calculations are being explicitly confirmed (Ueckerdt et al., 2013, Figure 2). Even in these calculations – and the effect was calculated with the perceived "high" allowance price of EUR 20 per ton of CO2 – the related induced costs of the grid were higher than the (direct) investment costs of RES technology (measured with LCOE) with a share of wind RES in the energy mix being of around 33 percent (which is, due to EU commitments, perceived as an unambitious mediocre goal today). And at that time, RES cost two to three times what it costs today (measured by LCOE), and the nuclear power plants were still assumed to remain in operation. However today, the price of CO2 is more than three times higher, the nuclear power plants were closed, so the induced integration costs (considered in the System LCOE) clearly dominate the investment costs (LCOE) even for lower values. Thus, the total price of electricity, which must reflect the total costs (and not only the baseload component), without doubt, cannot decrease at all.

Figure 2: Integration Costs in Germany



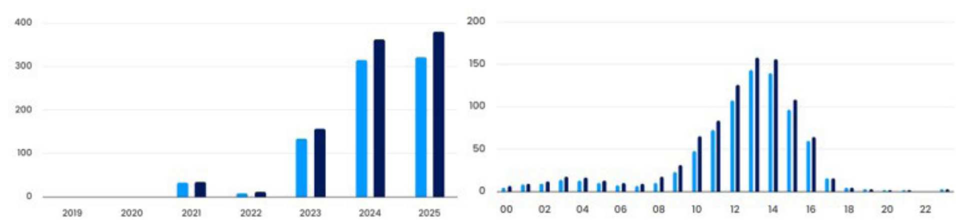
Source: Ueckert et al (2013), increasing estimated total system cost with break-even point about halfway down the graph, followed by convex curvature for a higher proportion

These unintended impacts of energy policies have started to be talked about in the European Union, but that's only because German companies have finally spoken up. And they came out because the German Constitutional Court prohibited the government from further debt, which was originally planned for further energy transition subsidies. It was only at this point that the Antwerp Declaration (2024) was created as a counterweight of industry against the loss of competitiveness due to ill-conceived energy policy. In other words, politicians got the news that ideology has definitively hit the laws of physics and people's wallets and the limits they set.

4 Cannibalization effect

The media are full of "great" news from the energy stock exchange (i.e., EEX or PXE) how much the price was negative again – that the situation is improving and electric energy prices shall eventually decrease. But what "goods" do we pay for to be removed? Waste – that's the name of the thing that someone takes over for money.

Figure 3: Negative hourly price frequency according to year and hour, respectively



Source: oenergetice.cz from ENTSO-E data, year 2025 till October. Negative prices in BLUE, negative prices including zero price in BLACK.

Negative prices (Figure 3) thus indicate not an improvement but another, **new, economic problem: cannibalization**. A situation where the overproduction of a certain technology makes it impossible to deliver return on the very investments. Investments that are still considered to be politically desirable – and further fostered with argument we have not invested enough in these. This is a new, state-invoked **regulatory-based type of market failure**. Cannibalization is also a predicted and described consequence in the above-mentioned German calculations. The social cost curve increases steeply with a higher share of uncontrollable resources - because of cannibalization (see Ueckerdt et al., 2013). The limit case, where almost all energy (95%) is provided by one type of source (so called LFSCOE, Levelized Full System Costs of Electricity), is shown in Table 1 (Idel 2022, and 2023) for two different climatic conditions. With higher share the costs of cannibalization already dominate all the other costs. The proof that this is not a theoretical problem is simple: investors today want not only investment support, but also operational support again, as the cannibalization effect is already slashing revenues.

Table 1: Comparison of LCOE and LFSOCE for Different Climatic Conditions

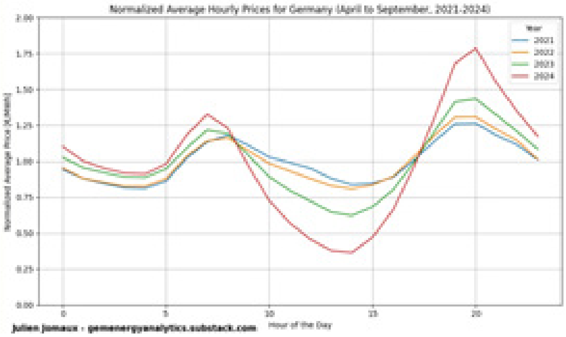
Technology	LCOE	LFSCOE	
		Germany	Texas
	[USD/MWh]	[USD/MWh]	[USD/MWh]
Biomass	90	109	126
Coal (USC)	83	110	124
Natural Gas CC	40	41	46
Nuclear	88	114	134
Solar PV	36	1465	456
Wind	40	587	358

Source: Idel (2023)

The difference between the demand for baseload and balancing electricity depends largely on climatic conditions: to what extent the production of unstable RES is correlated with consumption. In Central Europe, this is clear. The highest consumption in this geographical area is in the morning and evening and in winter. These are periods that RES, and especially photovoltaics, cannot deliver. On the other hand, in California and Texas, for example, they have peaks in consumption at noon and in the evening and in summer. But even this, far more favourable geographic scenario for RES, is not resulting in a cheaper mix with the massive deployment of RES than classic emission-free sources such as nuclear.

