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Energy and Economic Efficiency

Habilitation Thesis

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ABSTRACT

This habilitation thesis compiles specific research problems of economic effectiveness evaluation in power sector. The first part introduces tools for economic effectiveness evaluation which are linked to specific tasks in the parts that follow. The last part is devoted to the future research outlook.

The first topic starts off with European energy market integration. It covers bidding zones reconfiguration which is one of the most recent issue in the electricity market integration process. This thesis also discusses the issues of social welfare calculation since social welfare is the main criterion considered when planning market changes. The link between fundamental technical problem, insufficient transmission capacities with related unscheduled power flows, and economic impact is provided. Related chapters contain unscheduled flows calculation methods, economic welfare calculation and determination of inputs required for social welfare estimation.

The second discussed topic is the economics of nuclear power plants decommissioning and nuclear waste disposal. Nuclear power plants decommissioning and nuclear waste disposal are highly costly processes. According to polluter-pays-principle, nuclear power plant operator must have enough funds for successful realization of both processes. Therefore, special fees are imposed on each produced MWh of energy. Methodologies for fees calculations are provided.

The third topic covers the problems of revenues and cost allocations on element of energy system, from producers to consumers. This so-called specific revenues and specific costs are required for offsetting up the electricity tariffs structure. Theory of specific revenues is extended on new trends in power sector with increasing amount of energy produced by decentralized power sources and intermittent power sources.

The fourth topic covers the value chains in power sector. It deals with issue of distribution of economic effects from brown coal among entities that deal with brown coal mining, transportation, electricity and heat production. Since there is no global market with brown coal, the problem of valuation can occur when mentioned entities are not vertically integrated. The methodology for brown coal valuation is provided. The fair price between coal mine and power plant is determined according to the risk which both parties are exposed to.

The last topic shows the valuation of weather options which is estimated using simulations. Weather options are new financial product that can be used for hedging against uncertainty in weather (e.g. temperatures) development. Underlying of weather options is temperature, which is characteristically stochastic, but does not follow Brownian motion as stock prices do. Therefore, conventional approach for the valuation of options is not applicable and simulation approach is presented.

Appendix section contains important authors publications related with topics of this thesis.

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List of abbreviations

ACER	Agency for the Cooperation of Energy Regulators
AR	Autoregression
CACM	Capacity Allocation and Congestion Management
CAPM	Capital Assets Pricing Model
CAT	Cumulative Average Temperature
CDD	Cooling Degree Day
CF	Cash Flow
DGR	Deep Geological Repository
DPP	Discounted Payback Period
EAA	Equivalent Annual Annuity
GSK	Generation Shift Keys
HDD	Heating Degree Day
HV	High Voltage
IRR	Internal Rate of Return
LV	Low Voltage
MIRR	Modified Internal Rate of Return
MRP	Market Risk Premium
MV	Medium Voltage
NCV	Net Caloric Value
NPV	Net Present Value
OTC	Over the Counter
PI	Profitability Index
PP	Payback Period
PPP	Polluter Pays Principle
PTDF	Power Transfer Distribution Factor
ROI	Return on Investment
SPE	Special Purpose Entity
TSO	Transmission System Operator
VaR	Value at Risk
WACC	Weighted Average Cost of Capital

1 GOALS

The aim of this thesis is to provide comprehensive look into author's research in the field of economic effectiveness in power sector. Author shows how to deal with specific tasks of economic effectiveness in the power sector. Thesis introduces theoretical background, its extension and transformation into application in the sector of power sector. The set of goals is characterized by research and discussion in the following topics:

1. Supportive methods related to bidding zones reconfiguration process as a part of European energy market integration. This topic is covered in chapter 3 - European Energy Market Integration.
2. Methodology for calculation of fees related with nuclear power plants waste and decommissioning financing. Both, financing of nuclear power plant decommissioning and radioactive waste disposal, are covered in chapter 4 - Nuclear Power Plants Waste and Decommissioning Financing Issues.
3. Theory of specific revenues with relation to electricity tariffs. Specific revenues and specific costs connected to each element of electricity grid, are discussed in the chapter 5 - Decentralized Power Sources and Electricity Tariffs, as penetration of decentralized power sources demands changes in the structure of electricity tariffs.
4. Distribution of economic effects between entities in vertically integrated chain. Economic benefits from brown coal and their distribution between producer, consumer and government are covered in chapter 6 - Value Chains in Power Sector.
5. Valuation of weather options. Simulation approach of weather options calculation is presented in chapter 7 - Valuation of Options on Weather.

2 INTRODUCTION TO ECONOMIC EFFECTIVENESS

The decision-making process has changed after liberalization of power sector. Liberalization process transformed power sector from monopolies to market-oriented industry. The situation in Eastern European block was specific by state ownership of whole energy sector (production, transport and distribution). This situation allowed to plan power sector development from whole power system point of view and for a long-time horizon. Situation changed after liberalization, a time when all the participants were following their own interests that may not be conformable with the long-term goals of power sector. This resulted in the situation where private investors were not motivated for long term investments without governmental guarantees (contract for difference, feed-in tariffs, etc.). Principles of economic effectiveness evaluation are almost the same, however, the parameters for decision-making process have changed. The long-term stable environment changed into short-term less predictable conditions. This chapter describes evaluation scope (point of view), evaluation techniques and evaluation period for investments assessment.

2.1 EVALUATION SCOPE

Results for effectiveness of economic evaluation may differ as per the point of view of recipients' benefits.

1. System-view can be understood as an approach where recipients of benefits are a whole society, industry or entities linked to a specific part of industry regardless of benefit distribution among affected parties. For example, residents from a specific economic area, power producers or power customers.
2. Capital view takes into account the invested capital regardless of its sources, e.g. there is no difference between private or public sector investments and any kind of loans.
3. Investor view considers only the investment of a specific investor (equity) without external financing.

Example: economic effect of a new power line on a whole society can be (and usually is) different from the effect on invested capital or the effect on individual investors. There may be situations where the effect is positive for one side (e.g. investor) and negative for the other (e.g. society).

2.2 EVALUATION TECHNIQUES

This chapter introduces economic effectiveness evaluation tools and links them to specific tasks. The first part is devoted to cash-flow definition since it is essential parameters for a project evaluation. Cash-flows are entering decision making criteria such as Net Present Value or Rate of Return. The results obtained from criteria carries supporting information for final decision making. The other essential input is discount rate since it represents required return of invested money. Discount rate estimation techniques are also discussed. Recently, maximization of social welfare is often discussed. Social welfare is not strictly defined and its evaluation is based on multicriterial decision making. Thanks to unclear definition, social welfare calculation can lead to different results. Social welfare calculation and multicriterial decision making are explained and discussed in this chapter. The last parts of this chapter deal with uncertainty. It is devoted to options which can be used for decreasing of risk. Finally, simulation techniques are presented. Uncertainty in input parameters results in uncertainty of model output. Simulations give information about distribution of model results. This is very robust tool for quantifying of risk, for example providing variance of simulation results.

2.2.1 CASH-FLOW

In project financing, the term cash-flow is understood as the net balance of positive and negative flows of cash and cash equivalents in one year. It is reported as at the end of each year for the most of industries including the power sector. Cash-flow reporting can occur more frequently (e.g. monthly) in the IT sector, technological start-ups and similar projects where investment recovery period is very short.

Based on viewpoint, a cash-flow calculation can be divided into five groups:

1. stakeholders (investors)
2. debtholders (loan providers)
3. suppliers
4. employees
5. government

Evaluation Scope in section 2.1 defines three views: investor, capital (project) and system view.

For the sake of simplicity, usage of special-purpose entity (SPE) is considered for a project. The practical reason is to filter out the impact of activities which are not related to the project. Cash-flow generated by this company is the total project cash-flow or cash-flow from the capital point of view. Cash-flow cleared from loans payments is cash-flow for the investors. Application of evaluation criteria on these sets of cash-flows clearly results in final economic effect.

More problematic is the system view, since one has to define a system, identify valid cash-flow streams and in some cases, evaluate non-monetary effects in the monetary terms. If the system is defined as power grid, a calculation can be performed for all grid owners without any significant problems. If the system is whole region or society, there are usually non-monetary effects of investment such as impact on environment. In that case, pure cash-flow approach is not applicable and other decision-making tools such as multicriterial decision making must be used.

2.2.2 CRITERIA

This section presents the criteria used for project valuation. The most important input parameter is the stream of future cash-flows. Inaccuracy of cash-flow estimation will lead to improper criteria results and can lead to incorrect decisions.

2.2.2.1 Payback Period

Payback period (PP) is the time until investment is fully recovered. It does consider the time value of money and cash-flows after repayment. Nevertheless, it is used in Czech energy law [1] for calculation of feed-in tariffs of renewable power sources.

$$\sum_{t=0}^{PP} CF_t = 0 \quad (1)$$

CF_t t

cash-flow in period t

time period

Payback period criterion has very limited usage and it should be used only for rough calculations.

2.2.2.2 Discounted Payback Period

Discounted payback period (DPP) takes into account the time value of money. Its main drawback is overlooking of cash-flow after investment recovery. Discount rate estimation is another potential

difficulty, but it can be negligible in comparison with the main drawback. More attention is given to discount rate estimation in the sections 2.2.3 and 4.3.

$$\sum_{t=0}^{DPP} \frac{CF_t}{(1+r)^t} = 0 \quad (2)$$

CF_t
 t
 r

cash-flow in period t
time period
discount rate

Discounted payback period criterion usage is limited because it does not consider all cash-flows.

2.2.2.3 Return on Investment

Return on investment (ROI) measures the relative return of an investment. Time value of money is not respected at all. Formula (3) shows annualized ROI calculation.

$$ROI = \frac{\frac{\sum_{t=0}^T CF_t}{T}}{Inv} \quad (3)$$

CF_t
 Inv
 t
 T

cash-flow in period t
cash-flow in investment period, usually 0-th year
time period
evaluation period

Return on investment criterion should be used only for projects where time factor is negligible. Since the result is in relative numbers, so-called size problem can occur. ROI of low-cost investment can be higher than ROI of costly investment, but latter can be preferable.

2.2.2.4 Net Present Value

Net present value (NPV) is the absolute return respecting time value of money. Cash-flows from each year are discounted into present and summed up.

$$NPV = \sum_{t=0}^T \frac{CF_t}{(1+r)^t} \quad (4)$$

NPV is the most frequently used criterion for investment decision making. The main disadvantage is the assumption of constant discount rate; however, formula can be easily transformed for calculations with variable discount rate. Inaccuracy in the discount rate leads to biased result and may lead to improper decision, similar to the inaccuracy in cash-flow estimation. Proper NPV usage gives the results for correct decision-making.

Discount rate can be understood as opportunity cost of the investor's money or usual return in a given industrial sector including risk. Higher NPV means more profitable investment.

NPV < 0	Investment is unprofitable, its return is lower than discount rate.
NPV = 0	Investment is profitable and its return is equal to discount rate.
NPV > 0	Investment is profitable and offers return higher than discount rate.

2.2.2.5 Equivalent Annual Annuity

Equivalent annual annuity (EAA) is the product of NPV and annuity payment factor. NPV of equal cash-flows represented by EAA is the same as NPV of original (usually unequal) cash-flow stream. One can state that EAA is the average project cash-flow which considers the time value of money.

$$EAA = NPV \times a_T = \sum_{t=0}^T \frac{CF_t}{(1+r)^t} \times \frac{(1+r)^T \times r}{(1+r)^T - 1} \quad (5)$$

a_T | annuity payment factor for period T

EAA is usually used for comparison of several projects with different lifetime. In case all projects are repeatable (recurrence of economic consequences) EAA will lead to correct decision. Better project has higher EAA than worse project.

2.2.2.6 Profitability Index

Profitability index (PI) is ratio created by comparing the present value of future cash-flows and investment.

$$PI = \frac{\sum_{t=1}^T \frac{CF_t}{(1+r)^t}}{Inv} = \frac{NPV}{Inv} + 1 \quad (6)$$

Inv | cash-flow in investment period, usually 0-th year

Profitability index is based on NPV criterion and can lead to correct decision if it is properly applied. Since the result is a relative number, size problem can occur.

2.2.2.7 Internal Rate of Return

Internal rate of return (IRR) measures relative return respecting time value of money. It is rate of return at which the NPV for a project equals zero.

$$NPV = \sum_{t=0}^T \frac{CF_t}{(1+IRR)^t} = 0 \quad (7)$$

IRR can be calculated by equating NPV formula to zero where rate (IRR) is an unknown variable. Decision based on IRR result is correct and similar to the decision based on NPV criterion. Result is relative number, so size problem can occur. Calculation leads to the problem of solving polynomial equation of higher degrees and can lead to multiple or no results.

IRR < r	Investment is unprofitable since its rate of return is lower than discount rate.
IRR = 0	Investment is profitable.
IRR > r	Investment is profitable and offers return higher than discount rate.

2.2.2.8 Modified Internal Rate of Return

Modified internal rate of return (MIRR) avoids calculation problems of IRR (multiple or no result). It is calculated as geometric mean of ratio between future value of positive cash-flows and present value of negative (investment) cash-flows. Reinvestment interest rate and financing interest rate can differ, so it is more flexible. The main disadvantage is assumption of the obtained cash-flows reinvestment. This assumption is logically incorrect because it goes beyond the project and therefore MIRR results are incomparable to results obtained by IRR or NPV. MIRR impact is more academic than impact in real business applications.

$$MIRR = \sqrt[r]{\frac{\sum_{t=0}^T \frac{PosCF_t}{(1 + r_{inv})^{T-t}}}{\sum_{t=0}^T \frac{NegCF_t}{(1 + r_{fin})^t}}} - 1 \quad (8)$$

$PosCF_t$	positive cash-flow in period t
$NegCF_t$	negative cash-flow in period t
r_{inv}	reinvestment rate
r_{fin}	financing rate

2.2.2.9 Conclusion

NPV and IRR are the best investment decision-making criteria and they lead to the similar decisions, if correctly applied. IRR calculation can result in multiple or no solution and size problem can occur. Therefore, it is better to use NPV since it does not suffer from these problems. In some cases, EAA and PI can also be used, but even so they can be substituted by proper NPV application. Criteria not respecting time value of money and cash-flows after recovery period (PP, DPP, ROI) should be used only for rough calculations, not for final decision. Since the MIRR assumes reinvestment of obtained cash-flows (money exceeding project cash-flows), it should be used for decision making for specific project only. Moreover, NPV criterion can be used for tasks with assumption of cash-flows reinvestment and can substitute MIRR.

2.2.3 DISCOUNT RATE ESTIMATION

A discount rate of an investor is an opportunity cost of his money. It is the highest rate of return from similar investments. If an investor chooses to invest specific financial amount into one investment, he implicitly decides not to invest this money into other (similar) investments. In other words, investor loses return from other investments because he uses money for one specific investments. By similar investment, one can understand investment of the similar size and risk. Practically, when investor is active in a stable industry, he can use an average return of his former investments as the discount rate. If he does not have this information, he can use average return for his industry in countries where he has activities. This kind of information are being continuously reported by information agencies or there is popular free online source¹. Discount rate should reflect a risk connected to an investment. More risky projects require higher return.

2.2.3.1 Risk and Reward

Risk is strongly connected with uncertainty. It is usually expressed as the standard deviation of returns. By returns, one can understand a profit of single company, average profit of companies in one industrial sector or return from investment into stocks of specific company. There is no unified methodology as to what numbers to use, it always depends on the type of task, data availability and specific requirements. Risk and return are usually calculated from historical data, however there is no certainty that the past will be repeated. Sometimes, there is possibility to obtain expected values of risk and returns from market. In finance, the standard deviation of returns is referred as the volatility. Volatility calculated from historical data is the historical volatility and volatility obtained from market expectations is referred as the implied volatility. The same logic applies for returns, calculation can be performed on historical data or expected values can be used. Since the future is uncertain and there is often no suitable market data, investors often estimate expected return and volatility from simple probabilistic models. Formulas (9) and (10) show how to calculate these values from probabilistic models. The weakness of this approach is that probabilities and returns are estimated. In some

¹ <http://pages.stern.nyu.edu/~adamodar/>

situations, such as investment into securities, historical data may give better results. The combination of both approaches is also possible. [2][3]

$$E[r] = \sum_{i=1}^N p_i \times r_i \quad (9)$$

$$SD[r] = \sqrt{\sum_{i=1}^N p_i \times (r_i - E[r])^2} \quad (10)$$

$E[r]$	<i>expected return</i>
$SD[r]$	<i>standard deviation (volatility) of returns</i>
N	<i>number of states or scenarios</i>
p_i	<i>probability of i-th state or scenario</i>
r_i	<i>return of i-th state or scenario</i>

When using historical data, it is necessary to properly choose how far into past the data will be analysed. For example, volatility calculation for a project with two years lifetime should not cover the time period of 20 years.

Investors investing into physical assets (e.g. power systems), not financial securities, usually do not understand the risk as a standard deviation (volatility) of returns. They implicitly assume risk premium for investment into risky projects. The sum of risk-free return and risk premium (including profit) results in expected return. Even though the risk premium is often intuitively used, it can be evaluated using statistical approach.

Figure 1 shows a set of investment opportunities for an investor. All investment opportunities are lying right of the blue line. Coloured points on the vertical line represent the returns of various mutually exclusive investments with the same risk. Opportunity cost is the highest return for specific risk level. If investor decides to invest into any project lying on the black vertical line, opportunity cost will be the return of the project represented by the red point².

² Rational investor decides to invest into project with the highest return for specific risk.

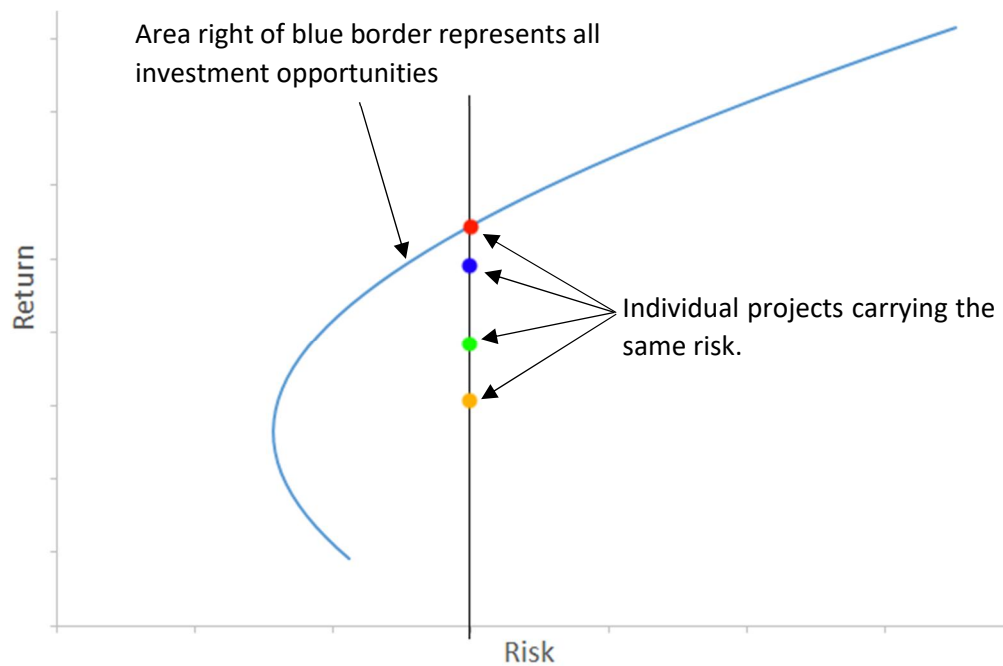


Figure 1: Area right of blue line is a set of investment opportunities. Coloured points represent several investments with the same risk. The red point represents the best investment and its return can be considered as the opportunity cost.

2.2.3.2 Capital Assets Pricing Model

Capital Assets Pricing Model (CAPM) is used for determination of required rate of return reflecting investments risk. Expected return based on CAPM model can be calculated using formula (11). Expected return of specific investment is the sum of risk-free return and risk premium.

$$E(r_i) = r_f + \beta_i \times (E(r_m) - r_f) \quad (11)$$

$E(r_i)$	expected return
r_f	risk-free return
β_i	asset beta, sensitivity on market changes, measurement of risk
$E(r_m)$	expected market return

Risk-free return is the return which can be obtained by investment into assets carrying no risk. Governmental bonds are considered to be risk-free. In reality, governmental bonds carry risk, but if government (country) defaults its currency, it will have negligible value if any. Therefore, it is more rational to invest free cash into governmental bonds than holding cash.

Risk premium is the product of asset beta and market risk premium (MRP). It expresses return (premium) for exposing to risk of specific investment.

Asset beta expresses a sensitivity of asset returns on market returns. If asset beta is higher than 1, investment into this asset is riskier than investment into the market. Technological companies have usually higher betas because they must invest into research and development, which is very risky. On the other hand, companies with low beta are in the food industry. For example, tobacco companies have low beta because they do not have to make risky investments and they have a stable customer base.

Market risk premium is premium for investors who invest into specific market. It is the difference between expected market return and risk-free return, often mentioned as market excessive return. It can be obtained from information agencies or free online sources³. Investment into market can be

³ <http://pages.stern.nyu.edu/~adamodar/>

understood as an investment into all assets available on the market or as an investment into market index which should include all essential assets.

Expected market return and beta are statistically calculated from historical data. The same warning applies for CAPM as mentioned in previous section 2.2.3.1, that the future is uncertain and one cannot expect the same outcomes as were reported in the past.

CAPM assumptions:

1. Markets are perfectly competitive. There are many small investors and investors are price takers⁴.
2. There are no taxes, transaction costs and restriction on short-selling.
3. Investors can lend and borrow unlimited amounts of money for risk-free interest rate.
4. Investors are rational and risk-averse.
5. Investments are all divisible into small parts and liquid.
6. Investors maximize their economic utilities.
7. All investors have access to the same information.
8. There are no riskless arbitrage opportunities.

A risk, from the origin point of view, can be divided into systematic (market) risk and non-systematic (individual/unique) risk. CAPM model assumes market risk only, since the unique risk can be diversified. It is empirically proven [2] that investing into five to ten assets is practically enough to reach market return and market risk.

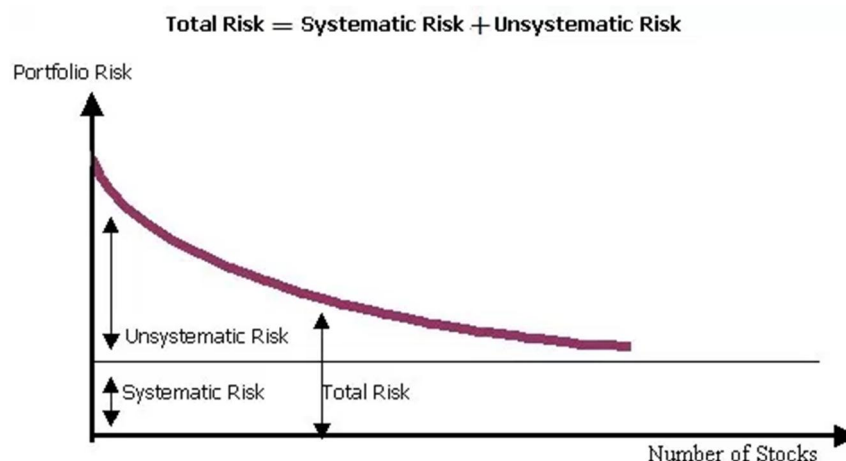


Figure 2: Portfolio risk decreasing as the number of investments is increasing

(source: <https://ranjatkulkarni.com/2011/04/05/diversification-how-can-an-individual-investor-reduce-portfolio-risk/>)

If one decides to invest into specific asset (project), his opportunity cost calculated by CAPM will reflect systematic risk only. The reason being the investor can invest his money into several smaller investments or his investment can be the part of portfolio where unique risk is minimized. In other words, if a small entrepreneur decides to invest into one specific project, he cannot assume risk premium for unsystematic risk. One can ask: why small entrepreneurs are doing their businesses? The answer is: they think⁵ that they are better than market. Since CAPM assumptions are not realistic, there exist market imperfections, different information for market participants and other violation of CAPM assumptions.