As the seasonal cycle of the difference between production and consumption deepens with higher RES installations, this economically harmful trend will continue over time, see Figure 4.

Figure 4: Duck Curve in Germany over Years



Source: Jomaux (2025)

The increase in volatility, i.e., the so-called duck curve in Figure 4, is not without an impact on the total economic price for two reasons, again, both are contributing to price (consumer costs) increase. First, someone must pay for those negative moments (as we pay the garbage collector) and so in reality they will be reflected in additional costs (we may model it both as costs of overinvestment and costs of subsidies as well). The second factor is the excessive volatility itself. Here we can bring to our attention studies in the financial markets. Higher volatility means higher risk and thus rewards for the undertaken risk, i.e., increased price. The effect of increased volatility can be also documented with the so-called volatility tax (also volatility drag), e.g., Messmore (1995). As documented by Jacquier at al. (2003) (even with an unbiased estimator and stable distribution) the future value of an asset calculated using the arithmetic average historical return results in an upward biased and forecast obtained by using the geometric average will be downward biased. Finally, Becker (2012) was able to show the approximation (1) between arithmetic and geometric means used in empirics can be derived without distribution assumptions:

$$r_G \approx r_A - \frac{\sigma^2}{2} \tag{1}$$

where r_A and r_G is the arithmetic average return and geometric return to the asset, respectively, and σ^2 denotes its variance. The difference between the returns based on arithmetic and geometric means is one half of the variance.

In the following calculations we will limit the scope to the direct effect of the duck curve due to price variation effect only and leave out the effect of the costs of increased volatility that should be added as pure inefficiency waste on top of our calculations should we prefer to evaluate these costs as well.

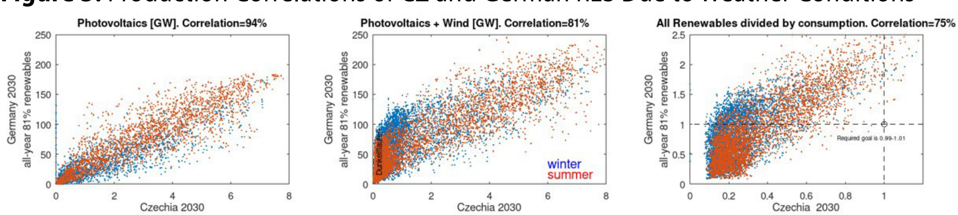
5 Model of the impact of expected energy imports on GDP in the Czech Republic

In the previous sections we have briefly described the reasons why the average yearly price cannot be used for serous modelling and is a grossly misleading simplification. In standard economics, price is determined by the nature of the goods, the place, and time of delivery. The market price changes to balance demand and supply. However, in the electricity sector the specifics of the electricity market must not be ignored or assumed out, i.e., that it cannot (yet) be (economically) stored in sufficient quantities and can only be supplied to where the distribution network allows. In addition, at a given time, production (supply) adapts to consumption (demand) at a given price. The paradigm shift from a central scheme with controllable resources to distributed production thus means a shift from the emphasis of price on its nature (commodity) to the attributes of the supply itself, i.e., **time** and **place**. Therefore, it cannot be expected that the final prices for customers will be based on the slowly falling investment costs of RES (LCOE) but will reflect the accelerating costs of the system (System LCOE), described in the section above.

In addition to the general effects above, the Czech Republic will face further challenges. Unfortunately, all of them are in favour of additional price shock in regulation energy. First, all baseline scenarios of resource adequacy (MAF CZ 2022) show an annual total deficit of 14-15GWh in 2030 and 20GWh in 2035, which is negligible. However, as shown by the modelling of Horáček and Sedmidubský (2024) and the balance heatmaps themselves in the subsequent MAF (MAF CZ 2023), **the distribution of deficits over time is heavily uneven during the year**; the domestic system shall have significant deficits in the winter and substantial export ability in the summer, similar to the situation in neighbouring countries.[2] The model thus shows that the seasonal deficit have to be compensated by an increase in **import dependence in the order of thousands of GWh** (see Appendix Table 1A). This implies further possible pressures on the price and its volatility – **exports revenue potential will be minimal in the summer, often even facing negative prices, while balancing imports will become more expensive in times of shortage, in winter, during usual *dunkelflauten* spanning with high probability** (see Figure 5) **in both Germany and Czechia and probably other neighbouring countries**. Therefore, the price estimates of the cost of import dependence in MAF CZ 2022, page 98, based on average annual prices, may be optimistically strongly skewed downwards. A realistically constructed weighted sum of the economic balance, which would respect the difference in export and import prices due to different market conditions (deficits vs. surpluses), would look significantly more pessimistic, as we will show in the simplified model later.