⁴ Single investor cannot affect price.

⁵ Many of them bankrupts quickly.

Investment (INV) depicted on figure 3 has the same risk as point B and the same return as point A. Area to the right of the curve represents combination into all investment opportunities. Tangent to curve with origin in point r_f represents Capital Market Line (CML). Tangency point M is the market portfolio. Investor can theoretically reach any point on CML by combined investment into risk-free asset and market portfolio [4]. According to CAPM model, point A does not carry any unique risk, it carries systematic risk only. Investor can put his money into point A and has the same return as INV with substantially lower risk. If investor accepts risk of INV, he can invest into point B with higher return. Opportunity cost will always lie on CML.

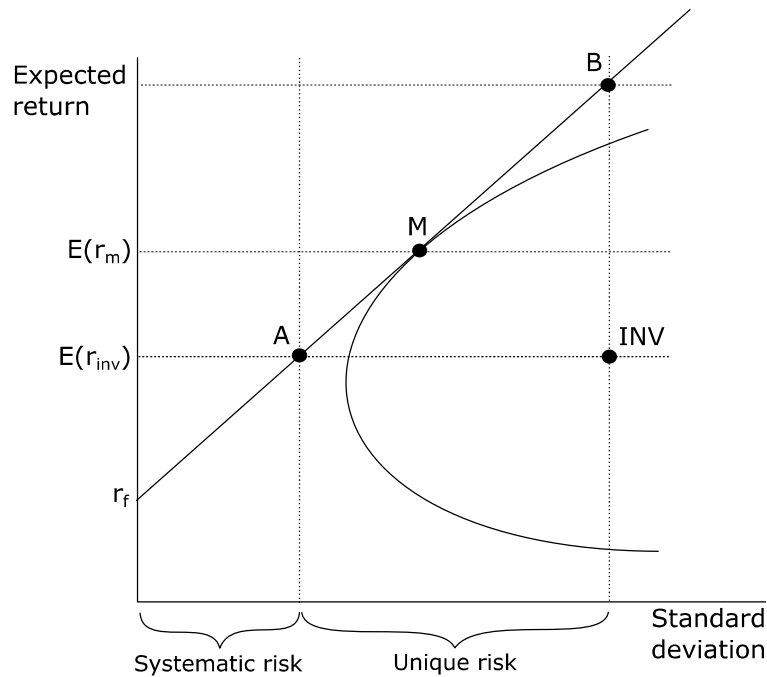


Figure 3: Capital Market Line

If investor accepts no risk, he invests all his money into risk-free assets (r_f point). In case he accepts market risk, he invests all his money into market portfolio (point M). Point A means partial investment into risk-free asset and partial investment into market portfolio. If investor is willing to invest in point B, he must borrow money at risk-free rate and invest his money and the borrowed money into market portfolio. One can object that borrowing at risk-free rate is impossible. It is true, but it is one of CAPM assumptions. Therefore, CAPM is very good tool for estimation of expected return, but one must be aware of its limitations, mainly given by CAPM assumptions and way how the data is collected.

2.2.3.3 Weighted Average Cost of Capital

Weighted average cost of capital (WACC) can be used as discount rate which reflects capital structure of a company. CAPM model results in expected return on equity. If a company had no debt, return on equity can be considered as discount rate. If a company has debt, return on debt must be included in discount rate calculation. The reason being the required return on debt is different (usually lower) than required return on equity. This is reflected in formula (12) where return on equity is weighted by the equity ratio and return on debt is weighted by debt ratio. By the return on debt one can understand average interest rate paid. The tax deduction from interest payment is considered.

$$WACC = \frac{E}{E + D} \times r_e + \frac{D}{E + D} \times r_d \times (1 - t) \quad (12)$$

<i>WACC</i>	<i>weighted average cost of capital</i>
<i>E</i>	<i>equity</i>
<i>D</i>	<i>debt</i>
<i>r_e</i>	<i>return on equity</i>
<i>r_d</i>	<i>return on debt</i>
<i>t</i>	<i>corporate tax rate</i>

Investor has two possibilities:

1. Use return on equity and include whole financing into cash-flow calculations. Results (e.g. NPV) will provide point of view of an investor.
2. Use WACC and exclude financing. This approach can be used for big companies with stable debt ratio. New project should not change the debt ratio. The results will provide capital point of view where both equity and debt owners are rewarded.
 - a. If a new project requires extra capital that is not covered by usual debt management, the best practice is to create special purpose entity⁶ (SPE) for calculation. This SPE, subsidiary, will have return on equity equal to WACC of parent company as it is its 100 % shareholder. New debt related to this company will be treated the same way as indicated in point 1.

2.2.4 SOCIAL AND ECONOMIC WELFARE

Social welfare definition is not unified, it can be understood as summation of all individual welfares in a society. Professor Arthur C. Pigou defined welfare in his work Welfare Economics [5]. Since social welfare is very broad, he divided it into economic welfare and non-economic welfare. Economic welfare is part of the social welfare, which can be expressed in monetary units, non-economic welfare cannot be expressed in monetary value. Maximization of social welfare is often discussed in relation with European energy market integration, see chapter 3. This concept was theoretically elaborated by prof. Francis M. Bator in his work The Simple Analysis of Welfare Maximization [6].

Practically, if there are two separate markets with the same commodity, e.g. electricity, and these markets become joined, the final price will settle between former prices in both markets. This will lead to positive effect for producers leading to higher profits in a market with lower price and consumers receiving lower price in a market with higher price. On the other hand, there will be negative effect for producers in market with higher price (lower profits) and consumers in market with lower price (higher price). Social welfare will increase, sources utilization will be more efficient, but individual welfares will decrease for specific groups in society.

Figure 4 shows the market with settlement (equilibrium) price 21 200 EUR. Surplus of one producer is the difference between the settlement price and the price for which he will agree to sell a product (electricity) in case his price is lower than settlement price. Surplus of one consumer is the absolute value of the difference between the settlement price and the price for which he will agree to buy a product in case his price is higher than settlement price. For example, if a supplier is ready to sell one GWh of electricity for 20 000 EUR, his surplus will be 1 200 EUR because he earns 1 200 EUR more than he expected. A consumer who is ready to pay 23 000 EUR earns 1 800 EUR because he will buy the product cheaper by 1 800 EUR. The sum of all consumers' and producers' surpluses is 1 722.7 thousand EUR and this amount is economic welfare.

⁶ SPE is usually created for any bigger project. However, for economic efficiency calculation it is enough to have a virtual SPV which means that a new legal entity is not created, but it is considered in calculations only.

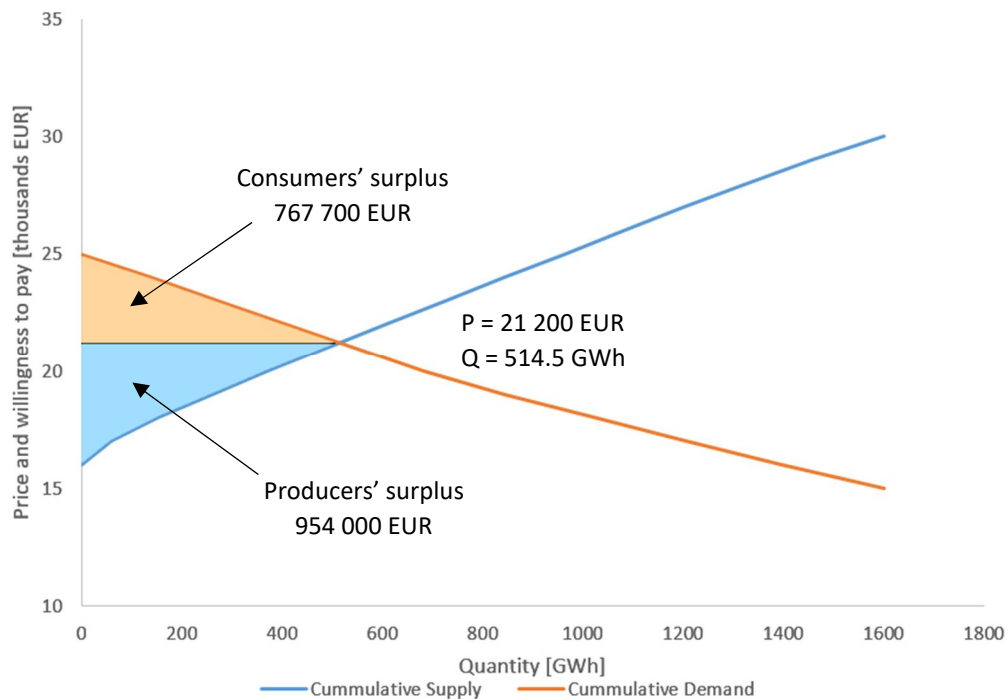


Figure 4: Electricity supply and demand curve for market A.

Figure 5 shows the situation on market B that is bigger than market A from figure 4. The settlement price is 24 800 EUR on this market. Economic welfare for market B is 7 353 thousands EUR.

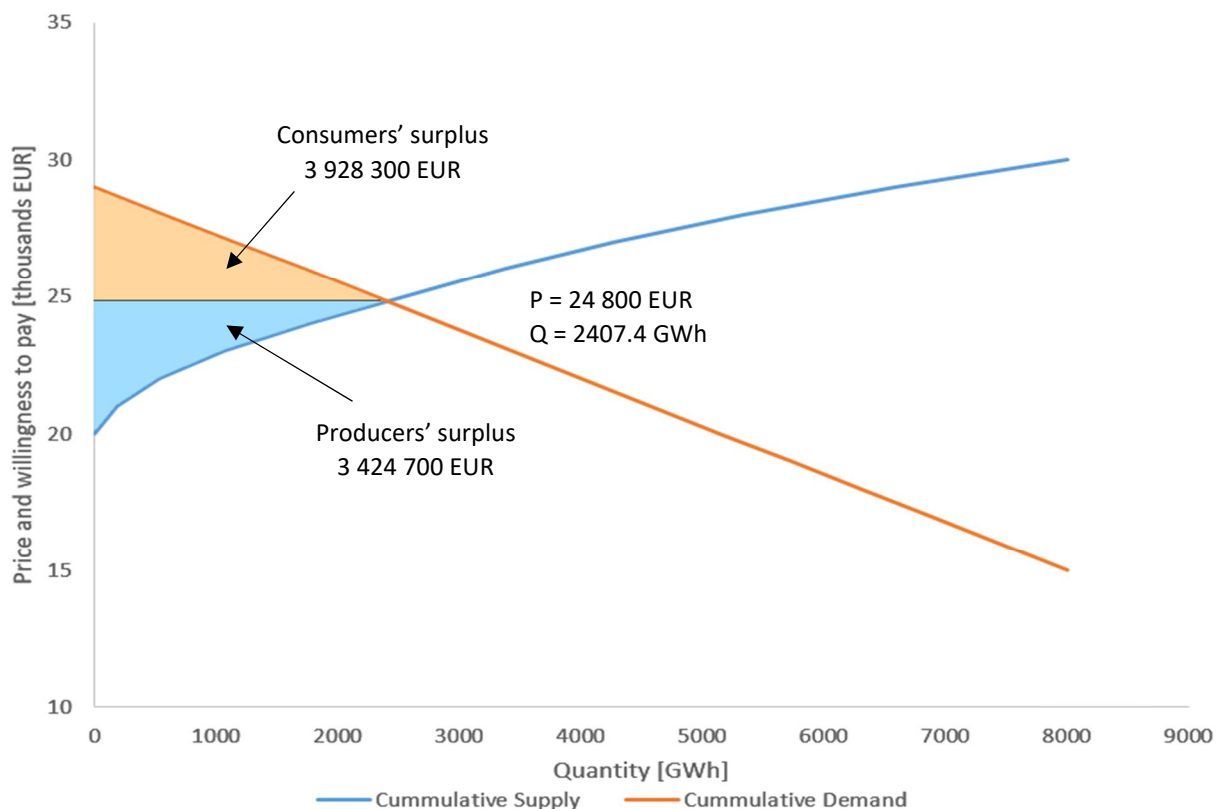
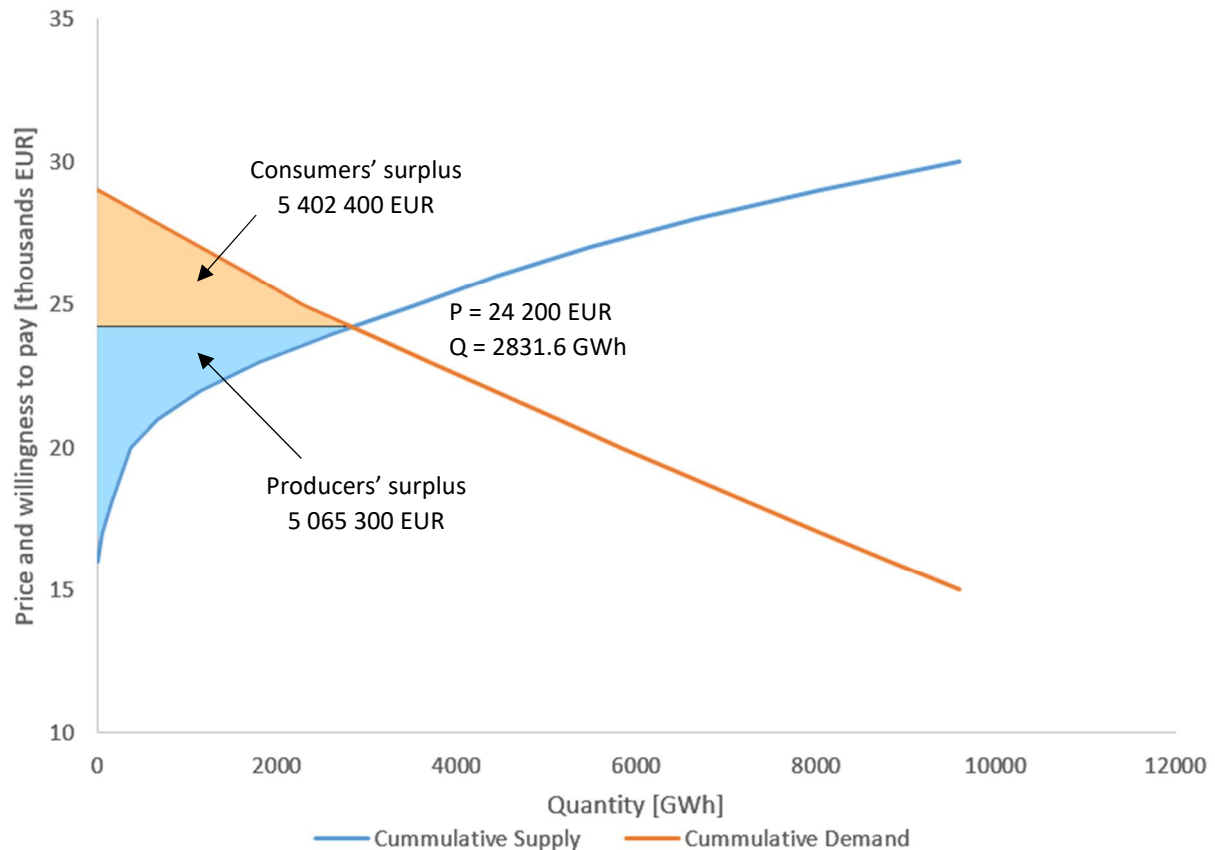


Figure 5: Electricity supply and demand curve for market B.

Figure 6 shows joint market A+B. The settlement price is 24 200 EUR and economic welfare is 10 477 thousands EUR. Economic welfare of joint market is higher than individual economic welfares of markets A and B. Market integration does have positive impact on economic welfare. On the other

hand, price for participants on the bigger market B decreased by 600 EUR per GWh (-2.4 %) and price for participants on the market A increased by 3 000 EUR per GWh (+14.2 %). One can notice dramatic decrease of economic welfare for consumers in market A and small increase of economic welfare for consumers in market B. This is the simplified example, more information about energy market integration issues is provided in the section 3.



Former example shows direct impact of an action (e.g. market integration) on economic welfare. There are indirect impacts on economic welfare, a feedback on direct impacts (e.g., electricity price change will be reflected in consumer goods prices). Monetary estimation of indirect impacts is complicated, but not impossible. The last group is impact on non-economic welfare (e.g. environment) which should be incorporated in decision-making, but cannot be expressed in monetary units or the transformation to monetary units is doubtful. In that case, multicriterial decision making takes place.

2.2.5 MULTICRITERIAL DECISION MAKING

A significant number of problems in power sector lead to the application of multiobjective evaluation and to the multicriterial decision. There are two major categories of problems:

1. Financial profitability of a project is one of several aspects of decision process. Other aspects can be related to environment, impact on infrastructure, impact on unemployment etc. Final decision is trade-off between all requirements. Multicriterial decision model can be very useful for a fair evaluation. This approach is suitable even for benchmarking purposes.
2. All aspects (components) of decision process are evaluated in financial terms. Each component needs to be transformed into monetary units. This is the key process that affects the final results and consequently affects final decision.

One of the key tasks in multicriterial decision making is to set-up weights for each individual criterion and to find proper transformation function into the required units (usually money). This chapter describes the process of criteria weights determination since this can be essential e.g. in social welfare calculation. The link to application on specific tasks is provided. A few words are dedicated to discussion about datatypes since nominal and ordinal data are frequently used in economic sciences.

Input parameters of criterial functions can have different nature and meaning. In general, there are four data types that can describe the input parameters of decision process:

1. Nominal data – this data is described (classified) by a symbol, for example colour (red, blue, green, etc.), gender (male, female) or day in week. Nominal data can be described by numeric values, but these values cannot be used for ordering or direct numerical calculations. For example (Monday = 1, Tuesday = 2, ..., Sunday = 7) or (Male = 1, Female = 2). Transformation of such kind of data into numerically used parameters is almost impossible. There are specific tasks such as credit scoring where these data are transformed into real number that are used for further calculations [7].
2. Ordinal data – data that do not have numeric character, but can be rank-ordered. For example, education (primary school = 1, secondary school = 2, college = 3, university = 4). Numbers can be assigned to elements and values can be compared and ordered. University education is better than secondary school education for some specific purposes. On the other hand, the distance between elements do not have any interpretation.
3. Interval data – the most widely used numerical data. For example, temperature and most of the other measurements. The differences between two temperature (or distance) measurements have meaning and interpretation. On the other hand, ratio between some measurements may have wrong or no interpretation. For example, ratio of measured temperatures (in Celsius or Fahrenheit) degrees does not have meaning. One cannot say that 40 °C temperature is two times higher than 20 °C.
4. Ratio data – its meaning is to have meaningful ratios, usually in measurements with the absolute zero. Distance measurement, number of clients, money or even temperature in Kelvins can be used in ratios with meaningful interpretation.

A multicriterial decision making problem can be represented by the following generalised model (13) [8].

$$\begin{array}{l} \text{Maximize } [C_1(x), C_2(x), \dots, C_k(x)] \\ x \in X \end{array} \quad (13)$$

x	<i>any specific alternative</i>
X	<i>a set representing the feasible region or available alternatives</i>
C_k	<i>k-th evaluation criterion</i>

This group of problems is referred as selection or mathematical programming problems. More information about mathematical techniques, definitions of problems and solutions can be found in [8]. Publication [9] contains essential techniques in multicriterial analysis and contains several case studies, where one of them is related with investigation of potential repositories for radioactive waste in UK. Author developed his own multicriterial decision making method [7]. It is related to the companies default prediction and its modification [10] was used for benchmarking purposes of companies in the sector of electricity distribution.

2.2.5.1 Criteria Weights Determination

Weights determination represents relative importance of criteria in accordance with the preferences of decision maker. The most of the multicriterial decision methods assumes that weights are normalised and fulfil condition (14).

$$\sum_{i=1}^N w_i = 1 \quad (14)$$

N | number of criteria
 w_i | relative weights of i -th criterion

Since the direct estimation of criteria weights may be a complex task, there are several methods [11] which can help with the calculation of weights.

Using so called scoring method, the evaluator's task is to assign a score to each criterion. Score is represented by a certain number of points from a predefined score point scale, in accordance with the opinion of decision-maker about the importance of the criteria. When creating a scoring point scale, it is recommended that it begins from zero, has an odd number of values and has a verbal description. The odd number is useful for having a natural central value. An example of a suitable scale can be: not important 0, little important 1, medium important 2, important 3 and very important 4. Normalised values of criteria weights can be obtained from equation (15).

$$w_k = \frac{a_k}{\sum_{i=1}^N a_i} \quad (15)$$

N | number of criteria
 a_i | score of i -th criterion
 w_k | relative weights of k -th criterion

Scoring method can be modified in a way that the criterion weight is interpreted as value of the ranking function. Decision maker's task is to rank criteria according to their importance where importance of some criteria may be considered as equal. Ranking function value is determined in a way that the least important criterion has value equal to one and the most important criterion has ranking function value equal to the number of criteria. Moreover, ranking of the criteria with equal order should lead to average value of ranking function, e.g. if two criteria with same importance are ordered on the 2nd and 3rd place, ranking function should assign the value 2.5 to them.

Another method, based on above mentioned scoring method, is called Metfessel method (allocation). Decision maker assigns 100 points among all criteria in accordance with his preferences and the most points should be assigned to the most important criterion.

$$w_k = \frac{a_k}{100} \quad (16)$$

a_k | score of k -th criterion
 w_k | relative weights of k -th criterion

The second group of weight determination methods are so-called pairwise methods where preference relation is determined for each criteria pair. For each pair of criteria $[c_i; c_j]$, one of three situations may occur:

1. i -th criterion is preferred over j -th criterion, $p_{i,j} = 1$;
2. j -th criterion is preferred over i -th criterion, $p_{i,j} = 0$;
3. i -th and j -th criteria are equivalent, $p_{i,j} = 0.5$;

Matrix p is filled with values $\{0, 1, 0.5\}$ as shown above. Standardized weights of criteria are calculated as shown by formula (17). The sum in numerator represents the number of preferences of j -th criterion, i.e. how many times is j -th criterion preferred over other criteria.

$$w_j = \frac{\sum_{i=1}^M p_{i,j}}{M(M-1)} \quad (17)$$

$p_{i,j}$	element of matrix p
w_j	relative weight of j -th criterion
M	number of criteria

Pairwise method can be extended by quantifying the intensity of relation between criteria in each pair. The ratio between criteria weights is estimated.

A popular method for weights determination is based on construction of criteria tree (ordered rooted tree). The determination of weights is performed for each individual branch on each hierarchical level of criteria tree. The final weight is determined as the product of relative criteria weight (the deepest tree level) and relative weights of superior nodes of the criteria tree. Criteria can be categorized, for example economic criteria, social criteria, ecological criteria, technological criteria. Each category can have relative weight among other categories. The final weight should be multiplied by category relative weight. The determination of weights for each individual category can be subject to analysis using above-mentioned techniques.