While the newer MAF 2023 already works with different prices during the year and different import needs during the year, the same type of problem, i.e., the application of the average annual price to different states of the grid in terms of energy availability, appears mainly in the SEEPIA models and thus the State Energy Policy (SEP). The basic problem, which SEP and SEEPIA do not consider, is **the growing divergence in both seasonal electricity prices** and the distribution of energy prices in baseload and balancing energy.[3]

Figure 5: Production Correlations of CZ and German RES Due to Weather Conditions



Notes: First graph covers PV only, middle adds wind generation, and the last one adds biomass. Own calculation using ETNSO-E data, Agora Energiewende, and https://www.electricitymaps.com/data-portal/czechia. In comparison to 2019 the Czech Republic plans to have 3.6x more installed solar and wind capacity in 2030.

2 *We provide sample of recent daily price curves in the summer and winter in the Appendix 3. While the winter curve exhibits historically common hump-shape with maximum during the day, the summer is a classical duck-shape with two maxima in the morning and evening and minimum (negative) during the daytime.*

3 *One of the most problematic aspects of both SEP and MAF 2023 lies in optimism about the availability of electricity supplies from abroad during the critical winter period. Unfortunately, there is no assessment of economic and security risks about this assumption. The theoretical sufficiency of import transmission capacities does not guarantee the availability of electricity at a reasonable price, e.g., the shortage in November 2024 with electricity prices reaching 800EUR/MWh.*

Unfortunately, the economic modelling of SEK and SEEPIA employs the annual balance only. Mathematically (and logically), the definition of a balanced electrical system is that at every moment, during each 15-minute interval, consumption must equal production (with 1% precision). This balance then directly results in the annual balance of production (plus the cross-border balance) and consumption. However, **this is an implication, not an equivalence**. Therefore, a balanced annual result does neither imply seasonal balance, nor even daily.[4]

The right part of Figure 5 is the most important as it shows that even with biomass in 2030, when the Germany claims to achieve 80% year-round coverage from RES, it will have significant surpluses and shortages at the same time as in Czech Republic

Daily balance would require huge investments into accumulation, namely a few pumped-storage dams or dozens of thousands of large battery storages and thus seasonal storage is sci-fi with today's technology. Hydrogen production has losses around ¾ in its full cycle and its transportation is challenging.

The electricity system will have significant surpluses in the summer middays (when the surrounding countries will also have surpluses and then export prices are low to zero) and deficits in the winter (when prices are higher than the annual average), see the HeatMap in MAF ČEPS (MAF CZ 2023). The difference between highs and lows has been growing over time as can be seen from Figure 4. Such a pattern is valid for German and Czech markets as well. Even though winter wind compensates for solar in summer, they are negatively correlated (they compensate) at only -21%. ENTSO/E data analysis reveals that total power of all solar plants is correlated 95% between Czechia and Germany (and similar figure would be probably for other neighbours). Including wind (that is said to be ideal complement to photovoltaic due its negative correlation), the general correlation is still 81%. All renewables (including water and biomass) are still correlated at 75%. Windless nights cover ¼ of a year in Czechia, especially in winter. This implies that surpluses of solar+wind+water electricity can hardly be sold cross borders as similar situations typically appear simultaneously on both markets (regions). Figure 5 shows these correlations of production due to weather conditions between Germany and the Czech Republic. In short, there is virtually no diversification effect in RES conditions.[5] In addition, due to the size of the German economy and its RES energy sector size, even during the uncommon situations of different weather conditions the German market would always dominate.

The situation of seasonally and continuously different prices, even with a balanced (!) annual energy balance (SEEPIA expects surpluses for exports in summer and balance

4 *The short-term hourly balance can be solved by short-term accumulation, but seasonal differences cannot be covered with direct electric accumulation. It is not yet possible to economically accumulate electricity between the seasons – that's why there are gas storage tanks for the winter to be able to increase production during this period.*

5 *The rolling blackout in Texas has been already subject to academic research, also with respect to weather conditions in neighbouring states. Wolak (2022) documents that the mechanism that was designed for a sector based on dispatch-controlled thermal generation units is inappropriate for a sector with a significant share of energy coming from intermittent renewable generation capacities.*

imports in winter) leads to a negative financial balance of foreign trade. The headline financial balance of imports due to volume imported is thus increasing with rising seasonal price differences and the surplus (deficit) in summer (winter). The increasing importance of this effect is not only seen in Figure 3 showing the increasing number of occurrences of nonpositive prices above but also is captured by the increasing volatility of the energy price.