All methods for weights determination have their advantages and disadvantages. Extended pairwise method requires a great deal of information with high risk of inconsistencies as preferences of decision maker are subject to his consideration. On the other hand, scoring method is very easy to apply since it requires criteria rank only. In case of high number of criteria, construction of criteria tree can be recommended as it is straightforward. Hierarchical ordering of criteria can help with logical connection between different criteria. In any case, the decision process is affected by subjective consideration of decision maker and results should be validated using other methods and / or expert estimate.

2.2.6 OPTIONS

An option is a financial derivative contract which provides the right to buy or sell underlying by a certain time in the future at a fixed price. There are two types of options, a call option and a put option. A call option grants the right to buy underlying. A put option grants the right to sell underlying. The option buyer has the right but not the obligation to sell/buy an underlying. The option seller is obliged to sell/buy an underlying. The option buyer also called option holder is in the long position and option seller also called option writer is in the short position. [12]

To obtain the right, the option buyer pays the seller option price when the option contract is initiated. The option price is often called the option premium. The price at which the option holder can buy or sell the underlying is called strike price or exercise price. Exercising the option means to use the right to buy or sell the underlying. The option holder cannot exercise the option after passing of the expiration date. If the option holder is exercising a call, he pays the exercise price and receives underlying or an equivalent cash settlement. The option writer receives the exercise price and delivers the underlying or pays equivalent cash settlement. If the option holder is exercising a put, he delivers the stock and receives the exercise price or a cash equivalent from option writer. [13]

Options can be divided into a several categories according to the exercise style and pay-off value calculation. Vanilla and exotic options are the two major categories. Vanilla options are the regular, most traded options with standard features like expiration date and exercise price. European and American options belong to the vanilla option category. Vanilla options are usually traded through the

stock exchange. Exotic options mostly differ from the vanilla options in the calculation of their pay-off value. The trading is usually realized in over-the-counter manner. [13]

A European option can be struck only at option expiration time, contrary to an American option which can be struck anytime arbitrarily. There are many types of financial options such as the stock options (the most common), index options, bond options, interest rate options, currency options and, for example, weather options.

An option holder is in so-called long position as his profit is theoretically unlimited and maximal loss is the option premium. An option writer is in short position and his financial situation is opposite to option holder. The diagrams above in the figure 7 show long (call and put) position option payoffs and the diagrams below show the short (call and put) positions.

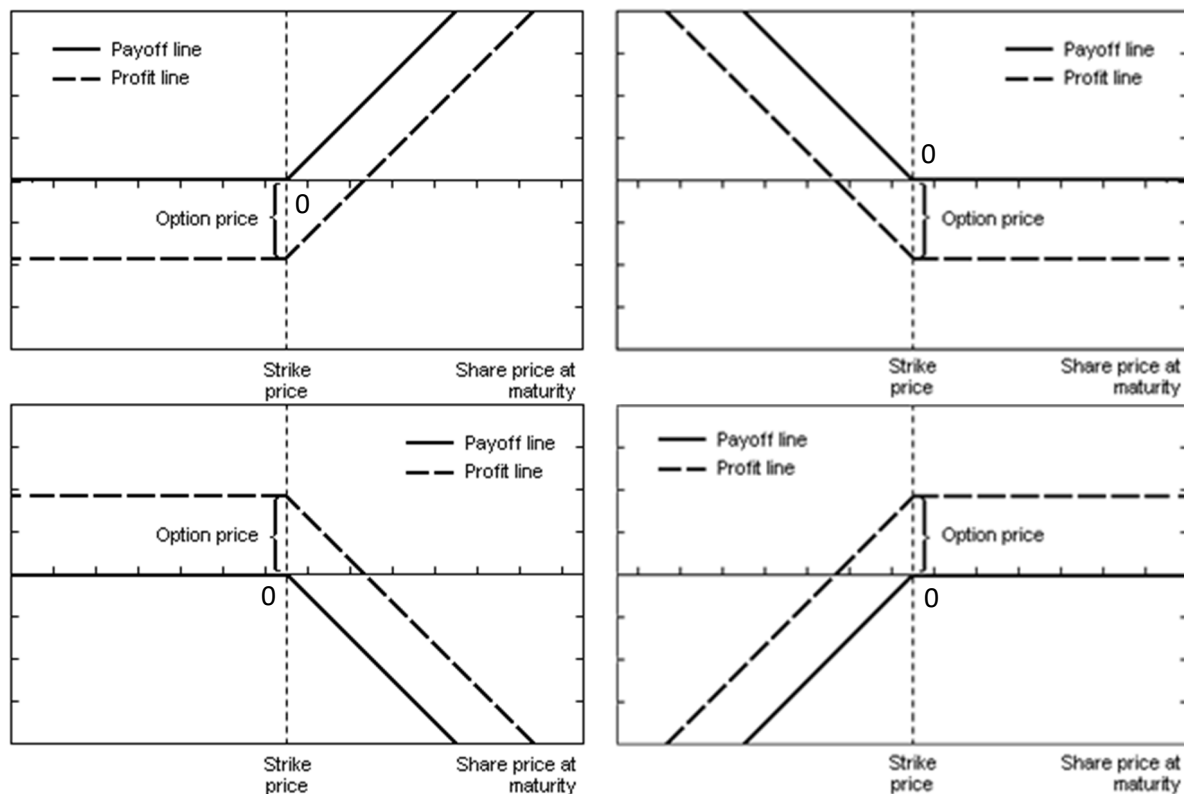


Figure 7: Payoff diagram for long call, long put, short call and short put options.

It is worth to mention so-called real options whose underlying is not a financial asset, but it can be a project value. The publication [14] explains application of real options theory on project in power sector.

2.2.6.1 Options Valuation

Option value at maturity date is the absolute value of the difference between the strike price and actual underlying value (fig. 7). The situation before maturity date is not such straightforward as there is randomness in moving of the underlying price. This is shown in figure 8 where the lines T_1 , T_2 and T_3 show the option value before maturity. Line T_1 shows the value of option long time before maturity. As the time to maturity decreases, the option value line gets closer to line B.

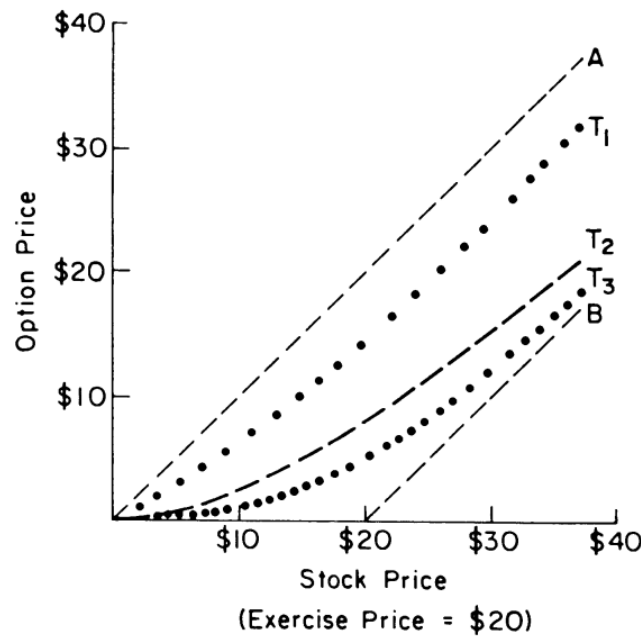


Figure 8: Option value before maturity.

Journal of Political Economy © 1973 The University of Chicago Press [15]

Derivation of option pricing formula (1973) by Black, Scholes and Merton was subject of the Nobel Prize (1997) [16]. Step by step procedure is described in [17] and it is based on the assumption that underlying price is a geometric Brownian motion. The value of European call option can be determined by partial differential equation (18). Application of boundary conditions [18] leads to closed-form solution (19) for call option. The value of put option can be calculated using formula (20).

$$\frac{dV}{dt} + \frac{1}{2}\sigma^2 S^2 \frac{d^2V}{dS^2} + rS \frac{dV}{dS} - rV = 0 \quad (18)$$

V	value of call option as a function of underlying price and time to maturity
t	time to maturity
σ	volatility of underlying returns
S	underlying price
r	risk-free interest rate

Black-Scholes model assumptions:

1. Efficient markets;
2. The price of the stock one period ahead has a log-normal distribution with constant mean and volatility;
3. Constant and known risk-free interest rate;
4. Investors can borrow and lend at risk-free interest rate;
5. There are no transaction costs and taxes.

For the sake of the completeness, it is important to notice that these closed form formulas can be used on underlying (stock) that pays no dividend and they are not applicable for American options. The book [19] contains exact or approximate formulas for pricing of the most types of options.

$$V_C = N(d_1)S - N(d_2)Ee^{-rT} \quad (19)$$

$$V_P = -N(-d_1)S + N(-d_2)Ee^{-rT} \quad (20)$$

$$d_1 = \frac{\ln\left(\frac{S}{E}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \quad (21)$$

$$d_2 = d_1 - \sigma\sqrt{T} \quad (22)$$

V_C	value of call option
V_P	value of put option
E	exercise (strike) price
N	cumulative distribution function of normal distribution

Interpretation of $N(d_1)$ and $N(d_2)$: “ $N(d_2)$ is the risk-adjusted probability that the option will be exercised. The interpretation of $N(d_1)$ is a bit more complicated. The expected value, computed using risk-adjusted probabilities, of receiving the stock at expiration of the option, contingent upon the option finishing in the money, is $N(d_1)$ multiplied by the current stock price and the riskless compounding factor. Thus, $N(d_1)$ is the factor by which the present value of contingent receipt of the stock exceeds the current stock price.” [20]

In the power sector, options are mostly used for hedging. For example the case where power producer wants to secure against low electricity prices. Intermittent power sources (wind and photovoltaic power plants) are dependent on weather conditions. With higher penetration of these power sources, weather options began to appear in the last decade. Producers can hedge against risk related to the weather. Since the weather does not follow geometric Brownian motion, Black-Scholes formula cannot be used for pricing of weather option. Weather option pricing using simulation is introduced in the chapter 7.

2.2.6.2 Weather Options

Weather options can be used for hedging against weather risk or for speculations related to weather. Differences between weather options and standard financial options are:

1. Underlying value (temperature) must be transformed into monetary unit;
2. Temperature does not follow geometric Brownian motion;
3. Temperature volatility is not constant.

Transformation of the temperature into money is made by multiplying temperature difference and amount of money per one index point (one degree). Temperature difference can be understood as the difference between average daily temperature and base (reference) temperature. Reference temperature may have the similar meaning as strike price in standard financial options.

Weather options are traded through exchange and on over-the-counter (OTC) market. Chicago Mercantile Exchange (CME), the largest commodity derivative exchange, quotes weather futures contracts and options on the weather futures. There are eight standardized traded products [21]. The main characteristic of future contracts is that both contract parties agree now on price in the future expiration date and they have obligation to make settlement in this price. This can be used for hedging against changes in the prices in both ways, contrary to the financial options where option holder has right to exercise and option writer has the obligation from the contract. Weather options traded on CME are options on future contract, it means that option holder has right to buy underlying (future contract) at option expiration date. However, OTC market can design its own specific product, e.g. option with pure temperature underlying.

The main weather indices are heating-degree days (HDD), cooling-degree days (CDD) and cumulative average temperature (CAT), see formulas (23) (24) (25) for definitions. Weather options are usually stripe options for specific period $[T_1, T_2]$ and one strike value (different from base temperature). Since the HDD/CDD/CAT are cumulative values, strike value reflects the length of the period. For example, CDD average value for five summer months is 1350, measured CDD value is 1300 and option strike is 1250. Option holder has right to compensate the difference $1300 - 1250$ CDD. On the other hand, option on the OTC market can have individual strike for each day. HDD and CDD indices are used for standardized US contracts. HDD and CAT are used for standardized European contracts. Finally, Japanese weather products are settled against Pacific Rim (PRIM), the arithmetic average of temperatures over specific period.

$$HDD = \int_{T_1}^{T_2} \max(b - T(t), 0) dt \quad (23)$$

$$CDD = \int_{T_1}^{T_2} \max(T(t) - b, 0) dt \quad (24)$$

$$CAT = \int_{T_1}^{T_2} T(t) dt \quad (25)$$

$$PRIM = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} T(t) dt \quad (26)$$

T_1	beginning of a measurement period
T_2	end of a measurement period
$T(t)$	average temperature in day t
b	base temperature

Regardless of detailed contract specifications, weather option attributes preclude usage of Black-Scholes formula for valuation purposes. Temperature simulation is convenient way how option value can be calculated. More information about simulations can be found in the following chapter 2.2.7. The complete process of option value calculation is shown in the chapter 7.

2.2.7 SIMULATIONS

Simulations are a set of effective tools used for modelling activities, processes or system behaviour without their realisation. Simulations, in the narrow sense, are numerical methods executing experiments on specific mathematical models. [22] This chapter is limited to Monte Carlo simulation where the input parameters are randomly generated number from specific probability distribution and its parameters. Monte Carlo can be used for solving stochastic (e.g. random walk) and deterministic (e.g. definite integral) problems. Simulations are particularly useful for solving problems which have no analytical solution.

A simulation process can be performed by application of the following steps:

1. Define mathematical model;
2. Choose the theoretical distribution for input parameters of defined model;
3. Estimate parameters of chosen distributions;
4. Perform simulations;
5. Interpret simulation results, e.g. mean value and standard deviation;
6. Perform hypothesis testing on results if applicable.

NPV calculation with stochastic input parameters can be a very useful example for Monte Carlo financial applications. This example will be used for description of a simulation process. Monte Carlo simulation can also be used in already running projects for estimation of financial requirements in individual phases of complex projects.

NPV model, equation (4) on page 9, has cash-flows and discount rate as input parameters. Cash-flows are the result of company operations and cannot be determined with 100 % accuracy. For example, sales are dependent on customers and there is whole chain of random events that can affect cash-flows estimation.

Company managers assume that the cash-flows will grow by 5 % annually and growth is the only stochastic parameter of NPV model. In other words, mean value of CF growth is 5 %. Assuming that growth follows normal distribution, estimation of standard deviation is required for the growth modelling. This is one of the biggest issues in distribution parameters estimation and improper estimation may result in bias of simulation results. There are natural processes that can be observed and for which the distribution parameters can be calculated. This can be useful for example in the field of physics. Unfortunately, economic (financial) tasks must rely on historic data (if available) and expert estimations.

Once distribution parameters are estimated, simulation can start. The number of simulation repetitions increases the accuracy of results. The final result is mean value and its standard deviation. For mentioned NPV, average value and standard deviation are calculated from results of each particular simulation. NPV simulation results of the aforementioned problem are shown in figure 9.

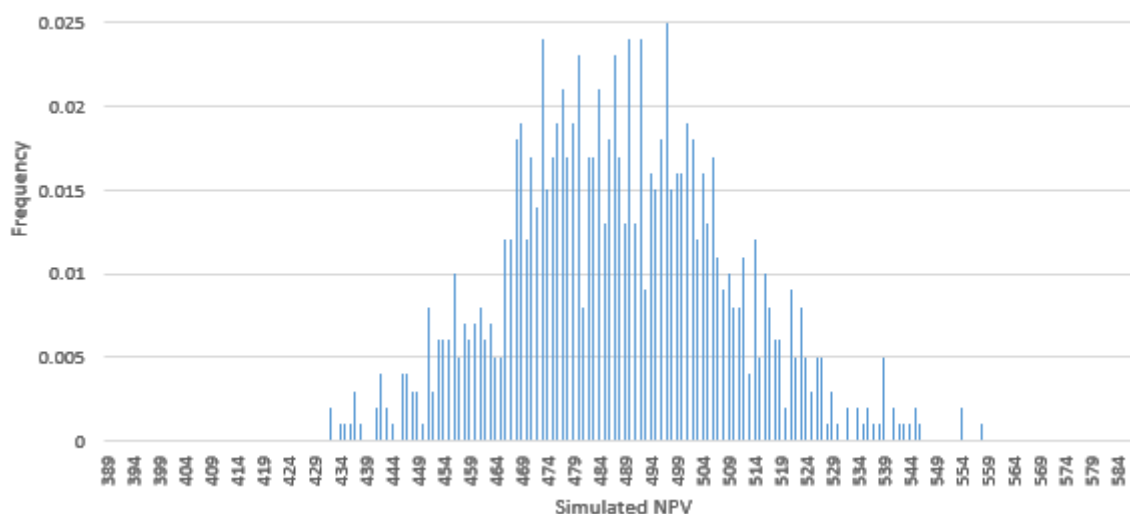


Figure 9: Result of Monte Carlo simulation.

Assumptions: investment 1000; CF_1 : 200; CF growth 5%, growth standard deviation 1%; discount rate: 10%.

This is demonstrative example and for simplicity, only 1000 runs were performed.

The number of simulations is 1000. Average value from NPV simulations is 487 and its standard deviation is 21. Results can be used for value-at-risk (VaR) calculation which is 453 for the 5 % level. Managers can state that project will have lower NPV than 453 with 5 % probability which is very useful information. One can notice the difference between simulated distribution and theoretic values of normal distribution (figure 10). Simulated results will approximate down to theoretical distribution with increasing number of simulations run according to central limit theorem.

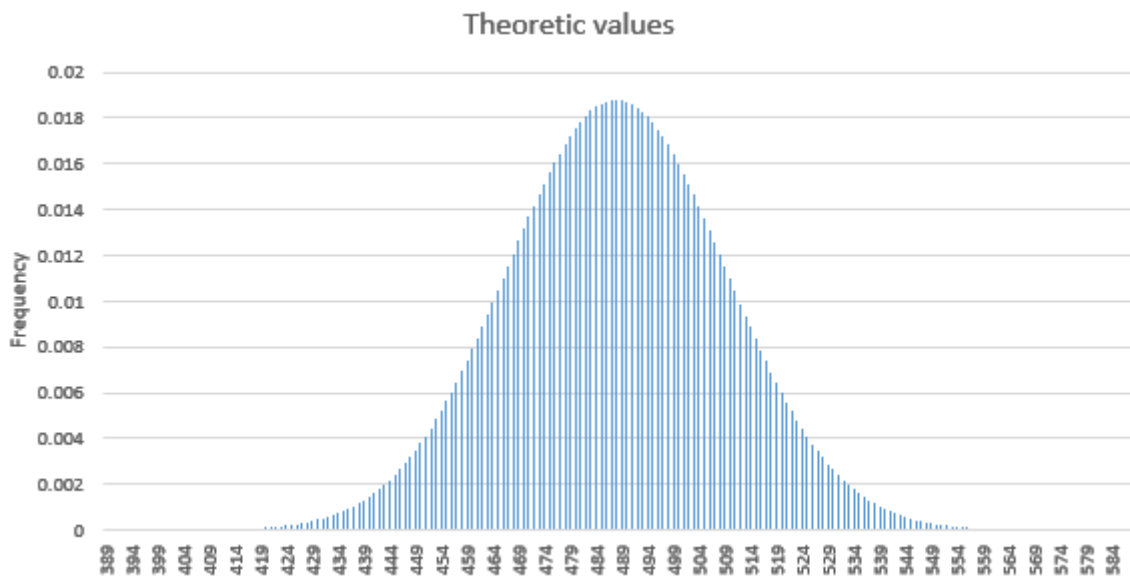


Figure 10: Theoretic values of normal distribution with mean 487 and standard deviation 21.

More examples of Monte Carlo applications can be found in [23][24].

2.2.7.1 Temperatures

Temperature modelling is used for weather options valuation (sections 2.2.6.2 and 7). Continuous autoregressive moving average (CARMA) models introduced in [25] are suitable for modelling evolution of temperature over time [26]. Author in [26] extends continuous autoregressive (CAR) models, subclass of CARMA models, to allow seasonality in the residual variance. Author uses vectorial Ornstein–Uhlenbeck process for modelling of de-trended temperature movement. Then, he explains the link between continuous and discrete autoregressive (AR) processes. Weather option valuation is based on the daily average temperatures that are calculated as arithmetic mean between daily highest and lowest temperatures. Therefore, discrete model of temperature evolution is more suitable for valuing of weather options. The discretization process of CARMA models for financial application is explained in depth in [27].

Temperatures have seasonal characteristics with possible trend. Seasonal function can be modelled by Fourier series. Truncated cosine Fourier series with trend element are used in formula (27).

$$\Lambda(t) = x_0 + x_1 t + x_2 \cos\left(\frac{2\pi(t - x_3)}{365}\right) \quad (27)$$

$$D_t = T_t - \Lambda_t \quad (28)$$

t	time
x	parameters
D	de-trended temperature data
T	daily average temperatures
Λ	seasonal part of temperature data

Seasonally adjusted temperature data can be modelled by a discrete autoregressive process. Analysis of specific data (69 years history from Paris-Orly, see chapter 7) suggests that AR(3) model is suitable for this purposes. However, change in locality may lead to different order of AR model. Formula (29) represents general AR(Q) model where Q denotes the order of AR model.

$$Y_t = \sum_{i=1}^Q \alpha_i Y_{t-Q+i-1} + \sigma_t \varepsilon_t \quad (29)$$

t	<i>time</i>
α	<i>parameters</i>
σ	<i>standard deviation of normal distribution</i>
ε	<i>independent and identically distributed random variables from standard normal distribution</i>
Q	<i>order of autoregressive model</i>

One can assume that the daily changes in temperature may be higher in spring and autumn as compared to summer and winter. This assumption leads to analysis of variance from AR model and suggesting seasonal form of variance modelled by truncated Fourier series.

$$\sigma^2(t) = \beta_1 + \sum_{i=1}^N \left[\beta_{2i} \cos\left(\frac{2i\pi t}{365}\right) + \beta_{2i+1} \sin\left(\frac{2i\pi t}{365}\right) \right] \quad (30)$$

t	<i>time</i>
β	<i>parameters</i>
$\sigma(t)$	<i>standard deviation of temperature for specific day in year</i>
N	<i>order of Fourier series</i>

More detailed application of temperature modelling is shown in chapter 7 where it is used for valuations of weather options.

2.3 EVALUATION PERIOD

Evaluation period is essential an input parameter in economic evaluation since it directly enters into economic effectiveness calculation criteria. Useful time constants in project evaluation are as follows.

1. Technical lifetime (T_T) – period during which an asset can technically work before it must be replaced.
2. Economic lifetime (T_E) – period during which an asset is useful for his owner. It is usually shorter than technical lifetime because an asset can become obsolete in its feasibility and usage. For example, technical lifetime of a bus is around 25 years. After 10 – 15 years of operation, one can recognize that the new buses have lower consumption, maintenance of old buses becomes more expensive, more frequent failures can occur. Owner can decide to replace old buses by new ones earlier e.g. after 15 years. In this case, 15 years are economic lifetime.
3. Parameters estimation horizon (T_H) – time until which economical and technical parameters can be accurately estimated. For example, estimation of power grid losses in three years can be done accurately. The same task for time in 30 years from now is practically impossible. Values beyond horizon period are roughly estimated by constant values of horizon year or by incremental values with specified annual growth.
4. Evaluation period (T) – period for which economic evaluation is performed.

Evaluation period for a single project with one major component can be set as the economic lifetime of major component. The same logic applies for a project with several major components of the same economic lifetime.

For a single project with several major components of different economic lifetime, two boundaries for evaluation period can be specified. Lower boundary is the lowest economic lifetime among all major components. Upper boundary is period for which economic consequences can be estimated or repeated. Infinity is used very often for projects in power sector. These boundaries define economic lifetime. Economic effectiveness for evaluation period from this interval leads to the same decision

regardless of chosen termination time. Scrap values of major components are considered in case of termination.

Above-mentioned approaches can be also applied for selecting the best project from several mutually exclusive projects. Evaluation period should be the same for all projects. If economic consequences can be repeated, the least common multiplier of projects economic lifetimes can be used as an evaluation period. Otherwise, one needs to decide what to do with other projects at the end of the economic lifetime of the shortest one. There are two possibilities: investor can sell other projects or make short-term investment to achieve equal evaluation periods.

3 EUROPEAN ENERGY MARKET INTEGRATION

A brief information about legislation behind European energy market integration is available in the document [28]. Up to 1990s, the energy markets were dominated by vertically integrated monopolies. One company owned production and grid infrastructures. The aim of new European legislation was to put into practice competitiveness on energy markets. New European legislation can be divided into four steps, the so-called energy packages.

1. The first energy package / directive (1996) introduced rules for third-party access to transmission and distribution networks. It introduced independent regulatory bodies and possibility for wholesale customers to change energy supplier.
2. The second energy package (2003) focused on unbundling, where energy production, distribution and transmission were separated into individual legal entities. Households were now able to choose electricity and gas suppliers.
3. The third energy package (2007) strengthened the unbundling regulation and independence of regulators, established Agency for the Cooperation of Energy Regulators (ACER), deepened cross-border cooperation between transmission system operators (TSO) and increased transparency in retail markets. [29]
4. The fourth energy package / winter package (2016) is currently under consideration and has not been approved yet. It deals with clean energy and energy efficiency.

This chapter is devoted to bidding zones reconfiguration issues.

3.1 BIDDING ZONES

Bidding zone is a set of interconnected nodes that can be understood as one node from the electricity trading point of view. Bidding zone can be interpreted as a copper plate, which means that there are no transmission limitations inside a bidding zone. Electricity (commodity) price does not vary inside one bidding zone.

Figure 11 depicts current bidding zones in Europe. Bidding zones represent tightest market integration. They were usually formed by political borders, since power grid was historically developed inside the countries. There are four countries in Europe that are split into several bidding zones (Norway, Sweden, Denmark and Italy) and two bidding zones that overlap countries' borders. The first one is Ireland which also includes territory of Northern Ireland, of course. The second bidding zone consists of German, Austrian and Luxembourg territory. The latter has been frequently discussed in recent years.



Figure 11: Bidding zones in Europe [30]

3.1.1 CURRENT PROBLEMS DESCRIPTION

Businesses operating on the electricity market, primarily in the geographical location of Czech Republic and Poland face the problem of insufficient electricity transmission capacities on the border with Germany. [31], [32] Available transfer capacities are severely limited due to the influence of so-called loop-flows (flows within the Germany-Austrian⁷ bidding zone, which flow through the transmission system of neighbouring countries). These business entities are losing business opportunities and their losses are not compensated [33], [34]. Loop-flows are unscheduled power flows and currently are not subject to payments for usage of transmission system. This situation is caused mainly by insufficient transmission capacities in Germany. Building of new power transmission lines is already lagging behind the timeline.

An effective solution of this problem is splitting of Germany-Austrian bidding zone into several smaller bidding zones. Current situation is profitable for participants from Germany-Austrian bidding zones because the cheap electricity from wind power plants from northern Germany can be transferred to southern Germany and Austria without payment for transmission fees in neighbouring countries. The whole Germany-Austrian bidding zone benefits from lower electricity prices. If this zone were divided, there would become a difference in electricity price between new zones (e.g. northern and southern Germany) [35]–[37]. This price difference would be caused by requirement of transmission capacity

⁷ Zone covers three countries: Germany, Austria and Luxembourg. Luxembourg area is very small and does not affect other countries. Therefore, this zone is called Germany-Austrian even if there is one more country.

allocation and related costs. Czech and Polish transmission system operators would obtain revenues from transmission capacity trading. Moreover, companies (mostly electricity traders) from Czech Republic and Poland could participate in capacity allocation mechanism and thus have opportunities of trading abroad. Multilateral debate led to decision to split Germany-Austrian Bidding zone. German and Austrian regulators agreed on allocation of transmission capacities on their border. Zone will split in October 2018 [38]. This decision will help the transmission system operators in Czech Republic and Poland, but congestion problems inside of Germany will persist since insufficient transmission capacities also prevail inside Germany. The issue will be minimized to some extent, but not eradicated.

Economic welfare (often erroneously referred to as social welfare) is used as the primary argument against splitting of Germany-Austrian bidding zone [35], [36]. There is no universal definition of social welfare and calculation of social welfare is very often (particularly in bidding zones reconfiguration) simplified to calculation of economic welfare. Economic welfare is defined as sum of consumers' and producers' surpluses and in the context of bidding zones as described in [39]. Prices of electricity have strong impact on whole society because electricity is used widely and industrial production is very sensitive on electricity price. Economic welfare calculation does not include secondary (indirect) impacts on society and it assumes a homogenous region (e.g. Central Europe or Central and Eastern Europe). The other problem is varying purchase power of countries with different economic development [40]. Increase or decrease of electricity prices by one euro has different impact on German residents and Czech residents. This discrepancy should be reflected in social welfare calculation. [41]

3.1.2 HISTORICAL BACKGROUND

Bidding zones theory was developed in 90s in US by [42]–[47] as the consequence of power grid congestion (insufficient electricity transmission capacities). Market liberalization and integration process in Europe begun significantly later.

Bidding zone can be defined as an area without internal business congestion. It means that transaction can be completed between any two points inside this area and electricity can be transferred without the requirement of transmission capacity allocation. Bidding zones' borders in many countries are the same as the political borders because countries were more isolated in the past than in present time but the situation is changing with the increasing international cooperation. Countries like Czech Republic, Slovakia, Poland, Hungary and France are examples of bidding zones that are identical with political borders. On the other hand, there is a single bidding zone that includes Germany, Austria and Luxembourg. [41]

Germany-Austrian (DE-AT) bidding zone was established in 2005, but the process of its legal origin is not almost described. DE-AT bidding zone does not fulfil condition for a being fully independent bidding zone. The main reason is that DE-AT zone cannot be understood as "copper plate" due to the congestion of transmission lines. ACER (Agency for the Cooperation of Energy Regulators) has adopted a legally non-binding opinion to split the German-Austrian single bidding zone as according to [48].

3.1.3 EVALUATION CRITERIA

Bidding zones reviewing process is defined in Regulation establishing a Guideline on Capacity Allocation and Congestion Management (CACM) [49]. This document contains criteria for reviewing bidding zones configuration (see the text below). Unfortunately, the definition of criteria is vague and unclear since the document is part of European energy related legislation. One can state that document explains only principles on which the criteria should be built. Several criteria based on these principles were introduced [50]. Since the power flows are changing, partially stochastic tools for

accurate description of the load were introduced [51]. Both articles [50][51] are part of appendix section.

1. *If a review of bidding zone configuration is carried out in accordance with Article 32, at least the following criteria shall be considered:*
 - a. *in respect of network security:*
 - i. *the ability of bidding zone configurations to ensure operational security and security of supply;*
 - ii. *the degree of uncertainty in cross-zonal capacity calculation.*
 - b. *in respect of overall market efficiency*
 - i. *any increase or decrease in economic efficiency arising from the change;*
 - ii. *market efficiency, including, at least the cost of guaranteeing firmness of capacity, market liquidity, market concentration and market power, the facilitation of effective competition, price signals for building infrastructure, the accuracy and robustness of price signals;*
 - iii. *transaction and transition costs, including the cost of amending existing contractual obligations incurred by market participants, NEMOs and TSOs;*
 - iv. *the cost of building new infrastructure which may relieve existing congestion;*
 - v. *the need to ensure that the market outcome is feasible without the need for extensive application of economically inefficient remedial actions;*
 - vi. *any adverse effects of internal transactions on other bidding zones to ensure compliance with point 1.7 of Annex I to Regulation (EC) No 714/2009;*
 - vii. *the impact on the operation and efficiency of the balancing mechanisms and imbalance settlement processes.*
 - c. *in respect of the stability and robustness of bidding zones:*
 - i. *the need for bidding zones to be sufficiently stable and robust over time;*
 - ii. *the need for bidding zones to be consistent for all capacity calculation time-frames;*
 - iii. *the need for each generation and load unit to belong to only one bidding zone for each market time unit;*
 - iv. *the location and frequency of congestion, if structural congestion influences the delimitation of bidding zones, taking into account any future investment which may relieve existing congestion.*
2. *A bidding zone review in accordance with Article 32 shall include scenarios which take into account a range of likely infrastructure developments throughout the period of 10 years starting from the year following the year in which the decision to launch the review was taken.*

Criteria for reviewing bidding zone configurations (Article 33 of CACM [49])

The most discussed criterion for bidding zones reconfiguration is social (economic) welfare. Congestion rent and congestion costs are strongly related with social (economic) welfare evaluation. Therefore, these are discussed in more details in the following paragraphs. Other criteria, with lower importance are mentioned in author's work [50] attached in the appendix section.

3.1.3.1 Social and Economic Welfare

In general, social and economic welfare were defined in the section 2.2.4. In terms of power grid, economic welfare can be calculated as the sum of consumers' surplus, producers' surplus, congestion rent and congestion costs. The part of congestion costs is redispatching⁸ and countertrading⁹ costs. These costs are necessary for the stability and reliability of power grid and because the transmission

⁸ Redispatching means a measure activated by one or several System Operators by altering the generation and/or load pattern, in order to change physical flows in the Transmission System and relieve a physical Congestion.

⁹ Countertrading means a Cross Zonal energy exchange initiated by System Operators between two Bidding Zones to relieve a physical Congestion.

system operators carry these costs. Redispatching and countertrading are the so-called remedial actions. For example, change in power production of specific power plants can relieve congested line. This action is not optimal from the economic point of view (minimal operational costs) but is inevitable in terms of reliability and stability of power grid.

Figure 12 describes (in simplified way) the logic of economic welfare calculation for two interconnected bidding zones with limited capacity. It assumes that there are no changes in supply curve in exporting region when changing the interconnection capacity (i.e. there are no changes in merit order in exporting region). One can expect changes in merit order in exporting bidding zones thanks to changes in generation and transmission constraints.

Considering two congested bidding zones, an investment into the increase of interconnection capacity will lead to the increase of overall social welfare (i.e. the sum of welfare for both zones) if the net increase of producer surplus, consumer surplus and congestion rent is higher than needed investment cost. Assuming also the price differences in these two zones (if there would be none, there would be no congestions) interconnection (or increase of interconnection capacity) inevitably leads to distributional effects in both zones. In importing zone (high price zone) this will lead to price decrease and transfer of part producer surplus to consumer surplus. Exporting zones will face opposite situation. Changes of electricity prices depend namely on: the size of each bidding zones, steepness of supply curve on both markets and on interconnection capacity.

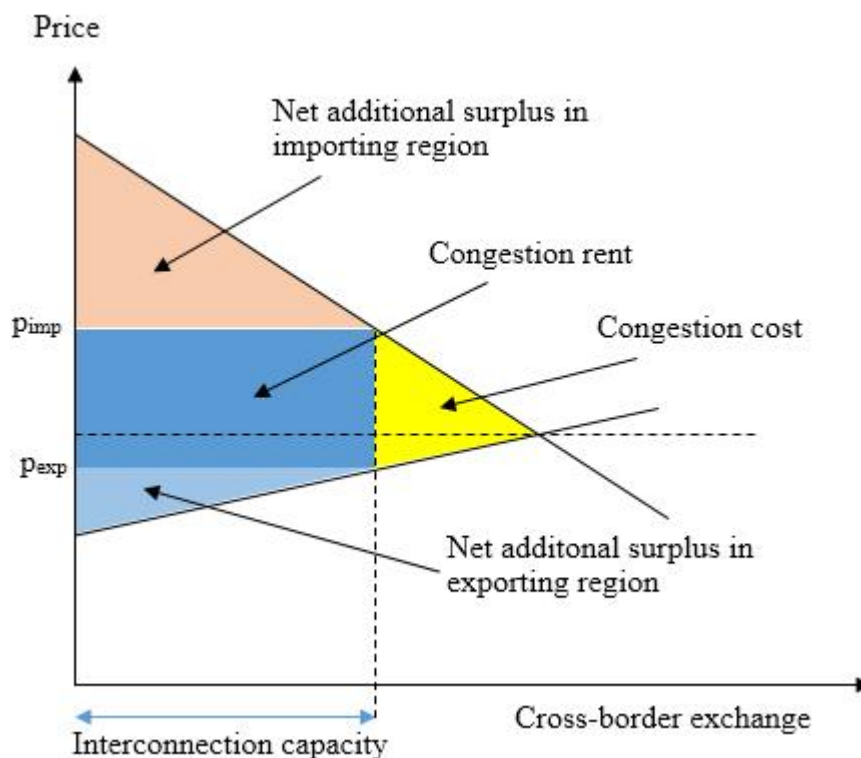


Figure 12: Congestion impact on economic and social welfare. [39]

Various literature sources (e.g. [39]) discuss two different terms: economic welfare and social welfare. The term economic welfare is based on the logic of market equilibrium between supply and demand. If all cost related to the given commodity (in this case, electricity) are borne by the suppliers and all the benefits are on side of consumers, the market equilibrium will result in largest possible economic surplus (i.e. economic welfare). If other subjects (not buyers) benefit from the electricity consumption or if subjects other than sellers bear the cost of electricity production and transmission, the total

welfare should be defined as the so-called social welfare. Definition of social welfare thus includes also the benefits and costs of third parties, which are not directly included in the market transactions. In many cases, it is very difficult to identify and evaluate in monetary terms these effects on third parties.

Authors in [52] used the Market Coupling algorithm to calculate the social welfare. Authors compared differences in results between calculations of social welfare only, redispatch costs and social welfare corrected by redispatch levels. Based on the results authors concluded, among other points, that: *the (uncorrected) social welfare in the case of single-zone market turned out to be the highest, since no congestion constraints are then put on the market solution. However, high redispatch costs associated with correction of this solution lead to the lowest corrected SW for single-zone market.* [52]

An in-depth discussion over social welfare in the terms of power grid, can be found in author's original publication [41], which is attached at the appendix section.

3.1.3.2 Congestion Rent

Congestion rent is *the amount collected by the owners of the rights to the transmission line. In a one-line network these rights would typically pay the owners an amount equal to the line's capacity times the difference between the prices at the two ends of the line. In the case of a load pocket, this is the difference between the internal price and the external price. Congestion rent is a transfer payment from line user to line owner, as using the line has no actual cost.* [53]

$$CR = (P_{max} - P_{min}) \times Q \quad (31)$$

P_{max}	Price in a region with higher price
P_{min}	Price in a region with lower price
Q	Energy exchange

Congestion costs and congestion rents are graphically shown in figure 12. Identification of bidding zones borders can be done with help of Congestion Rent calculation for various scenarios of bidding zones configuration. Scenario with the highest Congestion Rent identifies the optimum setting of bidding zones borders. Congestion Rent criterion as well as Congestion and Difference in Marginal Prices should be thus maximized. The reason being:

1. High Difference in Marginal Prices between bidding zones¹⁰ says that there is relatively high congestion between bidding zones. In case of improper bidding zones configuration there could be congestion inside bidding zones and congestion between bidding zones would in turn tend to be lower. Therefore, maximizing Congestion (between all adjacent zones) leads to maximal Difference in Marginal Prices and vice versa. In other words, bidding zones borders are on the congested lines.
2. Congestion rent calculation is dependent on the difference in prices ($P_{max} - P_{min}$), and power flow. Maximization of these two elements leads also to maximization of Congestion Rent.

3.1.4 LOOP FLOWS

Calculations of power flows are fundamental for any further calculations and application of any evaluation criteria. There exist criteria that do not require direct use of intensity of power flows, but power flows and their behaviour is main driver for any economic calculation. There are two methods to calculate power flows: Power Flows Decomposition (PFD) and Natural Flows (NF).

Both methods were applied on a simplified power network published in [54]. This network is divided into three bidding zones (zone 1, zone 2 and zone 3). All calculations were realized using a DC method which neglects losses and reactive power. The procedure varies slightly for the AC calculation [55],

¹⁰ In case there are not dramatic differences in power source structure.

because it is necessary to solve how the losses will be divided. Both, the system configuration and the load are estimated with a degree of uncertainty. Therefore, DC approach is appropriate for analysing the mutual influence of loop flows and zones. In other words, AC approach would be the exact calculation over inaccurate inputs. Moreover, DC approach linearizes problem and simplifies the solution.

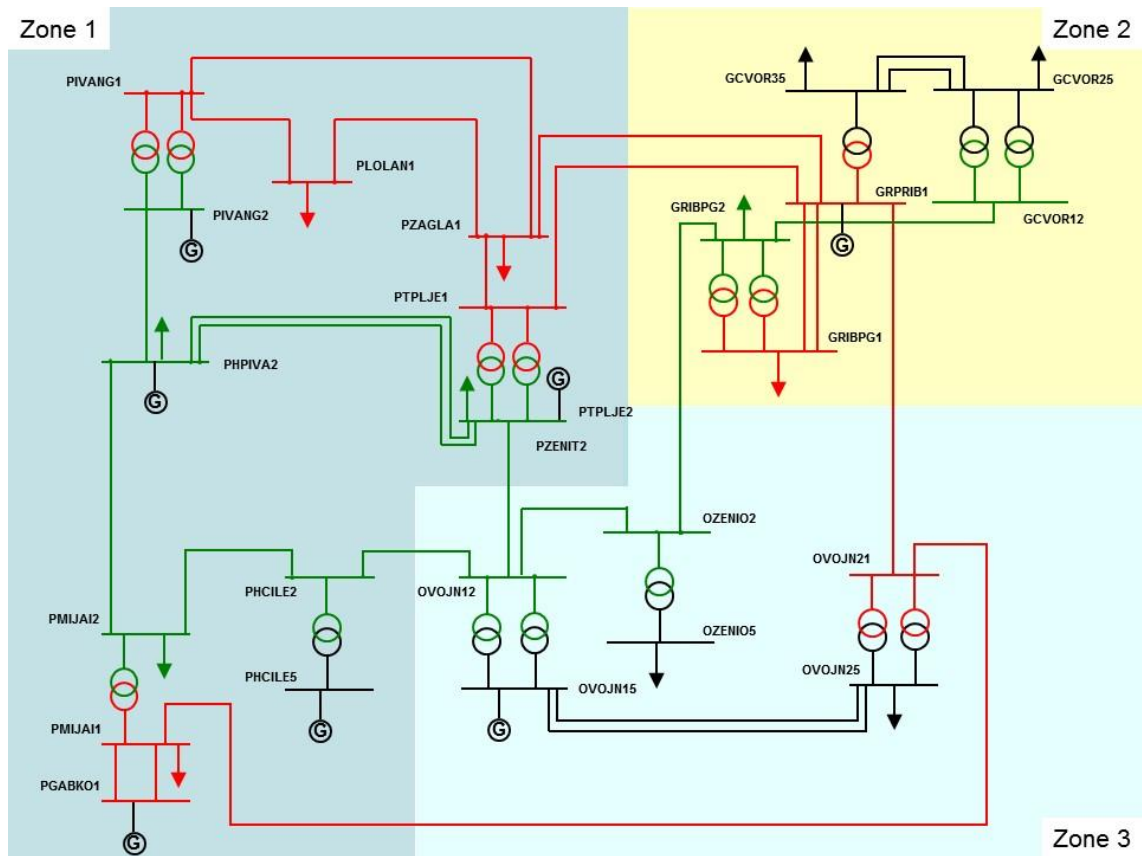


Figure 13: The scheme of simplified network [54].

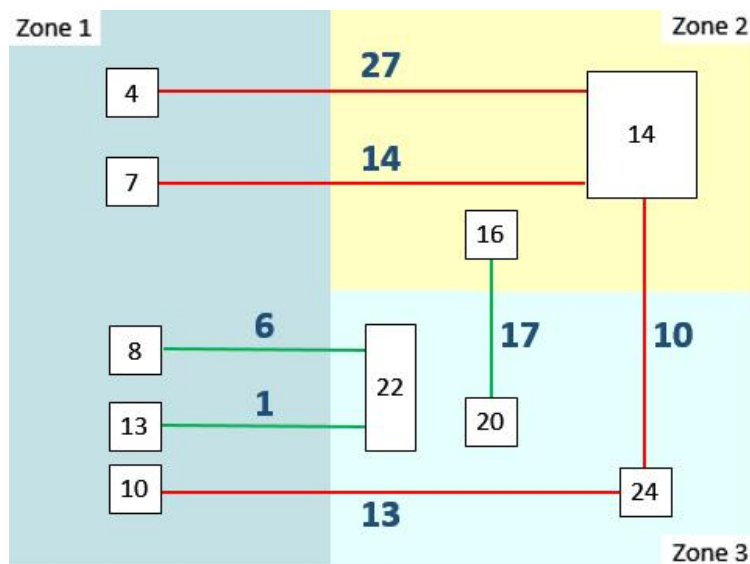


Figure 14: Simplified scheme with border lines (bus) only.

Blue numbers represent line ID, numbers in squares represent node ID.

The more detailed information about the network is shown in figure 15. Red values in white circles represent power balance between production and consumption in specific zone.

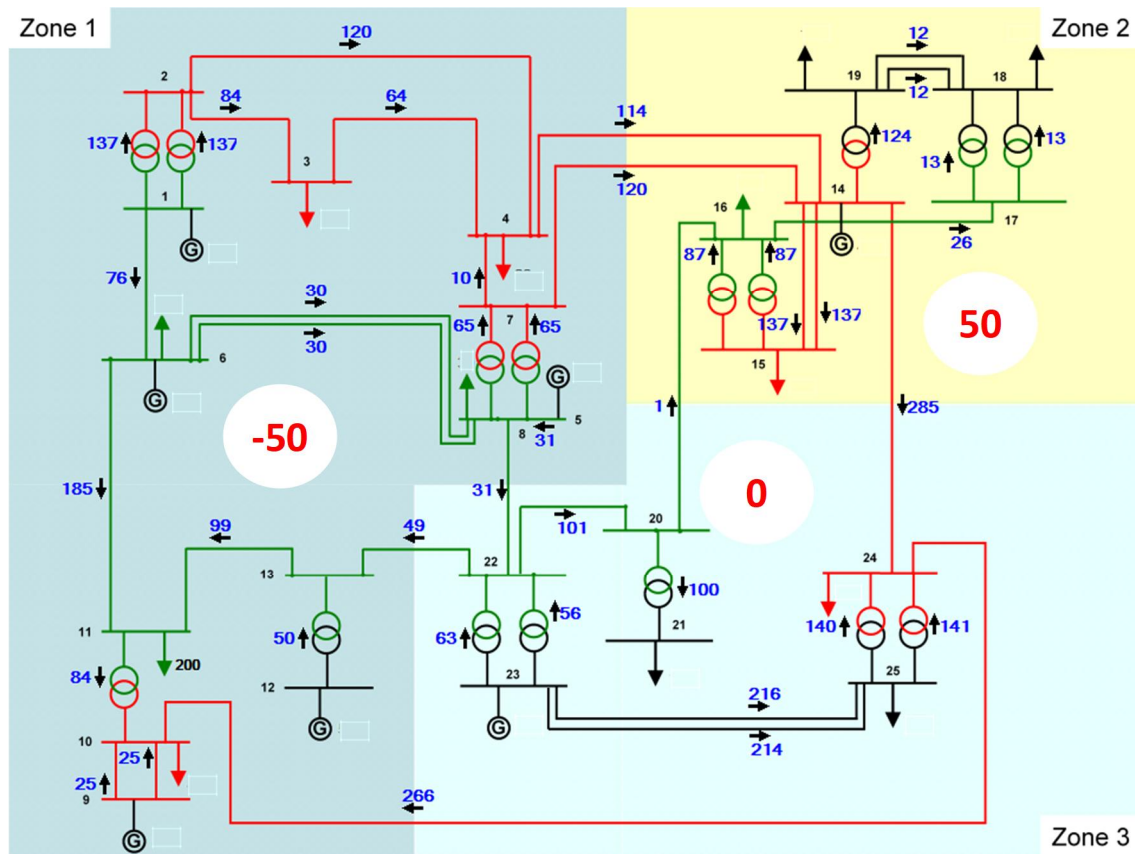


Figure 15: Physical flows in all power lines (blue numbers). Nodes IDs are small numbers in range 1-25.