The increasing daytime price spread from year to year is not only a problem in the EU (EMBER, 2024). It is a typical manifestation of higher volumes of PV installations, as evidenced by the increase in the likelihood of negative daytime prices AEMO (2024) in Australia suggests. Thus, one should not make an economic evaluation based on average prices (as both SEP and SEEPIA do), but it is necessary to work with variable prices during the day and seasons.[6]

As the seasonal cycle of the difference between production and consumption deepens with higher RES installations, the inevitable price differences will lead to a significant change in the financial balance of foreign trade, and thus to a further decline in GDP. The bigger the seasonal price difference the bigger the financial imbalance, ceteris paribus.

In the subsequent simplified modelling, we will show the effect of the increasing divergence of seasonal prices and daily prices on foreign trade results using the Horáček and Sedmidubský (2024) balancing energy production mix model.[7] In our calculation we will show how the change in the price of the net balance of electricity increases with increasing differences during the year and day. By augmenting the original model of physical balance with prices we will be able to model change in the trade balance and therefore in GDP. We will extend the above-mentioned model by Horáček and Sedmidubský (2024) to include an estimate of the direct change in GDP (i.e., we calculate only the initial effect without multipliers, see e.g. Jurajda et al. (2006) for the Czech Republic and Lízal (2012) directly for the analysis of the effect of emission allowances). This gives a basic estimate of the error caused using average annual prices in the SEEPIA model ignoring seasonal price differences used in SEP. We will also show a situation close to the minimum of economically feasible local coal mining and compare it to no mining (and no electricity production from brown coal) scenario, taking the capacity of coal-fired power plants in 2030 from SEP WAM3 model, i.e. 3 GW, as the limit.[8]

6 *In addition, SEEPIA scenarios work unrealistically with both the arbitrary amount of coal mined and the scalable size of nuclear power plants. However, there is a limit to the profitability of mines, i.e. from a certain level it is no longer possible to decline, but there is a step change in the closure of mines. This must always be modelled as a discontinuous transition in the model to another state with discontinuous changes.*

7 *The physical balance-production simple model of the app.energy-mix.cz is described in the Appendix 1 and with a greater detail on the public model web pages.*

8 *We provide various scenarios of production volume check in the Appendix 2. Unfortunately, these checks show unrealistic full reduction of CO_2 despite the enormous costs. Given the fact that many global firms announced cancellations, shelving, or steps back from their hydrogen plans due to surmounting costs, we doubt the speed if not feasibility of the gas-hydrogen transformation in a near future. The more stringent recent proposal of reduction of CO2 in EU by 90% by 2040 fails in the same direction.*

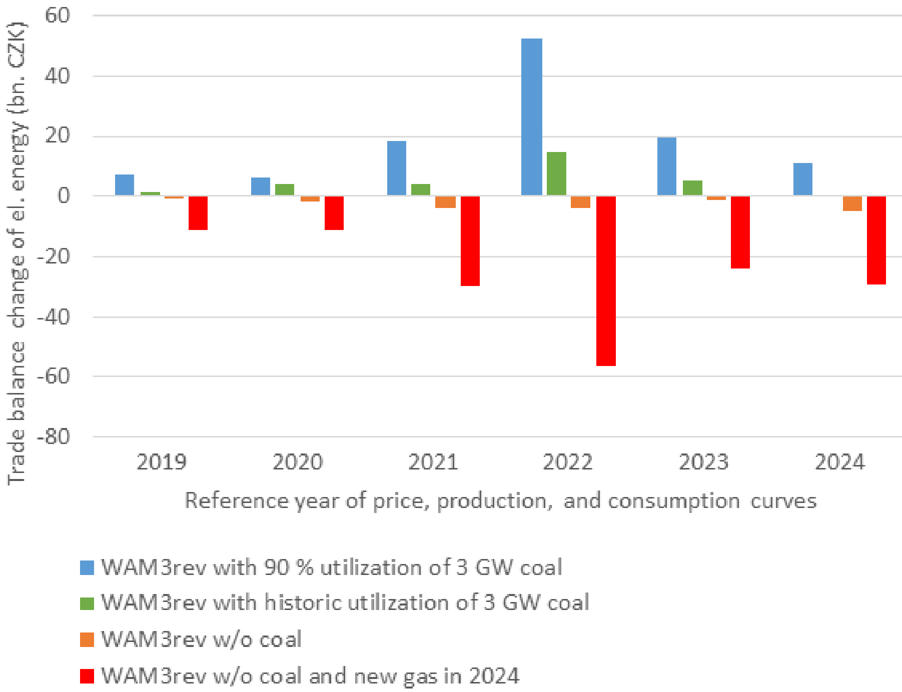
To avoid problems stemming from the inadequate future mix affecting prices in an unknown way or with a scheme driven by assumptions, we reverse the problem. Our basic idea is simple. We ask a question "What would happen in past years should the production mix be the envisaged one from the future?" We acknowledge that this is a very conservative approach, but we avoid both consumption and price prediction errors. Past values known and easily verifiable. The drawback is that we estimate the lower bound limit of the economic effect as the prices will diverge more in the future. Yet still, as we show, even the lower-bound has a size of 1% GDP yearly.

To augment the energy production mix model with economic dimension we apply prices to the *app.energy-mix.cz* production model in the WAM3 scenario as follows. To eliminate the influence of holidays and other volatile calendar influences, we calculate the average price for each hour of the day in each month. These average hourly prices that vary by each month (and thus capture both daily (hourly) and annual changes (volatility)) are then applied to the system surpluses/shortages in individual hours of the day and summarized for the whole year. We assume that the Czech Republic is a price-taker by default, i.e., regionally the Czech demand or supply will not affect the average prices achieved on the entire regional market. A surplus means exports and a positive contribution to the trade balance, a shortage of electricity is balanced with its imports and payments outwards. However, we eliminate exports at negative prices, assuming that in these situations RES are disconnected so that they do not generate further losses.[9] According to the assumption of MAF 2023, which considers a 16% yearly increase in total consumption between 2025 and 2030, we use this amount as a "target" that needs to be covered in the future production. Note that winter consumption increase will likely be even higher due to switching of coal-powered heaters towards electricity-powered heating. Indeed, coal burners consume yearly 45 000 GWh for pure heating - nearly ¾ of the Czechia 2022 electricity consumption.

We also show the sensitivity of the scenarios to different degrees of decommissioning of domestic coal-fired sources and the assumptions of their use (historical averages vs. unrealistic high availability in SEP or SEEPIA). The selected value of 3 GW (assumption of coal-fired power plant capacity in 2030 according to SEP WAM3) with high utilization undoubtedly meets the condition of the minimum necessary size of the sector, without the closure of mines due to a drop in profitability to negative values. In our results we also work both with historic (varies around 80%) or assumed high availability of production factor (set at 90%). The result is then shown in Figure 6.

9 *However, a disconnection may not be the option as any disconnection is only possible for reasons of system stability. In addition, in the case of feed-in subsidies, it pays to produce even at negative prices if the negative price (in absolute value) is lower than the guaranteed feed-in subsidy. Our simplification thus may lead to underestimation of the financial impact, i.e., we may again estimate lower bound of the impact.*

Figure 6: Models of Trade Deficit Changes with Energy Mix of 2030



Source: Authors' simulation of SEP WAM3 on the extended app.energy-mix.cz model

From the point of view of the overall change, it is necessary to note that the last scenario "without new gas" applies de facto with new gas as well, only the change in the trade deficit will not be visible in electricity column but will be reflected in a similar amount in increased gas imports. Gas imports, however, are not captured in the chart but due to the tie-up of electricity prices with gas as a result, we may rely on the fact that gas sources are the "closing merit order" production facilities at the instance of scarcity. Thus, the last column in Figure 6 is also sufficient for the first rough approximation of the same total fiscal effect with new gas imports. In terms of financial impact, the decreases in imports of electric energy due to the substitution of increased gas imports for electricity productions are equivalent.

These two sub-scenarios are therefore actually financially similar in terms of the overall impacts on the change in the GDP trade balance, and de facto the last, red column applies; just one can note that with new gas power plants the system has a better position in terms of domestic regulatory potential (so will not have to import balancing electricity as well).

In sum, as the nominal GDP in the year 2022 and 2023 was 7000 and 7600 bn CZK, respectively, the primary effect being change about 40-50 bn CZK represent change in GDP between 0.5% - 0.7%. With Czech fiscal multipliers being estimated around 0.5-0.6 (e.g., claim of Klyuev and Snudden, 2011, on CNB models) we get the total impact being between 0.75% and 1.12%, each year.

Conclusion

The development of the energy sector is and will be driven by the (state) regulatory interventions. Unfortunately, these are often reactive, i.e., they react only to an already existing problem and are not introduced proactively to prevent forthcoming issues.