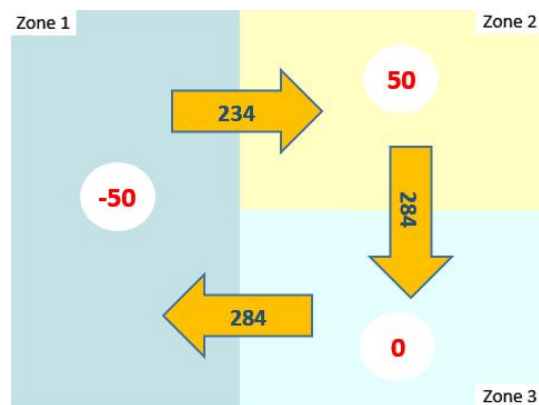


Figure 16: Aggregated power flows.

Natural Flow method is described in [54]. The principle of NF:

1. generators and consumptions in one zone are set in a way that the zone covers its consumption by own production;
2. resulting flows are so-called natural flows;
3. loop-flows caused by a specific zone are considered as flows that arise in case when generators and consumptions from all other zones are disconnected.

Power (generation and consumption) in all zones is balanced using so-called generation-shift-keys (GSK) which can be determined in many ways. This is the main shortcoming of NF method. The results can differ based on GSK settings. Theoretically, generation and consumption in each zone can be changed. In real cases, only generation is changed (used for balancing). Strong assumption of this

approach is that each zone is self-sufficient in means of power. Figure 17 shows natural flows for case where generators (sources) contribute on consumption evenly in each zone.

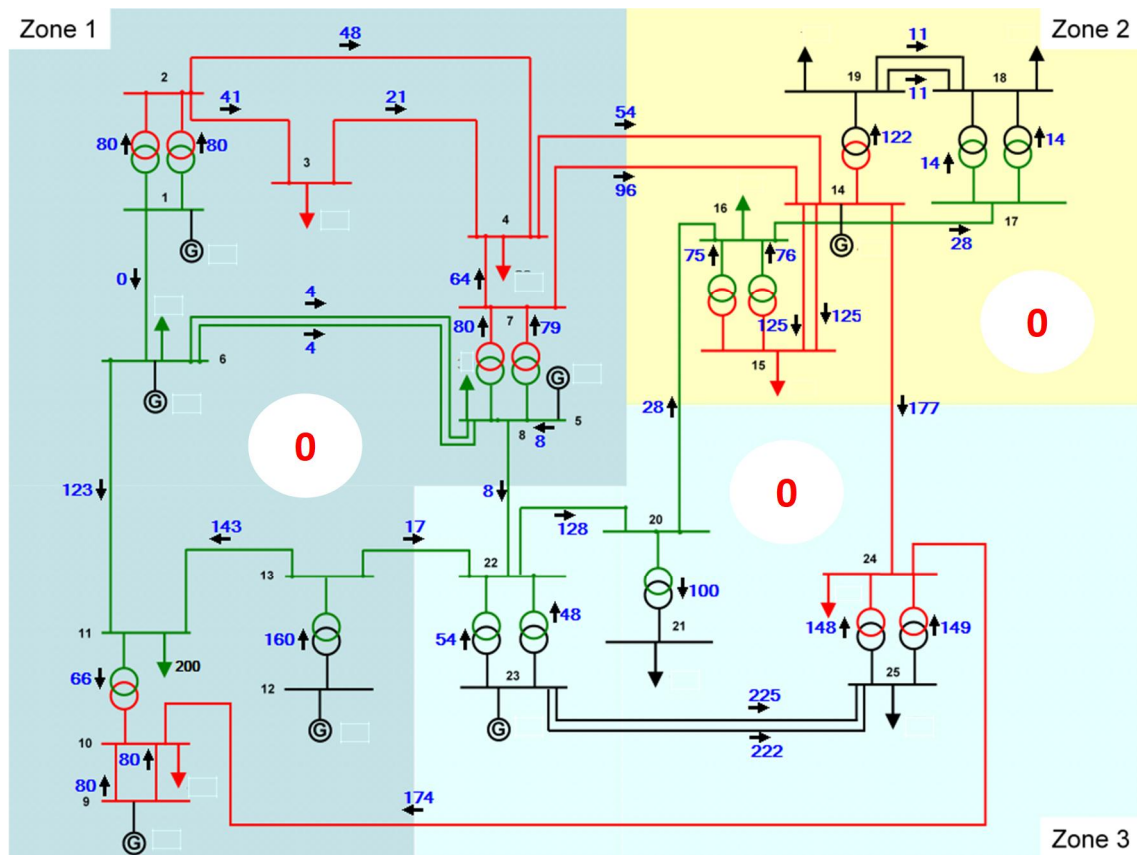


Figure 17: Network operation when generation and consumption equals in each zone. Generators contribute on consumption evenly in each zone.

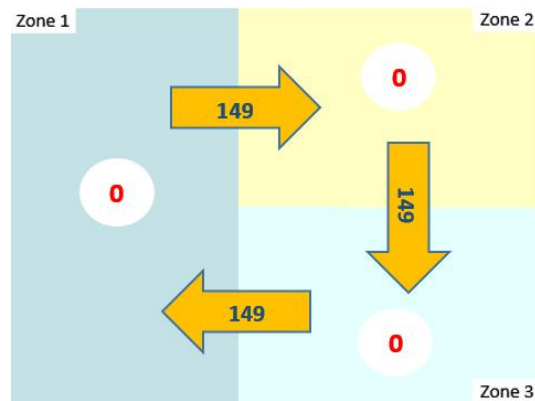


Figure 18: Aggregated natural flows from previous figure.

NF results depend on GSK settings and it is calculated as hypothetical grid state. Figure 19 shows natural flows caused by the zone 1 in zones 2 and zone 3.

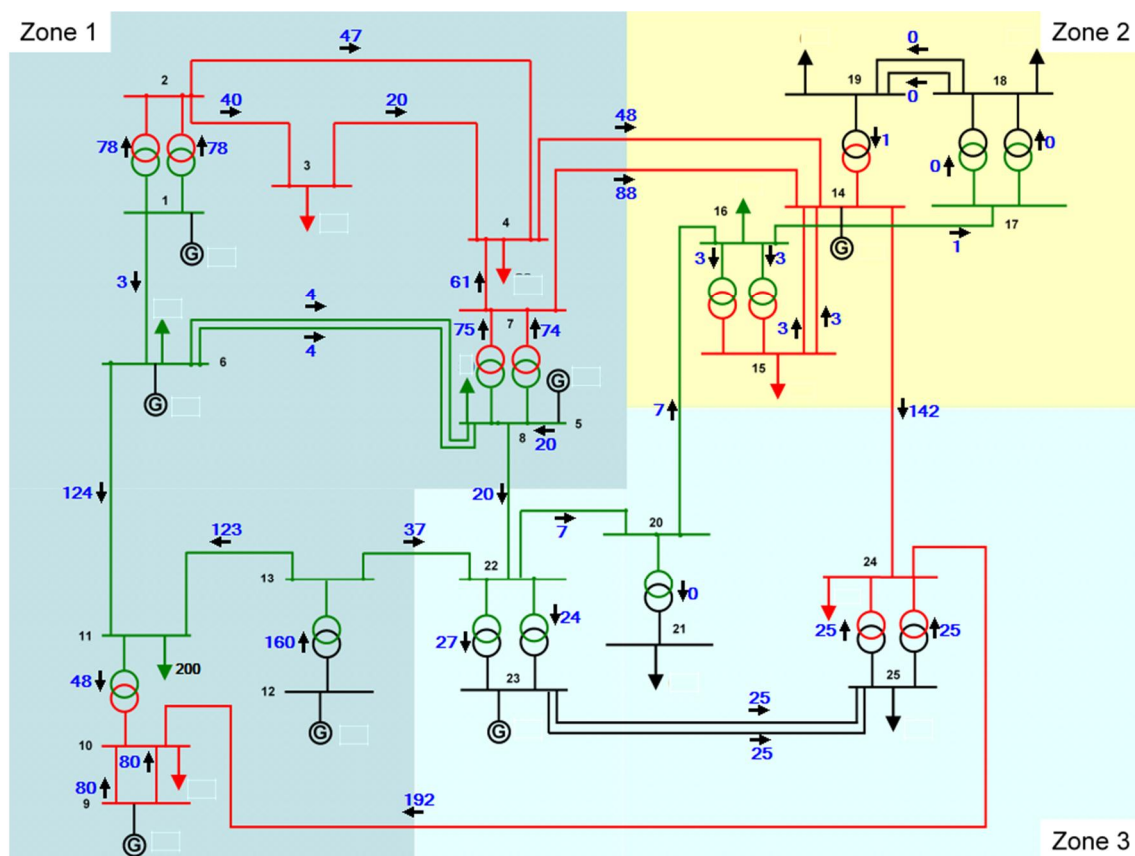


Figure 19: Network operation when the generators and consumptions are disconnected in zones 2 and 3. Flows in zones 2 and 3 are loop-flows caused by the zone 1.

Zone 1 causes a 135 MW (48 MW + 88 MW) loop flow in the boundary line with Zone 2. It also causes 7 MW loop flows from zone 3 to zone 2 and 142 MW from zone 2 to zone 3. The directions of these flows are opposite and it is not accurate to subtract from each other (due to the loss of information about the real volume of the loop flows). A similar situation occurs in the lines between zones 1 and 3.

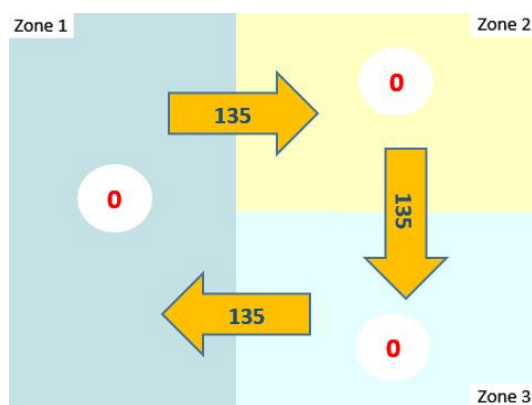


Figure 20: Aggregated loop flows caused by zone 1.

The calculation of loop flows caused by the zones 2 and 3 are analogic. The results are shown in figures

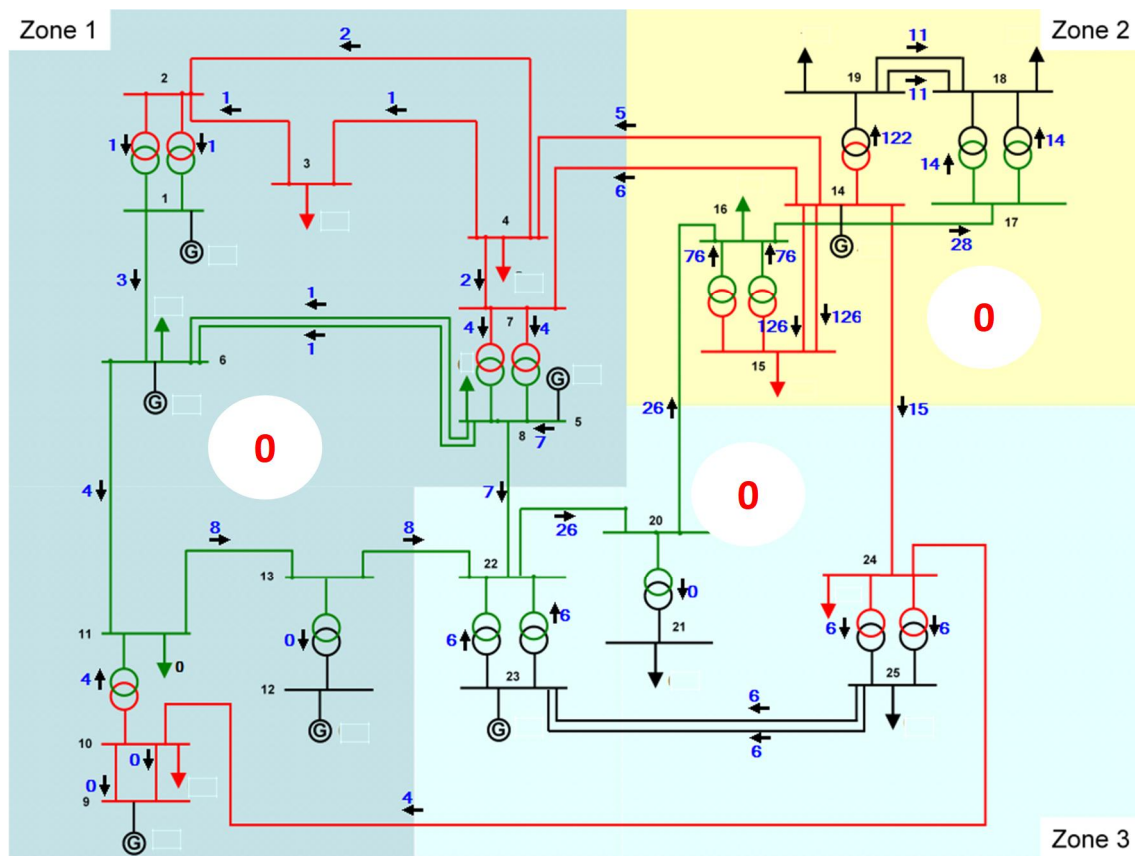


Figure 21: Network operation when the generators and consumptions are disconnected in zones 1 and 3. Flows in zones 1 and 3 are loop-flows caused by the zone 2.

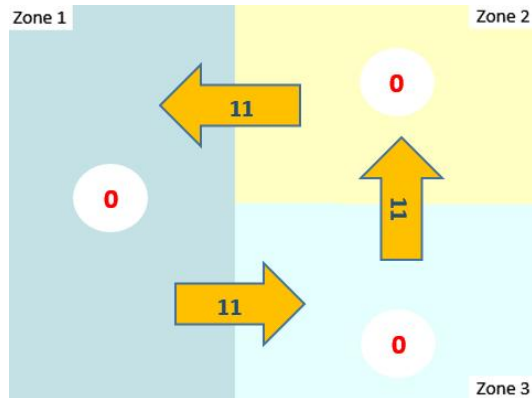


Figure 22: Aggregated loop flows caused by zone 2.

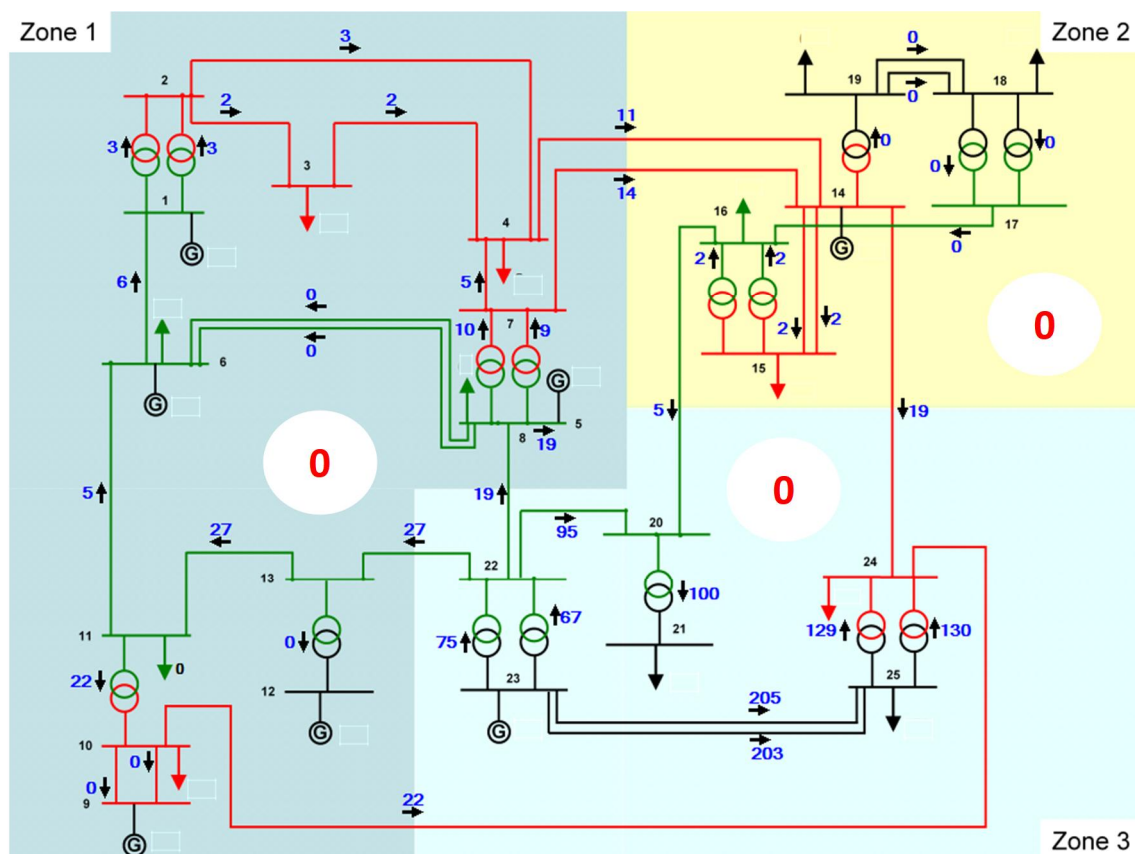


Figure 23: Network operation when the generators and consumptions are disconnected in zones 1 and 2. Flows in zones 1 and 3 are loop-flows caused by the zone 3.

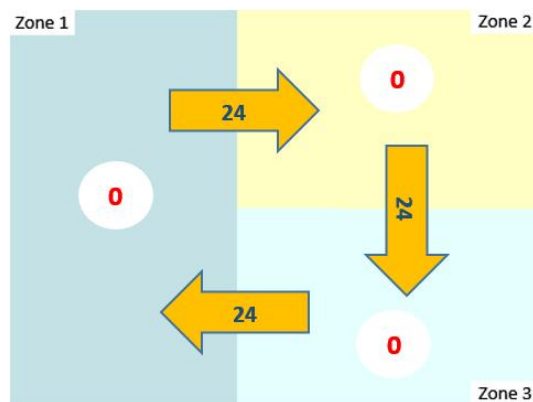


Figure 24: Aggregated loop flows caused by zone 3.

PFD method is described in [56]. Network flows are calculated individually for each combination of generation and consumption node when all other generation and consumption nodes are disconnected. Final flows are determined by super-positioning. Further analysis can determine whether if a transmission line is internal, transit or import / export or if there is a loop flow occurrence.

Figure 15 shows the physical flows. The partial calculation of flows is shown in figure 25. Consumption in the node 24 is covered by generation in the node 1. There is $13 \times 7 = 91$ combinations of generation and production nodes. Therefore, super-positioning of 91 calculations is needed for final power flows calculations.

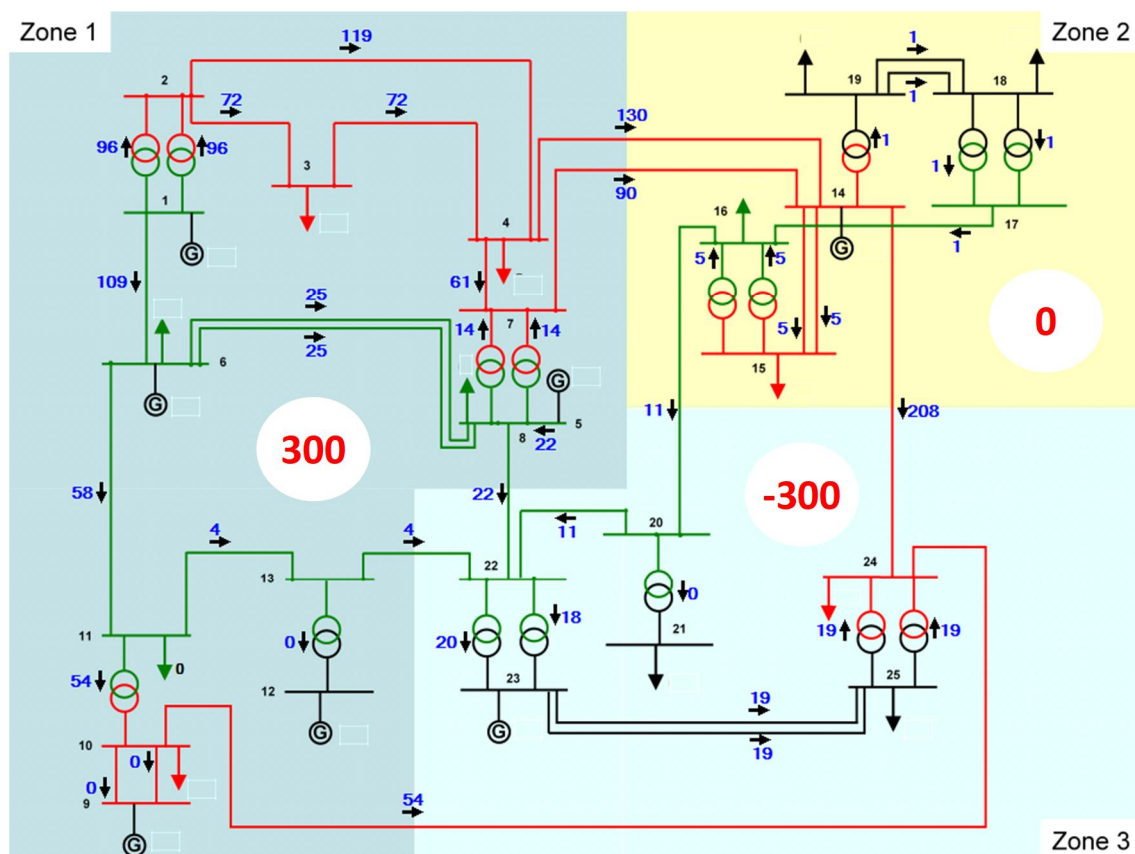


Figure 25: Partial calculation of flows for one generation and one consumption nodes.

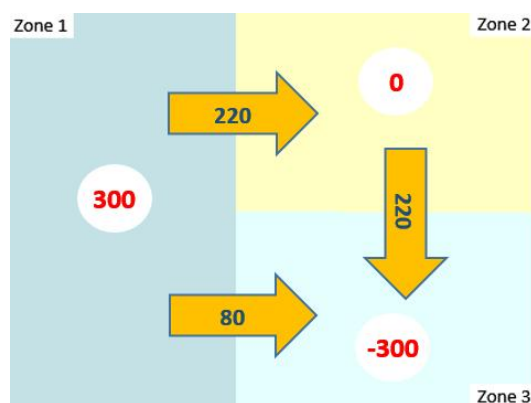


Figure 26: Aggregated form of previous figure.

Assuming power grid with N nodes, M lines, G generations and L loads. Total generation is equal to total load because losses are neglected. Matrix X (eq. (32)) can be defined assuming that each generation node covers each consumption node proportionally to its share on total power generated (consumed).

$$X = \frac{P_G \times P_L^T}{P_{\text{sys}}} \quad (32)$$

P_G	Vector of power generations [MW]
P_L	Vector of power loads [MW]
P_{SYS}	Total load [MW]

The dimensions of the matrix X are $N \times N$. An element X_{ij} indicates how much of the load in j -th node is covered by generation connected to i -th node. The sum of powers in column " j " is equal to load of the node " j " and the sum of the powers in row " i " is equal to generation connected to node " i ".

Aforementioned network P_G and P_L vectors:

- $P_G = [350, 0, 0, 0, 100, 200, 0, 0, 50, 0, 0, 50, 0, 0, 450, 0, 0, 0, 0, 0, 0, 0, 550, 0, 0]$
- $P_L = [0, 70, 20, 80, 0, 30, 0, 0, 0, 400, 200, 0, 0, 0, 100, 150, 0, 50, 100, 0, 100, 0, 0, 300, 150]$

Bus	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	SUM
1		14	4	16		6				80	40				20	30		10	20		20			60	30	350
2																										0
3																										0
4																										0
5		4	1	5		2				23	11				6	9		3	6		6			17	9	100
6		8	2	9		3				46	23				11	17		6	11		11			34	17	200
7																										0
8																										0
9		2	1	2		1				11	6				3	4		1	3		3			9	4	50
10																										0
11																										0
12		2	1	2		1				11	6				3	4		1	3		3			9	4	50
13																										0
14		18	5	21		8				103	51				26	39		13	26		26			77	39	450
15																										0
16																										0
17																										0
18																										0
19																										0
20																										0
21																										0
22																										0
23		22	6	25		9				126	63				31	47		16	31		31			94	47	550
24																										0
25																										0
SUM	0	70	20	80	0	30	0	0	0	400	200	0	0	0	100	150	0	50	100	0	100	0	0	300	150	1750

Figure 27: Matrix X showing coverage loads by generations.

Element $[i, j]$ indicates how much of the load in j -th node is covered by generation connected to i -th node.

Power Transfer Distribution Factor (PTDF) matrix S^r is determined for arbitrary reference node " r ". The dimensions of matrix are $M \times N$. Element S^r_{ij} represents the power flowing through i -th node in case of generation 1 MW in j -th node and consumption of 1 WM in reference node " r ". Values in the column of reference nodes are zeros. A change of reference node requires subtraction of values of new reference column (vectors) from all other columns. The more detailed information about PTDF matrix construction can be found in [57], [58].

Matrix U^v shows how the v -th line is loaded by supplies and loads in all individual nodes of power grid. The matrix dimensions are $N \times N$ and the matrix is calculated for each line. The matrix element U^v_{ij} is calculated as:

$$U^v_{ij} = X_{ij} \times S^j_{vi} \quad (33)$$

These flows can be easily classified as internal, loop, transit and import/export flows.

30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Zone 1													Zone 2					Zone 3						
1		0	0	0		0				3	1				0	0		0	0		2			4	5
2														Transit flows between zones 1 and 2					Import/export from/to zone 1						
3	Loop flows caused by zone 1																								
4																									
5		0	0	0		0				1	0				0	0		0	0		1			1	1
6		0	0	0						2	0				0	0		0	0		1			3	3
7																									
8																									
9		0	0	0		0					0				0	0		0	0		0			0	1
10																									
11																									
12		0	0	0		0				2	1				0	0		0	0		0			1	1
13																									
14		0	0	0		0				2	2				0	1		0	0		3			4	6
15																									
16														Loop flows caused by zone 2					Import/export from/to zone 2						
17																									
18																									
19																									
20																			Import/export from/to zone 2						
21														Import/export from/to zone 2					Internal flows						
22																									
23		4	1	5		2				20	14				6	10		3	6		10			12	2
24																									
25																									

Figure 28: The matrix of inter-nodal flows for line ID 30 (border nodes of line are in zone 3). Numbers represent a flow from node in left column to node in upper row. The green colour of numbers represents positive values and the red colour represents negative values.

The first array “Loop flows caused by zone 1” contains all flows through line (ID 30) that are caused by generations and loads in the zone 1. Line (ID 30) itself is completely in zone 3. The sum of these loop flows is loop flow in line (ID 30) caused by zone 1. The second array „Transit flows between zones 1 and 2” shows flows that are caused by generations and loads between nodes of the zones 1 and 2. The third array „Import/export from/to zone 1” represents flows caused by generations and loads between nodes of zones 1 and 3. Since the line lies in the zone 3, one can assume that these flows are imports or exports. Array “Internal flows” (blue background) contains flows caused by generations and consumptions of zone 3.

Figures 29, 30 and 31 show the loop flows caused by zones 1, 2 and 3 respectively. The sum of nodal currents doesn't have to be equal to zero, since only the loop flows are shown. Other present flows (internal, transit, import / export) are not visible in these figures.

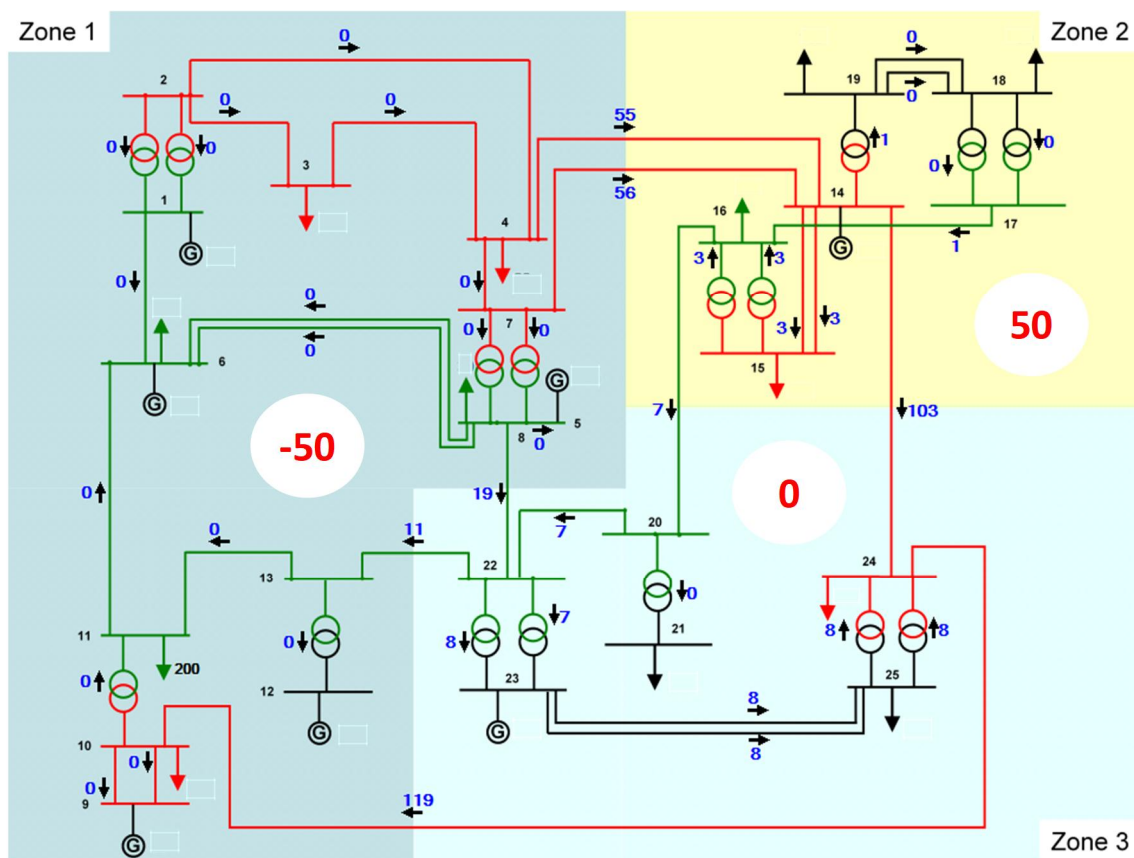


Figure 29: Loop flows caused by the zone 1.

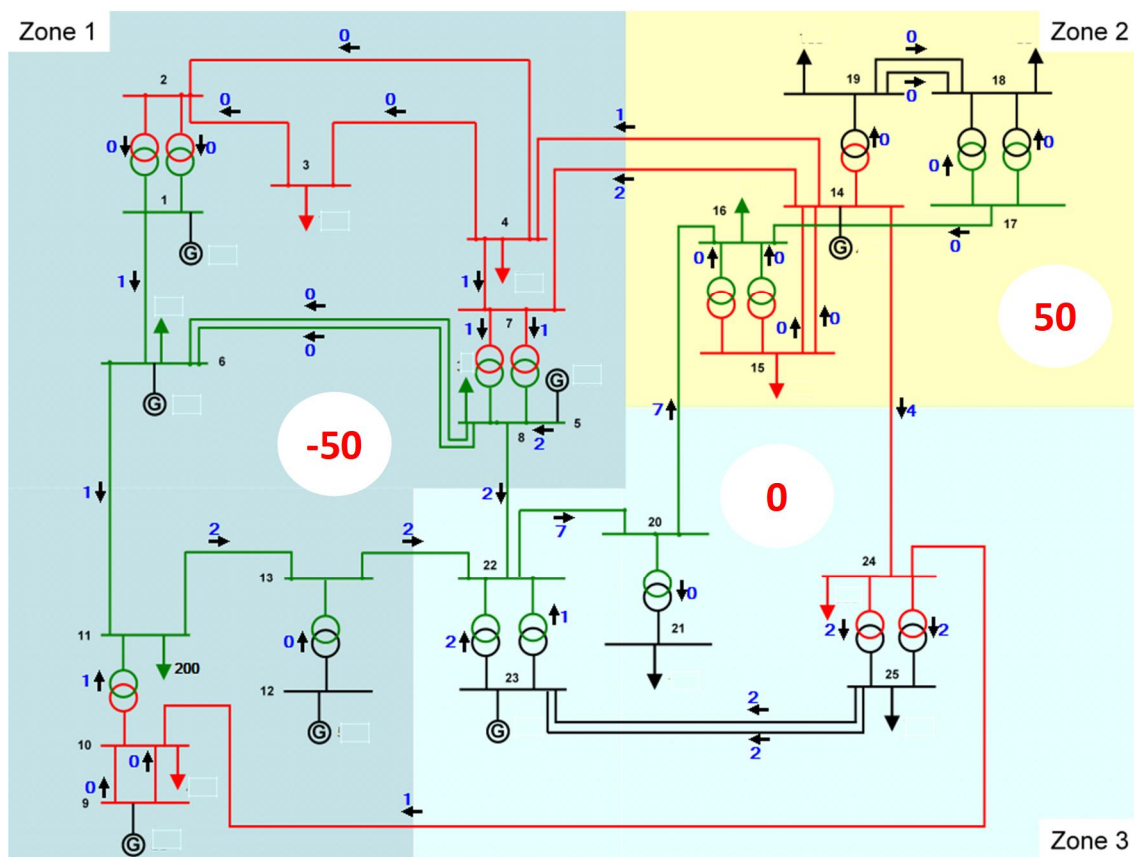


Figure 30: Loop flows caused by the zone 2.

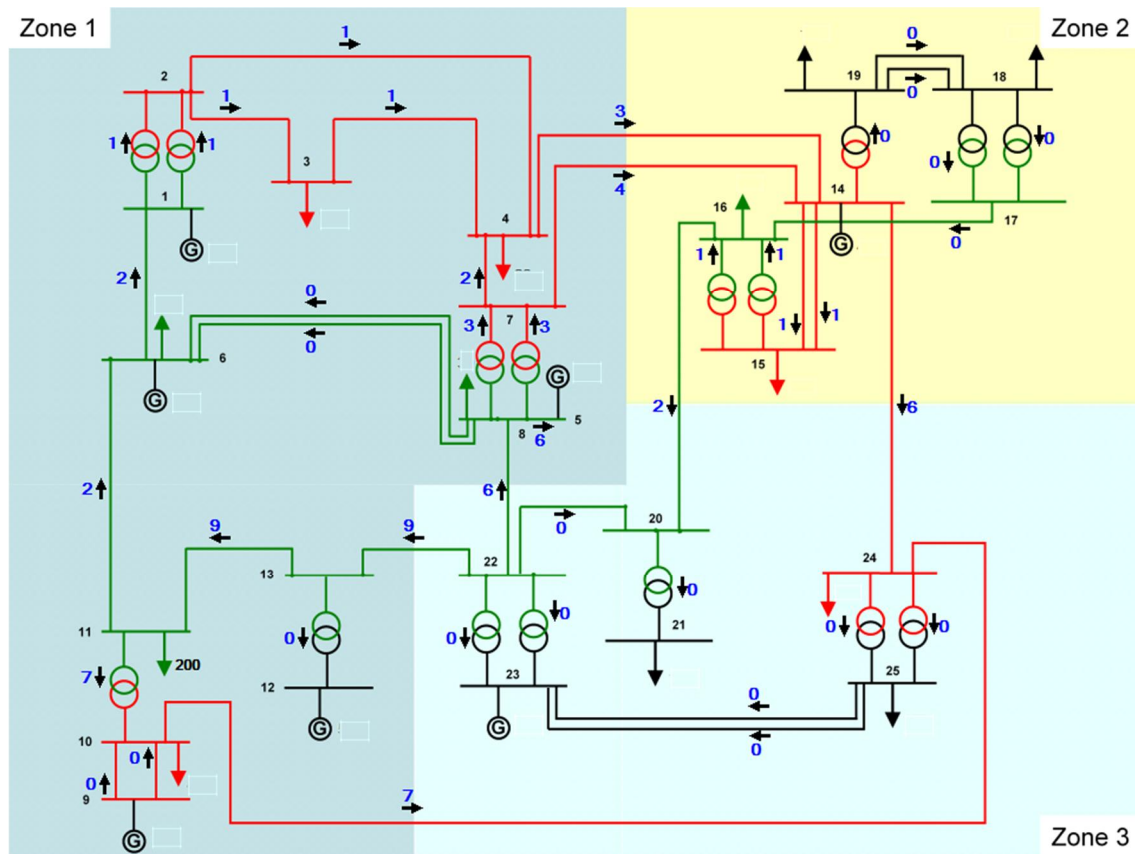


Figure 31: Loop flows caused by the zone 3.

Finally, figure 32 shows the sums of all loop flows show in figures 29 30 and 31. The important information is, the loop flows in the opposite direction can compensate each other. Aggregation of loop flows is also important in evaluation of their final effects.

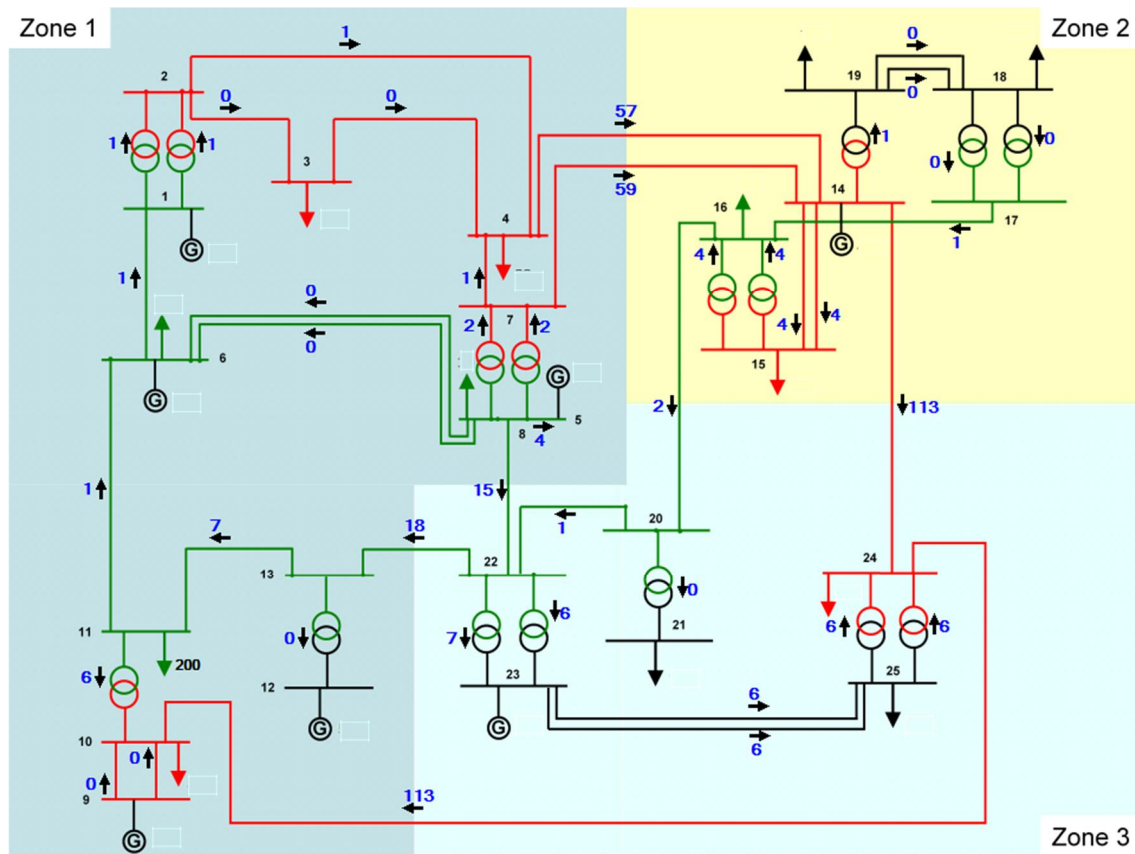


Figure 32: The sums of all loop flows caused by all zones.

3.1.5 FUTURE RESEARCH

Social welfare was presented as main criterion for bidding zones reconfiguration process [30][36][59]. As aforementioned, calculations of social welfare were limited to economic welfare only. Bidding zones evaluation problem can be described by figures 4-6. Figure 6 is analogic to current state where Germany and Austria are part of single bidding zone. Economic welfare in Central European region is maximized, but economic welfare of producers and customers in smaller affected market (e.g. Czech) is decreased.

The future research should combine economic welfare and multicriterial decision making. This can lead to relevant social welfare evaluation. The most challenging part will be an agreement upon the input parameters. One group of input parameters are components (features) that should be the part of the social welfare calculation. The second group of input parameters are weights (importance) of input components. A consensus should be reached by engaged parties to determine the social welfare calculation process. Moreover, this process should be periodically updated to include newly emerging information.

4 NUCLEAR POWER PLANTS WASTE AND DECOMMISSIONING FINANCING ISSUES

This chapter deals with a financing problem where the highest financial outflow will be made in remote future. Chapters 4.1 and 4.2 describe essential information related to the dealing of radioactive waste and decommissioning of nuclear power plants. Chapter 4.3 explains financing issues, the course of how to accumulate enough money for covering costs of nuclear waste management system and nuclear power plant decommissioning.

Nuclear power plant decommissioning costs [60] can reach investment costs in the prices of the same year. Nuclear power plants usually operate in-between 40-60 years and the decommissioning begins after. A similar situation is with nuclear waste disposal [61]. Spent fuel is stored in temporary storage close to power plants. Many countries, including Czech Republic, plan to build deep geological repository for final disposal of spent nuclear fuel [62]. Both, decommissioning of power plants and nuclear waste disposal are capital-intensive investments. According to polluter-pays-principle (PPP), these costs should be included in current costs of nuclear power station.

4.1 RADIOACTIVE WASTE IN CZECH REPUBLIC

Main producers of radioactive waste in Czech Republic are nuclear power plants. Minor producers are research and medical institutions and industry. There are four radioactive waste disposal sites: Dukovany, Richard, Bratrství and Hostim (closed). Dukovany repository is the newest and the most modern repository. It is used for storage of ILW and LLW from the both Czech nuclear power stations (Dukovany and Temelín), but it is not intended for storage of spent nuclear fuel. Spent nuclear power is temporary stored in nuclear power stations and will be finally disposed in deep geological repository (DGR). Czech Republic does not assume spent fuel reprocessing. The final decision for locality and backup locality of DGR will be chosen until 2025 [63]. Estimated cost of deep ground repository are around 2 – 4 billion EUR [64].

Nuclear waste produced in Czech Republic can be divided into three categories:

1. low-level radioactive waste (LLW);
2. intermediate radioactive waste (ILW);
3. spent nuclear fuel.

System for radioactive waste disposal must have enough funds for required investments (e.g. DGR construction), operation, monitoring and operation of radioactive waste repository authority. In accordance with PPP and system sustainability, a fee is imposed on energy (each MWh) produced in nuclear power stations.

More detailed information about waste disposal process and comparison with other countries can be found in author's original publication [61] which is attached in appendix part.

4.2 DECOMMISSIONING OF NUCLEAR POWER PLANTS

Nuclear power plant comprises two major parts: the nuclear island and conventional island. Nuclear island consists of the reactor (reactor core and controls system), the reactor coolant pumps, the pressurizer, the steam generators, the primary piping, the containment and fuel handling area. Conventional island is the same as it is in steam power plants, consisting of the turbine, the generator, and the feedwater pumps. Whole scheme is shown in figure 33. Only nuclear island is subject to decommissioning process.

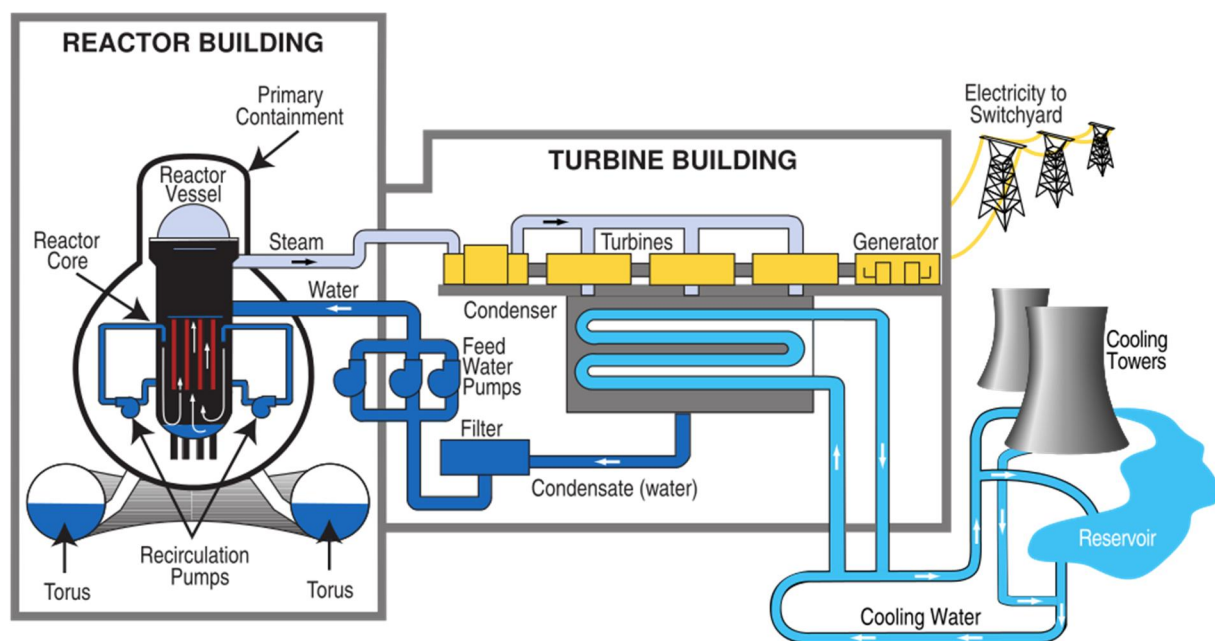


Figure 33: Scheme of nuclear power plant.
(source: <http://www.tva.com/news/downloads.htm>)

There are three decommissioning strategies:

1. Immediate decommissioning (e.g. NPP Jaslovské Bohunice V1 and V2);
2. Deferred decommissioning (e.g. NPP Jaslovské Bohunice A1);
3. Entombment decommissioning (e.g. NPP Chernobyl).