Developments in the energy sector will thus continue to be determined only by political decisions, and fundamental changes can therefore only be expected either within the election cycle (after the elections) or as a response to an acute crisis (e.g., the recent blackouts).

In a simplified model, we have shown that the results of the current economic and energy policy lead to a situation where the Czech Republic will be significantly dependent on the external environment and spend dozens of billions on electricity imports (just as we spend on oil, for example), which is a net loss in terms of GDP, and behaves like energy tax levied on the whole economy. In fact, the development aims against the original philosophy of energy transition, which had the primary goal of reducing energy import dependence. Unfortunately, this is the most likely scenario, as we have been moving towards it for several years by gravity. Our simple model estimates the effect of around 1% of GDP, annually.

The negative impact on GDP and the increase in energy prices for end customers brings up the question of adequacy and social sustainability of the whole concept. A necessary condition for maintaining social justice and the financial stability of the system is electric distribution tariff reform (Lízal, 2024). However, its inevitable aspect (in addition to resolving the current anti-social redistributive character towards those who cannot enjoy the benefits of their own domestic PV plants) must also be an element that significantly penalizes deviations of customers or producers (e.g., the use of the so-called G-component). Only such an approach can allow us to pass on the rising costs of the deviation to its originators more fairly. However, from the customer's point of view, the result will be a decrease in customer comfort and an increase in the final price for the self-producers. These recommendations are in line with findings of Wiser et al. (2025) who found evidence using USA data that states with the greatest price decreases typically exhibited increasing customer loads while behind-the-meter solar standards increased prices.

However, the above outlined options and scenarios have unpleasant political and economic costs that cannot be avoided. So far, the passive approach of postponing the solution of the problem carries the risks of significant (electric) energy import dependence and social impacts and increases the distortions as well as incumbent pressures to stop any reform. Changing the trend and revision of the State Energy Policy requires fundamental strategic policy decisions.

Acknowledgements and Disclaimer

The research was in part supported under contract no. MF-4768/2025/76. The opinions expressed are those of the authors' and do not represent the views of the author's institutions nor financing institution.

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Contact Address

Lubomir Lizal (corresponding author)
CTU FEE, Dept. of Economics, Management and Humanities
Jugoslávských partyzánů 3
166 27 Praha 6
Czech Republic
(lubomir.lizal@cvut.cz)

Jan Horacek and **Vaclav Sedmidubsky**
Institute of Plasma Physics of the Czech Academy of Sciences
U Slovanky 2525/1a
182 00 Praha 8
Czech Republic
(horacek@ipp.cas.cz and sedmidubsky@ipp.cas.cz)

Annex 1: APP-ENERGYMIX – Description of The Energy Production Balance

The hourly production and consumption data used in this model comes from a public source, ENTSO-E as well as data on installed capacities in historical years. A following definition of the electricity production and consumption curve used in the https://app.energy-mix.cz model:

- Hourly production curves represent the so-called net production of electrical sources.
- The hourly consumption curve represents the consumption of the Czech Republic, including total losses, i.e. losses in the transmission system and distribution systems.

Model Assumptions and Limitations

The app.energy-mix.cz model is based on assumptions that allow us to test the self-sufficiency of any electricity mix in the Czech Republic. Since electricity shortages and surpluses occur mainly in different seasons, they do not compensate for each other. The grain size of the model is hourly. The following assumptions are "optimistic" – they underestimate the resulting shortcomings of electricity, which makes this model conservative. The real shortage of electricity therefore will be worse than the simulation suggests.

Technical Assumptions

- Ideal transmission network without loss,
- immediate start-up of gas sources and unlimited gas supply,
- no extraordinary outages of the sources, sources copy the outages in the selected reference year,
- analogously to the MAF assumptions of growing demand the annual electricity consumption is assumed to be increased (but conservatively) to 70 700 GWh in 2030,
- the consumption curve defined in this way does not include the expected relative increase in winter electricity consumption due to the gradual transition of heating to heat pumps.

Control algorithm

In the control algorithm, the so-called scaled and partially controlled sources are always connected to the power grid as a priority. Scaled sources include nuclear, hydroelectric power plants (except pumped storage), biomass + other RES. The only partially controlled source is coal, for which the scaling of the historical production curve is supplemented by an adjustable coefficient of annual utilization. The continuous lack of electricity after the connection of these sources is compensated for by so-called controlled sources, i.e., first by accumulation and then by gas. The ongoing surplus electricity is then used to charge storage capacities and export. The storage source represents the storage capacity of the Czech Republic with a charging and discharging cycle efficiency of 90%. It combines pumped-storage hydroelectric power plants and battery systems into one modelled source.