From the financial perspective, immediate decommissioning has the lowest risks. On the other hand, it has higher environmental risks because radioactivity is essentially decreased after 40-50 years and there is lower risk of contamination. Deferred and entombment decommissioning carries the risk of decommissioning costs increase. Power plants operators in Czech Republic are obliged to put money into special fund managed by state authority. This money can be understood as fee (financial reserve) which is imposed on each MWh produced by power station. The situation is very similar to radioactive waste financing.

More detailed information about process of nuclear power plants decommissioning, related financial issues and comparison with other countries can be found in author's original publication [60] which is attached in appendix part.

4.3 FINANCING AND DISCOUNT RATE ESTIMATION

Each country has its own specific way of financing of nuclear power plants decommissioning and radioactive waste disposal. Presented approach highlights the Czech Republic case. The calculation of fee for nuclear waste disposal is based on the logic that accumulated amount of money must be equal to amount required. Following equation compares the present value of fees and present value of future money requirements.

$$\sum_{t=1}^T \frac{fee_0 \times (1 + inf)^t \times Q_t}{(1 + r_n)^t} + C_C = \sum_{t=1}^T \frac{C_{0,t} \times (1 + inf)^t}{(1 + r_n)^t} \quad (34)$$

T fee_0 Q_t inf r_n C_C $C_{0,t}$	 	<i>assessment period [years]</i> <i>fee in the 0-th year [EUR/MWh or EUR/drum]</i> <i>volume of waste produced in year t [MWh, drum]</i> <i>inflation rate [-]</i> <i>nominal discount rate</i> <i>currently cumulated money [EUR]</i> <i>costs of the t-th year in the prices of 0-th year [EUR]</i>
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Fee is expected to grow accordingly with the inflation rate. Future costs are calculated from costs of reference (or 0-th) year. Inflation rate is used as the escalation factor of these costs. Investment of money obtained from fees (accumulated money) is very limited. Accumulated money can be, for example, invested into Czech governmental bonds. More information about investment possibilities of money obtained from fees can be found in § 116 of Nuclear Law [65]. Therefore, nominal discount rate, understood as opportunity cost of cumulated money, can be estimated from the return of long-term governmental bonds. The return of Czech governmental bonds with ten years maturity, is currently around 0.9 %, its value was around 5 % ten years ago¹¹. Inflation rate was fluctuating between 0 – 7 % in past ten years. Therefore, it is very difficult to estimate discount rate properly. Inflation target of Czech central bank is 2 % and this number is frequently used as estimation for distant future. Formula (37) describes relation between nominal and real discount rate. Since the input parameters are unstable, it is enough to estimate and use real discount rate. Fees calculations [61] assumes real discount rate in range 0.2 % to 1.2 %.

$$(1 + r_n) = (1 + r_r) \times (1 + inf) \quad (35)$$

r_r		<i>real discount rate</i>
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Formula (38) shows calculation of fee using real discount rate. These calculation steps are universal for all systems for nuclear waste disposal and nuclear power plants decommissioning that are based on cumulating money and polluter-pays-principle.

$$fee_0 = \frac{\sum_{t=1}^T C_{0,t} \times (1 + r_r)^{-t} - C_C}{\sum_{t=1}^T Q_t \times (1 + r_r)^{-t}} \quad (36)$$

T fee_0 Q_t inf r_n C_C $C_{0,t}$	 	<i>assessment period [years]</i> <i>fee in the 0-th year [EUR/MWh or EUR/drum]</i> <i>volume of waste produced in year t [MWh, drum]</i> <i>inflation rate [-]</i> <i>nominal discount rate</i> <i>currently cumulated money [EUR]</i> <i>costs in prices of 0-th year [EUR]</i>
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The same logic applies for financing of decommissioning of nuclear power stations. Mathematics behind fees calculation is the same as in any other financing project. The biggest difference between general business projects and aforementioned project is in the estimation of parameters. The reason being, even a small inaccuracy in their estimation can lead to lack of money in remote future. Therefore, calculation is periodically updated¹². CAPM model cannot be used for discount rate estimation as it is based on robust statistical analysis of many companies. Nuclear power station decommissioning and nuclear fuel disposal is very specific business with very long-time constants. Dealing with risk cannot be the same as in case of conventional business.

¹¹ <http://www.kurzy.cz/cnb/ekonomika/vynos-desetileteho-statniho-dluhopisu-maastrichtske-kriterium/>

¹² Each five years in case of Czech Republic

The major difference between financing of nuclear power plant decommissioning and waste disposal is that decommissioning costs are fixed costs, independent of the amount of energy produced. On the other hand, radioactive waste disposal costs are partially fixed and partially variable. Decommissioning costs must be unconditionally paid even in case of unexpected or unplanned closure of nuclear power plant. In this case, there will not be enough money for decommissioning because fee is linked to energy production. If the energy produced is lower than expected, there will not be enough money cumulated. In waste disposal case, unplanned closure of one nuclear power plant would lead to redistribution of fixed cost (of nuclear waste disposal sites) between less waste producers, but funding would not be threatened as in case of decommissioning. The example of early closure of nuclear power plant is case of Jaslovské Bohunice V1, it was a condition of accession of Slovakia into the European Union. Closure of German nuclear power plants are another example of irrational political decision.

The work [66] presents calculation of fee (financial reserve) for nuclear power plant decommissioning. The assumption is a nuclear block with installed power 1 000 MW, the lifetime 50 years, annual energy production is 7 500 GWh, the inflation rate is 2 % and nominal discount rate (invested money appreciation) is 2.5 %. The costs of immediate decommissioning are 5.8 billion of CZK¹³ and the costs of deferred decommissioning are estimated to 6.2 billion of CZK¹⁴ in prices of year the reference (0-th) year.

The sensitivity of fee on main input parameters (inflation rate, discount rate, decommissioning costs and electricity production) is shown in figures below. Charts are built from calculations in [66].

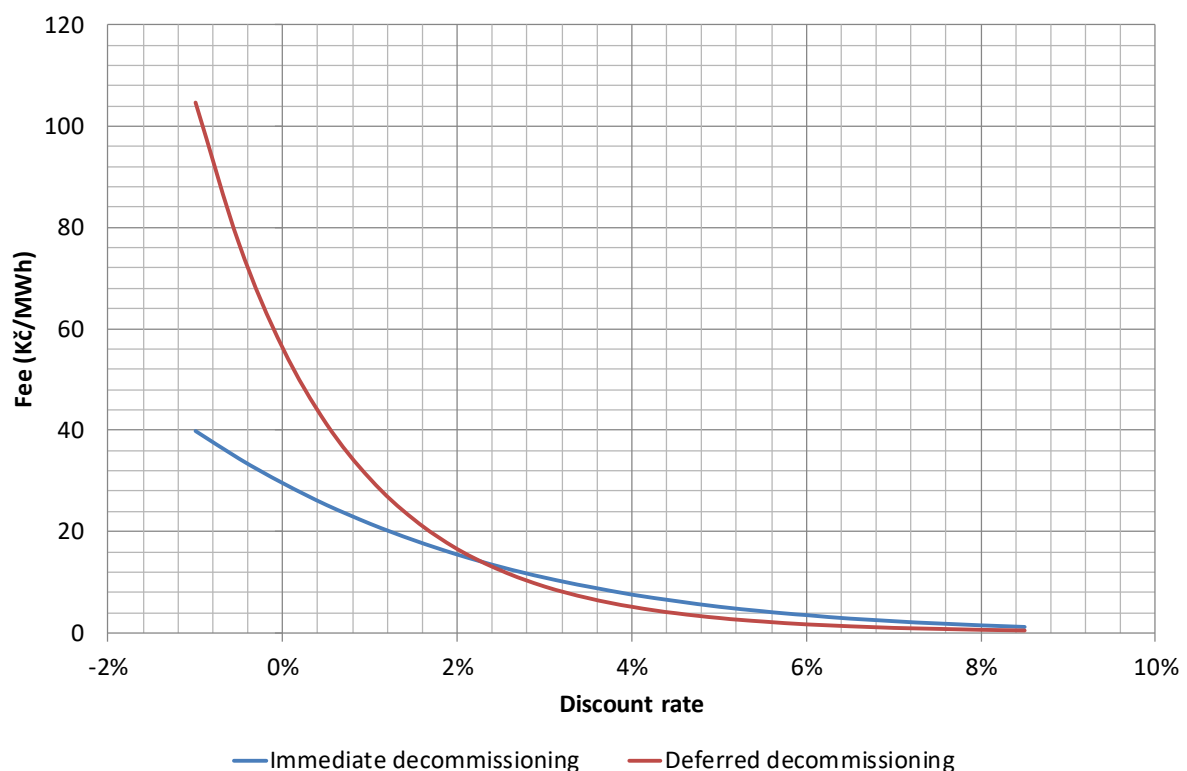


Figure 34: Sensitivity of fee on nominal discount rate (appreciation of money).

¹³ 232 millions EUR at rate 25 CZK/EUR

¹⁴ 248 millions EUR at rate 25 CZK/EUR

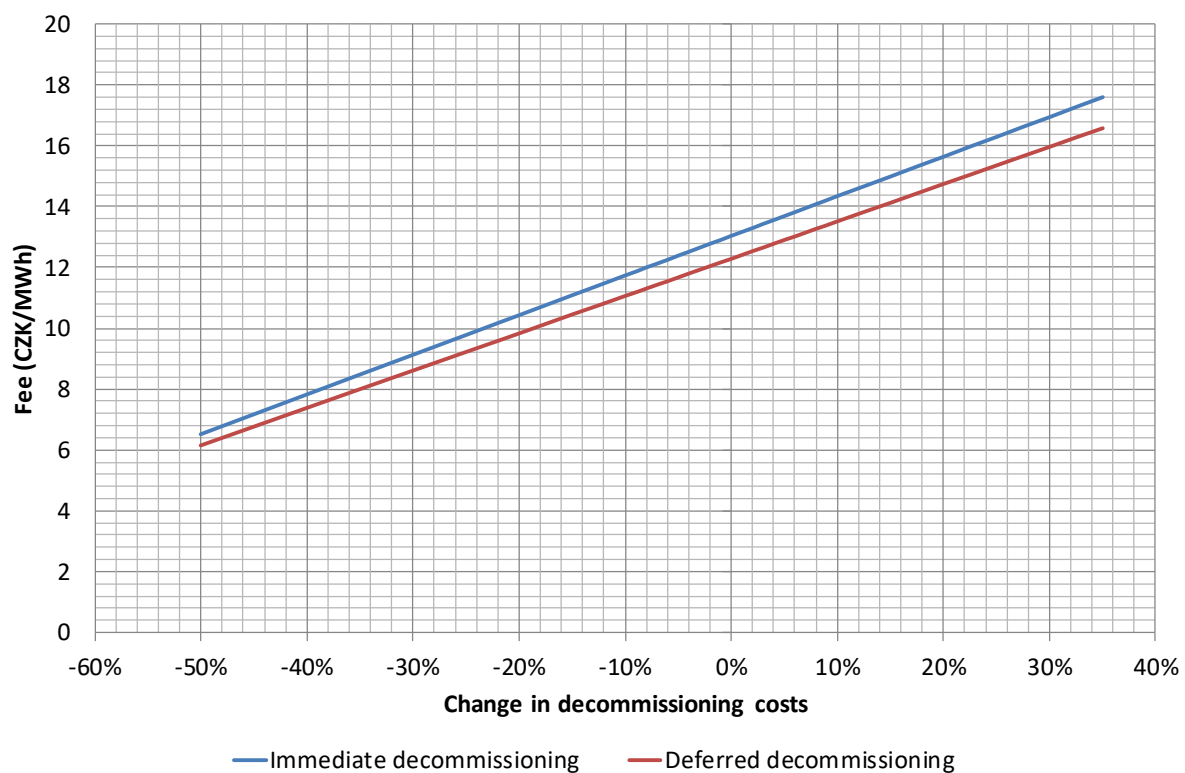


Figure 35: Sensitivity of fee on the decommissioning costs.

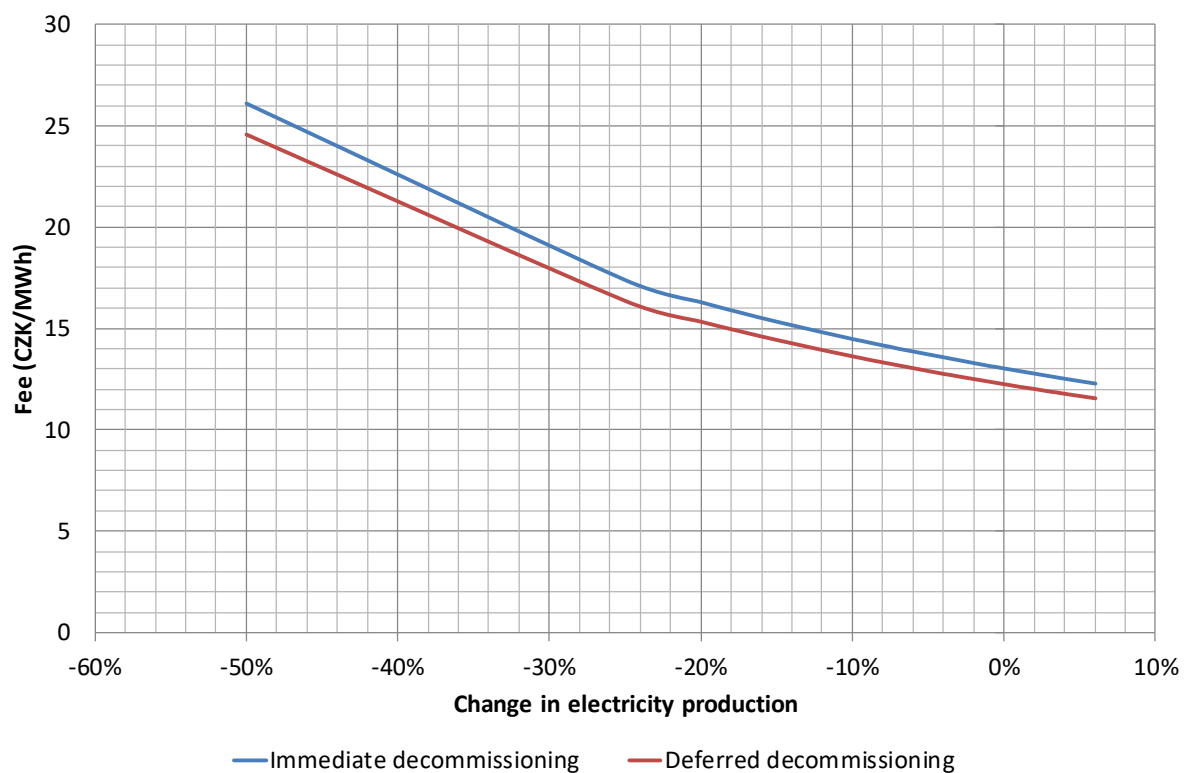


Figure 36: Sensitivity of fee on the change in electricity production.

One can notice that high discount rate dramatically increases the required fee value. Moreover, the difference between fee in immediate and deferred decommissioning scenario, is very high. The same situation applies for the low value of the discount rate. The reason is, that the deferred

decommissioning starts around 45 years after power plant shutdown and the time effect of extreme inflation and discount rate values is significant.

4.4 CONCLUSION

The biggest challenge in these type of calculations is the extremely long-time horizon which can change even during the evaluation period. Uncertainty in escalation rates and discount rate can lead to significant changes in the results. This problem is solved by periodically updating of the economic calculations.

Each country has unique approach for financing of NPP decommissioning and nuclear waste management. Therefore, it is nearly impossible to compare economic effectiveness of individual calculation systems between different countries. Hence, a common European methodology for related reporting would be beneficial for correct comparison of real costs of NPP decommissioning and nuclear waste disposal.

5 DECENTRALIZED POWER SOURCES AND ELECTRICITY TARIFFS

Decentralized power sources are changing usual power flows in electricity grid. Power grid infrastructure was designed for distribution of electricity from centralized power sources. Power generated in power plants with high installed power (nuclear, thermal, etc.) is transformed to extra high voltage level, flows through transmission grid and distribution grid to customers in one direction. This flow implies costs for each voltage level and influences structure of tariffs. Penetration of decentralized power sources is causing the flows from lower to higher voltage levels because many of them are connected to low voltage grid. The large part of decentralized power sources (e.g. photovoltaics) are intermittent power sources. Besides the changes in the direction of the flows, these are changing quickly with changes in weather. To compensate this, new energy storage systems (batteries) are being developed and used. Fore-mentioned changes should be reflected in electricity tariffs.

This chapter will introduce a methodology (specific revenues) for pricing of electricity supplies on different voltage levels. This methodology should be used as a basis for new tariffs proposal.

The main idea of any customer-oriented investment is that the customer should cover the costs incurred by himself. A larger share of cost in power system (generation and distribution) are fixed costs and smaller share are variable costs. Nevertheless, structure of tariffs is opposite. Variable component is major and fixed component of tariffs is minor. The reason is to motivate for savings. The main part of fixed costs in power systems are depreciations and the main part of variable costs is fuel costs. If the tariffs structure reflected the real costs, customers would pay high fees for grid connection (fixed component) and relatively low fees for electricity consumption (variable component). The motivation for savings would not be as high as currently is. However, changes in electricity flows and increasing installed power in intermittent power sources require changes in electricity tariffs. New tariffs should reflect the dynamics of changes in power flows. Higher penetration of decentralized power sources leads to lower utilization of high-voltage grid and therefore fix part of electricity payments will increase. This must also be included in new tariff structure.

Adverse effect of current tariffs structure can be shown on a simple example. A customer, having photovoltaic panel installed on his roof, decreases his payment for energy consumed because he is able to produce energy. Currently, when fixed costs are covered by energy related payments, this customer will pay less amount than the amount required for coverage of fixed costs because he still raises these costs. The guaranteed capacity (power) for his connection is the same as it was before the installation of photovoltaic panels.

New tariffs will require new metering with online data gathering so-called smart metering. It is the first step to so-called smart grids, where demand-side management could be controlled remotely. With smart metering, electricity supplier will be able to charge customers with dynamic prices. For example, customer consuming electricity at night incurs lower costs (fixed and variable) than doing so in peak time of the day.

5.1 SPECIFIC REVENUES IN POWER SYSTEM

Revenues of the power system (generation and distribution) are generated at the end of the production and distribution cycle. Investments into generation and distribution are not directly connected with power consumers. The aim is to split revenues fairly between all elements of power system. Whole problem is specific kind of cost accounting task where costs and revenues need to be

properly assigned to individual power grid elements. The concept of specific revenues was introduced in [67]. This chapter provides detailed information about cost and revenues distribution between all elements of a power system.

Groups of power grid elements:

1. Power plants
2. Power lines
 - a. High voltage (HV)
 - b. Medium voltage (MV)
 - c. Low voltage (LV)
3. Transformation (HV/MV, MV/MV, MV/LV)

To reflect fixed and variable costs in power system, specific revenues from operation of power system should be divided into fixed and variable part. Fixed part is measured per unit of power and variable part is measured per unit of energy. Specific revenues for each grid elements can be denoted in EUR/MW per year and EUR/MWh.

$$R = \sum_{i=1}^N (P_i \times r_{P,i} + E_i \times r_{E,i}) \quad (37)$$

R	<i>total revenues of power system [EUR]</i>
N	<i>number of elements in power system</i>
P	<i>power, annual average of monthly maximal power load [MW]</i>
E	<i>energy, annual energy generated/transmitted/transformed [MWh]</i>
r_P	<i>annual fixed specific revenues for power [EUR/MW]</i>
r_E	<i>annual variable specific revenues for energy delivered to customers [EUR/MWh]</i>

The first step to calculate specific revenues is to perform a cost allocation for each element of power system. The calculation for fixed costs (revenues) and calculation for variable cost (revenues) must be done separately. Fixed costs are related to power (MW) and variable costs are related to energy (MWh). Figure 37 shows simplified power network with power plants connected to all voltage levels as well as customers connected to each voltage level, power lines and transformations between voltage levels. Specific revenues calculation and cost allocation will be provided for this simplified scheme and the logic behind the calculation can be used for power system of any complexity.

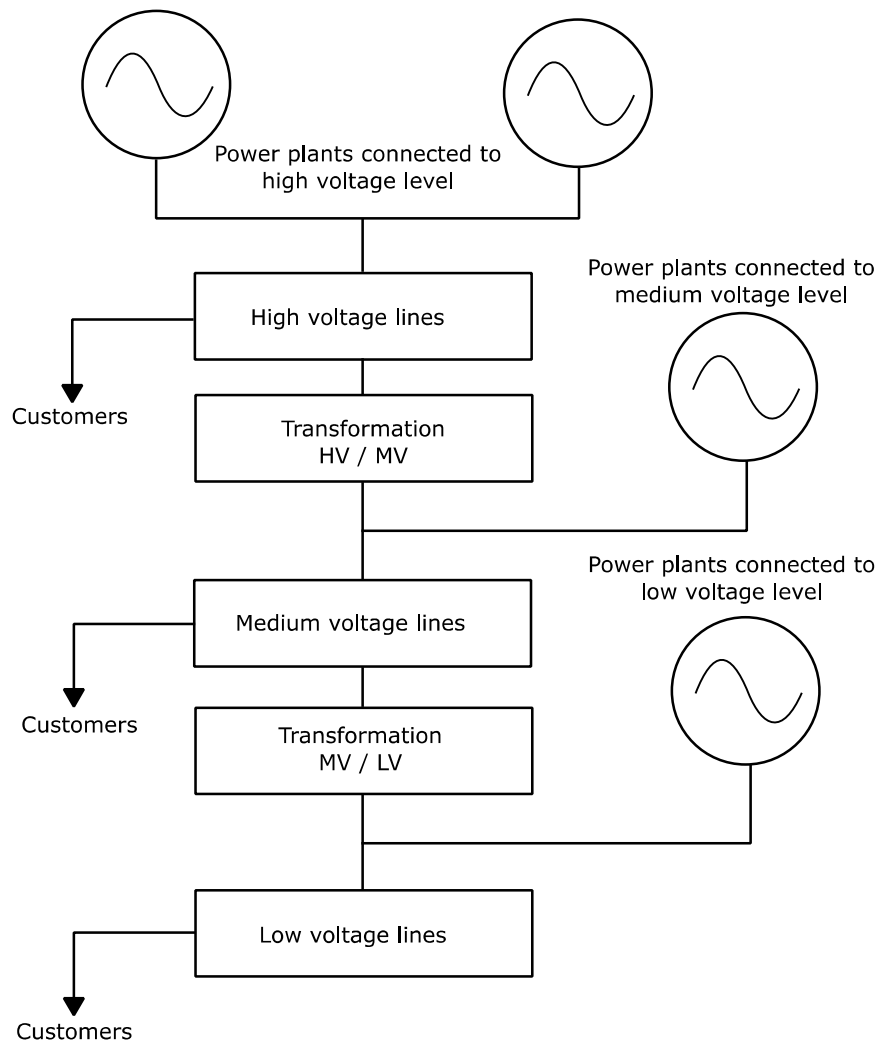


Figure 37: Simplified power system scheme

5.1.1 COST ALLOCATION

Principles of the cost allocation will be show on fixed costs and the usage for variable costs is analogic. Fixed costs allocation will be done in the orientation of power flows. The key information is a ratio between cost of specific element and cost incurred by power flows. Power flows are expected to flow from higher to lower voltage levels. This assumption is used for explanation purposes, however the flows from lower to higher voltage levels are implicitly included with negative sign in calculation procedure.