Coal-fired power plants and scaled sources

In the modelled scenario "WAM3rev with historical use of 3 GW of coal", the coal source behaves in the same way as other so-called scaled sources. This means that the electricity production curve is rescaled by a multiplying factor so that the set installed capacity of the source is a corresponding multiple of the installed capacity in the reference year. This scaling principle is also applied, for example, to the production curves of RES. In the scenario "WAM3rev with 90% use of 3 GW of coal" the coal production curve is transformed so that the resulting coefficient of annual utilization (average output of the source) is 90%. This corresponds to about 95% of average winter utilization and 85% in the summer.

Accumulation

Storage sources are charged only during periods of surplus electricity, with a maximum charging capacity of 2172 MW up to a maximum capacity of 7500 MWh. Discharging occurs only during periods of continuous shortage of electricity from priority sources, with a maximum discharge capacity of 2172 MW. When an electricity shortage occurs, the algorithm first evaluates the duration of the shortage period. If it lasts less than 24 hours, the initial available accumulated capacity is allocated evenly to the shortage period. In the case of a duration of more than 24 hours, the initial accumulated capacity shall be allocated evenly over the following 24 hours. The discharge power for each hour of the shortage period is then given as the minimum of the allocated energy for the given hour, the power needed to make up for the current consumption and the maximum discharge power.

Gas-fired power plants

In the event of a shortage of electricity even after the connection of storage capacities, gas-fired power plants are connected (all types combined into one category). For simplicity, we consider the possibility of immediate start-up up to the installed capacity, assuming unlimited gas availability and zero failure rate of the source. The algorithm tries to match the current electricity consumption and is limited only by the installed capacity. It is not used to generate excess electricity.

Limitations and Bias

In winter, the real consumption curve is therefore likely to be higher than assumed by the model. For these reasons, the estimated deficits are optimistic, i.e. smaller than what would result from a fully incorporated transition to heat pumps. In sum, for economic evaluation the model provides better (ideal) outcomes of energy balance and therefore the real economic impact would be higher due to inefficiencies and other mismatches neglected. This is in line with the rest of methodology that also focuses on lower-bound of the economic effect estimate.

Annex 2: APP-ENERGYMIX – Scenarios Balance Verification

Table A1: Long-term general verification of SEP WAM3:

Energy mix	Consumption as % of 2019	Gas		Accumulation		Solar	Wind	Biomass	Hydro	Coal		Nuclear	Invest. estimate [bn. CZK]	Produced $CO_{2,eq}$ [Mt]	Gross total electricity deficit [TWh]	Peak electricity deficit [GW]	Net total electricity surplus [TWh]
		installed power [GWp]	imported [TWh]	kapacity [GWh]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	average power utilization	installed power [GWp]					
Reference year 2019	100%	1,23	5,4	5	1,175	2,05	0,32	0,90	1,09	10	40%	4,04	0	43 +/- 2	0,00	0,0	16,1
WAM3 scenario 2025	100%	1,23	5,4	5	1,175	3,10	0,32	0,90	1,09	6	40%	4,28	61	27 +/- 2	0,49	1,8	0,9
WAM3 scenario 2025 coal 65 % average power utilization	100%	1,23	5,4	5	1,175	3,10	0,32	0,90	1,09	6	65%	4,28	61	38 +/- 2	0,00	0,2	9,8
WAM3 scenario 2030 (SEP) BASELINE ECONOMIC MODEL INPUT	110%	3,20	13,0	5	1,175	10,10	1,50	0,90	1,09	3	40%	4,04	313	22 +/- 3	0,50	2,4	1,5
WAM3 scenario 2030 self-sufficient	110%	5,60	13,5	5	1,175	10,10	1,50	0,90	1,09	3	40%	4,04	378	23 +/- 3	0,00	0,0	1,5
WAM3 scenario 2030 coal 80 % average power utilization	110%	3,20	5,4	5	1,175	10,10	1,50	0,90	1,09	3	80%	4,04	313	28 +/- 2	0,05	1,2	3,9
WAM3 scenario 2033	110%	3,20	19,8	5	1,175	10,10	1,50	0,90	1,09	0	0%	4,04	313	15 +/- 5	3,39	3,8	0,6
WAM3 scenario 2050	170%	4,00	23,1	5	1,175	26,10	5,50	0,90	1,09	0	0%	5,90	1 224	19 +/- 6	7,53	7,3	7,8
WAM3 scenario 2050 + 4x500 MW nuclear reactors	170%	4,00	15,6	10	2,344	26,10	5,50	0,90	1,09	0	0%	8,00	1 597	17 +/- 5	2,38	5,4	9,8
WAM3 scenario 2050 self-sufficient	170%	11,30	30,6	5	1,175	26,10	5,50	0,90	1,09	0	0%	5,90	1 421	24 +/- 7	0,00	0,0	7,8

Table A2: Short-term verification subset used in economic model

Energy mix sensitivity analysis for WAM3 at 2030	Consumption as % of 2019	Gas		Accumulation		Solar	Wind	Biomass	Hydro	Coal		Nuclear	Invest. estimate [bn. CZK]	Produced $CO_{2,eq}$ [Mt]	Total electricity gap [TWh]	Peak electricity deficit [GW]	time of required el. import > 2.5 GW [h]
		installed power [GWp]	imported [TWh]	kapacity [GWh]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	average power utilization	installed power [GWp]					
Reference year 2019	100%	1,23	5,4	5	1,175	2,05	0,32	0,90	1,09	10	40%	4,04	0	43 +/- 2	0,0	0,0	0,0
WAM3 scenario 2030	110%	3,63	2,2	5	1,175	10,05	1,44	1,42	1,09	3	95%	4,04	61	30 +/- 2	0,0	0,1	0,0
WAM3 scenario 2030 coal 0 %	110%	3,63	18,7	5	1,175	10,05	1,44	1,42	1,09	0	0%	4,04	61	14 +/- 4	1,4	3,0	35,0
WAM3 scenario 2030 coal 0 %, gas 50 %	110%	2,40	15,2	5	1,175	10,05	1,44	1,42	1,09	0	0%	4,04	313	12 +/- 4	5,0	4,3	424,0
WAM3 scenario 2030 coal 0 %, gas 50 % and renewables	110%	2,40	18,2	5	1,175	6,05	0,89	1,42	1,09	0	0%	4,04	378	14 +/- 4	6,9	4,3	588,0
WAM3 scenario 2030 coal 0 %, gas 50 % and renewables 1 nuclear reactor Temelin offline	110%	2,40	20,0	5	1,175	6,05	0,89	1,42	1,09	0	0%	2,95	313	14 +/- 5	12,8	5,3	1 698,0

Notes: Authors app.energy-mix.cz simulations, the colours denote the approximate degree of "problems" expected, green being the least problematic over yellow and orange to red that represents the most severe case. Due to different base of MAF 2023 the model final consumption increase corresponds to it.

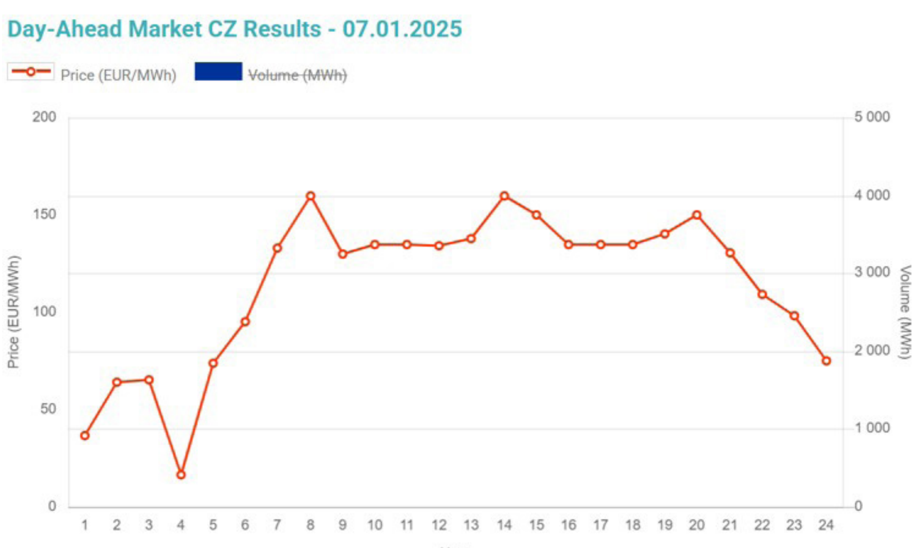
The various scenarios are verified using physical balance. For the subsequent economic modelling any excess of production can be exported, and any energy deficit can be covered using imports. The balance modelling shows increasing import dependency despite rising capacity investment costs. The models also show increasing seasonal patterns with growing surpluses in summer and increasing deficits in winter.

Sources: own app.energy-mix.cz simulations

Annex 3: Typical Summer and Winter Price Movements

Figure A1: Summer prices – typical example

Figure A2: Winter prices – typical example



Data is from OTE database: https://www.ote-cr.cz/en/short-term-markets/electricity/day-ahead-market?date=2025-05 for summer and for winter https://www.ote-cr.cz/en/short-term-markets/electricity/day-ahead-market?date=2025-01-07, trading volumes excluded from the graph for clarity, but all were above 2000MWh.