Cost entering (flowing into) high voltage lines is the sum of costs of all power plants connected to this voltage levels. The costs need to be split at the output from HV lines because it has to be allocated between customers on high voltage level and flows entering transformation into medium voltage level. Splitting is proportional to power flows.

$$C_{HV,C} = \frac{P_{HV,C}}{P_{HV,C} + P_{HV,T}} \times \left(\sum C_{HV,PP} + C_{HV,L} \right) \quad (38)$$

$$C_{HV,T} = \frac{P_{HV,T}}{P_{HV,C} + P_{HV,T}} \times \left(\sum C_{HV,PP} + C_{HV,L} \right) = \sum C_{HV,PP} + C_{HV,L} - C_{HV,C} \quad (39)$$

$C_{HV,C}$	costs allocated to customers connected to high voltage power lines [EUR]
$C_{HV,PP}$	costs of power plants connected to high voltage power lines [EUR]
$C_{HV,L}$	costs of high voltage power lines [EUR]
$C_{HV,T}$	costs allocated to flows transforming to medium voltage [EUR]
$P_{HV,C}$	power flows to customers connected to high voltage power lines [MW]
$P_{HV,T}$	power transforming from high voltage to medium voltage [MW]

Costs entering medium voltage lines are the sum of costs flowing from HV/MV transformation and cost of power plants connected to medium voltage lines. These costs increased by costs of medium voltage lines need to be allocated between customers on medium voltage level and flows entering transformation to low voltage level.

$$C_{MV,C} = \frac{P_{MV,C}}{P_{MV,C} + P_{MV,T}} \times \left(C_{HV,T} + C_{HVMV,T} + \sum C_{MV,PP} \right) \quad (40)$$

$$C_{MV,T} = \frac{P_{MV,T}}{P_{MV,C} + P_{MV,T}} \times \left(C_{HV,T} + C_{HVMV,T} + \sum C_{MV,PP} \right) \quad (41)$$

$$= \sum C_{MV,PP} + C_{HV,T} + C_{HVMV,T} - C_{MV,C}$$

$C_{MV,C}$	cost allocated to customers connected to medium voltage power lines [EUR]
$C_{MV,PP}$	cost of power plants connected to medium voltage power lines [EUR]
$C_{MV,L}$	cost of medium voltage power lines [EUR]
$C_{MV,T}$	cost allocated to flows transforming to low voltage [EUR]
$C_{HVMV,T}$	cost of transformation from high voltage to medium voltage [EUR]
$P_{MV,C}$	power flows to customers connected to medium voltage power lines [MW]
$P_{MV,T}$	power transforming from medium voltage to low voltage [MW]

Costs entering low voltage grid are the sum of costs flowing from MV/LV transformation and cost of power plants connected to low voltage grid. These costs increased by low voltage grid costs are allocated on customers connected to low voltage grid.

$$C_{LV,C} = C_{MV,T} + C_{MVLV,T} + C_{LV,L} + \sum C_{LV,PP} \quad (42)$$

$C_{LV,C}$	cost allocated to customers connected to low voltage power lines [EUR]
$C_{LV,PP}$	cost of power plants connected to low voltage power lines [EUR]
$C_{LV,L}$	cost of low voltage power lines [EUR]
$C_{MV,T}$	cost allocated to flows transforming to low voltage [EUR]
$C_{MVLV,T}$	cost of transformation from medium voltage to low voltage [EUR]

This principle is the same for variable costs allocation. The key for cost distribution is energy in MWh instead of power.

5.1.2 REVENUES ALLOCATION

Revenues allocation process starts at customers and flowing through power grid up to the power sources. The main principle of revenues allocation is explained below.

1. Elements in series: revenues are distributed proportionally to cost of elements or to the cost assigned to the power flows (net cumulated power flows through specific element).
2. Parallel connected elements: revenues are distributed proportionally to power flowing to these elements.

Revenues allocated on low voltage lines are the revenues obtained from customers connected to low voltage, split by the ratio of the cost of low voltage lines and total allocated costs on customers on this voltage level.

$$R_{LV,L} = R_{LV,C} \times \frac{C_{LV,L}}{C_{LV,C}} \quad (43)$$

$$r_{LV,L} = \frac{R_{LV,L}}{P_{LV,L}} \quad (44)$$

$R_{LV,L}$	revenues allocated on low voltage power lines [EUR]
$R_{LV,C}$	revenues from customers connected to low voltage power lines [EUR]
$P_{LV,L}$	power flowing through low voltage lines [MW]
$r_{LV,L}$	specific revenues of low voltage lines [EUR/MW]

Revenues, decreased by revenues of low voltage lines, needs to be split between power plants connected to low voltage lines and the rest of the system on higher voltage levels. The key for revenues splitting is the power delivered by both branches.

$$R_{LV,PP} = (R_{LV,C} - R_{LV,L}) \times \frac{\sum P_{LV,PP}}{P_{LV,L}} \quad (45)$$

$$r_{LV,PP} = \frac{R_{LV,PP}}{\sum P_{LV,PP}} \quad (46)$$

$P_{LV,PP}$	power of power plants connected to low voltage power lines [MW]
$R_{LV,C}$	revenues from customers connected to low voltage power lines [EUR]
$R_{LV,PP}$	revenues from power plants connected to low voltage power lines [EUR]
$P_{LV,L}$	power flowing through low voltage lines [MW]
$r_{LV,L}$	specific revenues of low voltage lines [EUR/MW]

The rest of the revenues enters the transformers (MV/LV) from low to medium voltage level. It is allocated to transformers by the ratio of transformers cost and cost allocated to the power flows in these transformers.

$$R_{LV,T} = (R_{LV,C} - R_{LV,L}) \times \frac{P_{LV,L} - \sum P_{LV,PP}}{P_{LV,L}} \quad (47)$$

$$R_{MVLV,T} = R_{LV,T} \times \frac{C_{MVLV,T}}{C_{MV,T}} \quad (48)$$

$$r_{MVLV,T} = \frac{R_{MVLV,T}}{P_{MVLV,T}} \quad (49)$$

$R_{LV,T}$	revenues allocated to flows entering transformation MV/LV [EUR]
$R_{MVLV,T}$	revenues allocated to transformers MV/LV [EUR]
$C_{MV,T}$	cost allocated to flows transforming to low voltage [EUR]
$C_{MVLV,T}$	cost of transformation from medium voltage to low voltage [EUR]
$P_{MVLV,T}$	power flowing through transformers MV/LV [MW]
$r_{MVLV,T}$	specific revenues of transformers MV/LV [EUR/MW]

Revenues entering calculation on medium voltage lines are the sum of revenues coming from transformation (MV/LV) and the customers connected to medium voltage level.

$$R_{MV,L} = (R_{LV,T} - R_{MVLV,T} + R_{MV,C}) \times \frac{C_{MV,L}}{C_{HV,T} + C_{HVMV,T} + \sum C_{MV,PP} + C_{MV,L}} \quad (50)$$

$$r_{MV,L} = \frac{R_{MV,L}}{P_{MV,L}} \quad (51)$$

$R_{MV,L}$	revenues allocated on medium voltage power lines [EUR]
$C_{MV,L}$	cost of medium voltage power lines [EUR]
$C_{HV,T}$	costs allocated to flows transforming to medium voltage [EUR]
$C_{HVMV,T}$	cost of transformation from high voltage to medium voltage [EUR]
$C_{MV,PP}$	cost of power plants connected to medium voltage power lines [EUR]
$P_{MV,L}$	power flowing through medium voltage power lines [MW]
$r_{MV,L}$	specific revenues of medium voltage power lines [EUR/MW]

In the next step, revenues are required to be allocated on power plants connected to medium voltage level and the system on high voltage level. Allocation is proportional to the power supplied.

$$R_{MV,PP} = (R_{LV,T} - R_{MVLV,T} + R_{MV,C} - R_{MV,L}) \times \frac{\sum P_{MV,PP}}{\sum P_{MV,PP} + P_{HVMV,T}} \quad (52)$$

$$R_{MV,T} = (R_{LV,T} - R_{MVLV,T} + R_{MV,C} - R_{MV,L}) \times \frac{P_{HVMV,T}}{\sum P_{MV,PP} + P_{HVMV,T}} \quad (53)$$

$$r_{MV,PP} = \frac{R_{MV,PP}}{\sum P_{MV,PP}} \quad (54)$$

$R_{MV,PP}$	revenues allocated to power stations connected to medium voltage power lines [EUR]
$R_{MV,PP}$	power of power stations connected to medium voltage power lines [EUR]
$r_{MV,PP}$	specific revenues of power plants connected to medium voltage power lines [EUR/MW]
$R_{MV,T}$	revenues allocated to flows entering transformation MV/LV [EUR]
$P_{HVMV,T}$	power flowing through transformers HV/MV [MW]

Revenues from high voltage system (including transformation to medium voltage level) are allocated to HV/MV transformers in ratio of transformers cost and cost allocated to flows transforming to medium voltage.

$$R_{HVMV,T} = R_{MV,T} \times \frac{C_{HVMV,T}}{C_{HV,T} + C_{HVMV,T}} \quad (55)$$

$$r_{HVMV,T} = \frac{R_{HVMV,T}}{P_{HVMV,T}} \quad (56)$$

$R_{HVMV,T}$	revenues allocated to HV/MV transformers [EUR]
$C_{HVMV,T}$	cost of transformation from high voltage to medium voltage [EUR]
$C_{HV,T}$	costs allocated to flows transforming to medium voltage [EUR]
$P_{HVMV,T}$	power flowing through transformers HV/MV [MW]
$r_{HVMV,T}$	specific revenues of HV/MV transformers

Revenues entering calculation on high voltage lines are the sum of revenues coming from transformation (HV/MV) and revenues from customers connected to high voltage level.

$$R_{HV,L} = (R_{MV,T} - R_{HVMV,T} + R_{HV,C}) \times \frac{C_{HV,L}}{\sum C_{HV,PP} + C_{HV,L}} \quad (57)$$

$$r_{HV,L} = \frac{R_{HV,L}}{P_{HV,L}} \quad (58)$$

$R_{HV,L}$	revenues allocated to high voltage power lines [EUR]
$R_{HV,C}$	revenues from customers connected to high voltage power lines [EUR]
$C_{HV,L}$	cost of high voltage power lines [EUR]
$C_{MV,PP}$	cost of power plants connected to high voltage power lines [EUR]
$P_{HV,L}$	power flowing through high voltage power lines [MW]
$r_{HV,L}$	specific revenues of high voltage power lines [EUR/MW]

In the last step, it is necessary to allocate the revenues on power plants connected to high voltage power lines.

$$R_{HV,PP,i} = (R_{MV,T} - R_{HVMV,T} + R_{HV,C} - R_{HV,L}) \times \frac{P_{HV,PP,i}}{\sum P_{HV,PP}} \quad (59)$$

$$r_{HV,PP,i} = \frac{R_{HV,PP,i}}{P_{HV,PP,i}} \quad (60)$$

$R_{HV,PP,i}$	revenues allocated to <i>i</i> -th power plant connected to high voltage power lines [EUR]
$P_{HV,PP,i}$	power of <i>i</i> -th power plant connected to high voltage power lines [MW]
$r_{HV,PP,i}$	specific revenues of <i>i</i> -th power plant connected to high voltage power lines [EUR/MW]

5.2 DISCUSSION AND FUTURE RESEARCH

Variable costs and variable revenues are analogic to allocation of fixed costs and fixed revenues. Formulas are the same, but basis for allocation will be energy (in MWh), not power (in MW). Both fixed/variable costs/revenues must be considered for the same period of time, usually one year.

Since the supplied parameters are annual, important factor is the setting up of power for each element, especially for power plants. From the fixed revenues point of view, it is required to use guaranteed power, the power that power plant is ready to supply. For conventional power sources, an average from monthly maximums is satisfactory. The same applies for power grid elements. The biggest issues are the intermittent power sources since they cannot guarantee the power supplies and future researches should be connected to this issue. However, this can be fully or partially solved by grouping intermittent power sources into virtual power plants.

Obtained specific revenues and costs can be used as a basis for new tariff design because the revenues are directly assigned to the costs. Revenue to cost ratio shows effectiveness of specific element of power grid. Above mentioned methodology shows calculation from whole power system point of view where power plants and power grid are the part of one system. This approach can be useful for regulators and for setting up the direction of power system development. Similar approach can be used for subgroups of power system, for example, the distribution grid where optimal elements repair and replace decision must be made on periodic basis.

6 VALUE CHAINS IN POWER SECTOR

This chapter deals with the distribution of economic effect between the entities in production cycle of electricity. The task is similar to the specific revenues allocation from the chapter 5.1 where revenues were fairly split between all elements in power system (power plants, transmission, distribution and final customers).

The aim of this section is to divide the economic benefits on entities before power plants. These economic benefits should be divided considering the risk. For example, customers of power plants with heat supplies are decreasing demand. This situation is mainly caused by substitution of centralized heating by individual sources and insulation of houses. Therefore, these power plants need compensate loses e.g. by selling more electricity on market, which is riskier. Since the brown coal producer (mine) and customer (power plant) are dependent on each other and electricity production became more risky, economic benefits from brown coal should be divided in favour of power plant. In other words, price of coal for power plant should be decreased to reflect the change in risk level. More detailed information about brown coal pricing can be found in the following section (6.1).

Very similar problem was solved in [68] where authors created biomass competitiveness model. The model contains information (costs, energy, minimal prices) for all of the steps in production cycle of pellets from raw biomass. Production cycle includes harvesting and transportation of raw biomass, storage of raw biomass, production of briquettes and pellets, distribution of briquettes and pellets and the storage of final products. Entities involved in this production cycle must agree on prices of intermediate product. This task is analogic with brown coal pricing problem. Author, as the member of the research team funded by the Technology Agency of the Czech Republic¹⁵, developed software for calculation of biomass potential based on biomass competitiveness model provided. Part of the outputs are the minimal price, energy and the mass of intermediate product for each step of production cycle.

6.1 BROWN COAL PRICING

Brown coal is a strategic fuel for power plants globally. Its importance in Europe increased following the closure of nuclear power plants in Germany. Steam power plants fuelled by brown coal cover usually base load and can be used for regulation. They are definitely stabilizing element in electricity network.

The price of brown coal (lignite) is tightly bound to locality because cost of transportation is very high. The net calorific value (NCV) of lignite is around 6-9 MJ/kg. Brown coal of higher quality has NCV around 11-12 MJ/kg, separated high quality brown coal can reach up to 20 MJ/kg. The highest quality black coal (anthracite) has NCV higher than 30MJ/kg. For the sake of reference, diesel and petrol have NCV between 45-50 MJ/kg. [69] One can notice, that transportation of one energy unit of fuel is the most expensive for brown coal. The lower NCV means higher cost per unit of energy.

Because there are high transportation costs, brown coal is not traded on world commodity exchanges and there is no global market price of brown coal. Moreover, brown coal is not a standardized product. Technologies used in power plants are optimized for combustion of locally produced coal. It means that changing of brown coal supplier can (and probably will) lead to suboptimal process of electricity production.

¹⁵ Grant TD03000039, Tools for analysis of market utilization and competitiveness of biomass for energy needs in local communities.

Vertical economic integration of mining companies and electricity production companies is evident in most of the cases. It means that investor built power station close to brown coal mine and the same investor (or a group with joint interests) is involved in mining process. This is the situation where brown coal valuation is not crucial. If mining company sells brown coal to electricity producer cheaply or expensively, there will be no direct effect on investors profit and money. One company would have higher profits on at the expense of other company. The more problematic case is the situation where one investor owns the mining company and another investor owns the power plant. In this case, setting of a fair price is substantial.

Massive privatization process in Central and Eastern European countries led to the situations where natural economic links between mining companies and power producers were broken. In this situation, it is very important to setup fair (proper) price of brown coal. Since the transportation costs are high, the miner's possibility to find another customer is very limited. The same situation applies for a power producer buying brown coal from another supplier.

The profit from natural resources (brown coal) should be divided between all concerned parties: energy producer, coal producer and society represented by government. Governmental income can be direct (fee for extracted mineral) and/or indirect (taxes). Land owner does not own natural resources deep under land surface in the most countries (including Europe). These resources are property of the society (government, state). On the other hand, there are countries (e.g. USA) where land owner owns natural sources under his land. In this case, the only state income from extracting of natural sources can be indirect through various ways of taxation.

There are two boundaries for determination of fair brown coal price:

1. Minimal price for electricity producer that will cover his costs and required profit. Minimal price should include transportation costs from coal producer. Coal producer and electricity producer can agree on sharing of the transportation cost. In that case, price should be decreased by the share of coal producer's transportation cost.
2. Minimal price for coal producer that will also cover his costs and profit. Minimal price must include fee for extracted mineral. If both parties agree on sharing transportation costs, price should be amended as in the previous point.

Methodology published in [70] assumes that the profit given by the boundaries should be distributed in proportion to invested capital. This approach can be appropriate if there is a lack of investments in one of the companies (coal producer or electricity producer). In case investors behave rationally and responsibly, investments should be already included in their costs in form of depreciations. From this point, profit distribution in proportion to exposed risk would be a better alternative. One can say that both parties are exposed to the same risk because they cannot exist without each other. This approach is also reasonable.

6.1.1 PROFIT DISTRIBUTION

There are two exchangeable ways how to distribute the economic effect (amount between calculated boundaries) in proportion to the risk:

1. Calculate NPV (4) of costs per unit of coal (EEA (5)). It will result in direct values of the boundaries. These can be used for proportional profit allocation.
2. Setup the price of coal in a way that the IRRs (7) of both parties would be calculated respecting ratio between risks of both companies.

Following equations show the calculation of minimal sales price of production. Cash-flow calculation is shown in formula (61). It takes into account the growth rate of both prices and costs. This approach can be used for estimation of the coal sale price.

$$CF_t = \left[P \times (1 + g_p)^t \times Q - C_F \times (1 + g_c)^t - C_V \times (1 + g_c)^t \times Q - D_t \right] \times (1 - \tau) + D_t \quad (61)$$

CF_t	Cash-flow in year t [EUR]
P	Price of production in the 0-th year [EUR/t]
Q	Production volume [t]
C_F	Fixed costs (expenditures) in the 0-th year [EUR]
C_V	Variable costs (expenditures) per produced output in the 0-th year [EUR/t]
D_t	Tax depreciations and other non-cash costs in year t [EUR]
g_p	Production price annual growth [-]
g_c	Costs (expenditures) annual growth [-]
τ	Corporate tax rate [-]
t	Calculation year [-]

Formula (62) expresses the condition for minimal production sales price, where NPV equals to zero. Minimal sales price can be calculated by combination of equations (61) and (62).

$$\sum_{t=1}^T \frac{CF_t}{(1+r)^t} - INV = 0 \quad (62)$$

INV	The value of investment in 0-th year [EUR]. Value represents discounted expenditures to the last year of investment period in case that investment period is longer than one year.
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Equations (63) and (64) shows simplified minimal price calculation. The simplifying assumptions are fixed price, fixed depreciations and fixed costs for whole project lifetime.

$$[(P \times Q - C_F - Q \times C_V - D) \times (1 - \tau) + D] - INV \times a_T = 0 \quad (63)$$

$$P = \frac{INV \times a_T - D}{Q \times (1 - \tau)} + \frac{D + C_F}{Q} + C_V \quad (64)$$

a_T	Annuity payment factor [-]
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Formula (61) must be modified to estimate maximal purchase price which power producer can afford. This modification is shown in the formula (65). There are two quantities in the formula, because brown coal is entering the production and electricity (or heat) emerges out from production process. Variable costs are divided between variable costs related with coal and energy respectively. This step is not necessary because these variable costs, related to the input (coal) can be recalculated on variable costs related with output (energy) and vice versa. Transportation is one of the most significant variable cost related to coal.

$$CF_t = \left[P \times (1 + g_p)^t \times Q_E - C_F \times (1 + g_c)^t - C_{V,E} \times (1 + g_c)^t \times Q_E - C_{V,C} \times (1 + g_c)^t \times Q_C - C_C \times (1 + g_c)^t \times Q_C - D_t \right] \times (1 - \tau) + D_t \quad (65)$$

C_C	Coal price (coal cost) in the 0-th year [EUR/t]
$C_{V,C}$	Variable costs (expenditures) in the 0-th year, related with input (coal) [EUR/t]
$C_{V,E}$	Variable costs (expenditures) in the 0-th year, related with output (energy) [EUR/MWh]
Q_E	Production volume [MWh]
Q_C	Coal volume [t]

Finally, the maximal coal price for power producer can be obtained from formulas (66) and (67) assuming simplifying assumption are used. One has to use numerical methods to estimate exact values

for the case where no simplifying assumptions have been adopted. Analytical solution is too complex in such case.

$$\left[(P \times Q_E - C_F - C_{V,E} \times Q_E - C_{V,C} \times Q_C - C_C \times Q_C - D) \times (1 - \tau) + D \right] - INV \times a_T = 0 \quad (66)$$

$$C_C = -\frac{INV \times a_T - D}{Q_C \times (1 - \tau)} - \frac{D + C_F + (C_{V,E} - P) \times Q_E}{Q_C} - C_{V,C} \quad (67)$$

a_T | Annuity payment factor [-]

Maximal acceptable coal price for the electricity producer and minimal acceptable coal price for the coal producer defines the trade interval of the coal price.

More detailed information about coal pricing methodologies and case study can be found in author's original publication [70] which is attached in appendix section.

7 VALUATION OF OPTIONS ON WEATHER

This chapter explains the valuation of option on weather using simulation method. The first step is to analyse weather data and determine parameters required for simulation. Data from Paris-Orly weather station was used and analysed (input data was obtained from European Climate Assessment & Dataset project <http://www.ecad.eu/>). Input date range is the 1st of September 1948 until 31st of August 2017. Daily average temperatures were used for further analysis. Average temperatures were calculated as the average value of maximal day-time temperature (06:00 – 18:00) and minimal night-time temperature (18:00 – 06:00). Average temperature calculation was made by the data provider.

7.1 ANALYSIS OF TEMPERATURE

Temperatures for 29th of February of each leap year were removed from dataset. Temperature data have seasonal character. Truncated cosine model series with trend (formula (27) on page 27) is used for modelling of seasonal part. Figures 38 and 39 shows the fitting of this model on the first and last three years of dataset. One can notice that seasonal cycles are well described with suggested model. Fitted parameters $\{x_0, x_1, x_2, x_3\}$ for model (27) are¹⁶ $\{10.40, 0.00, 7.95, -37.69\}$.

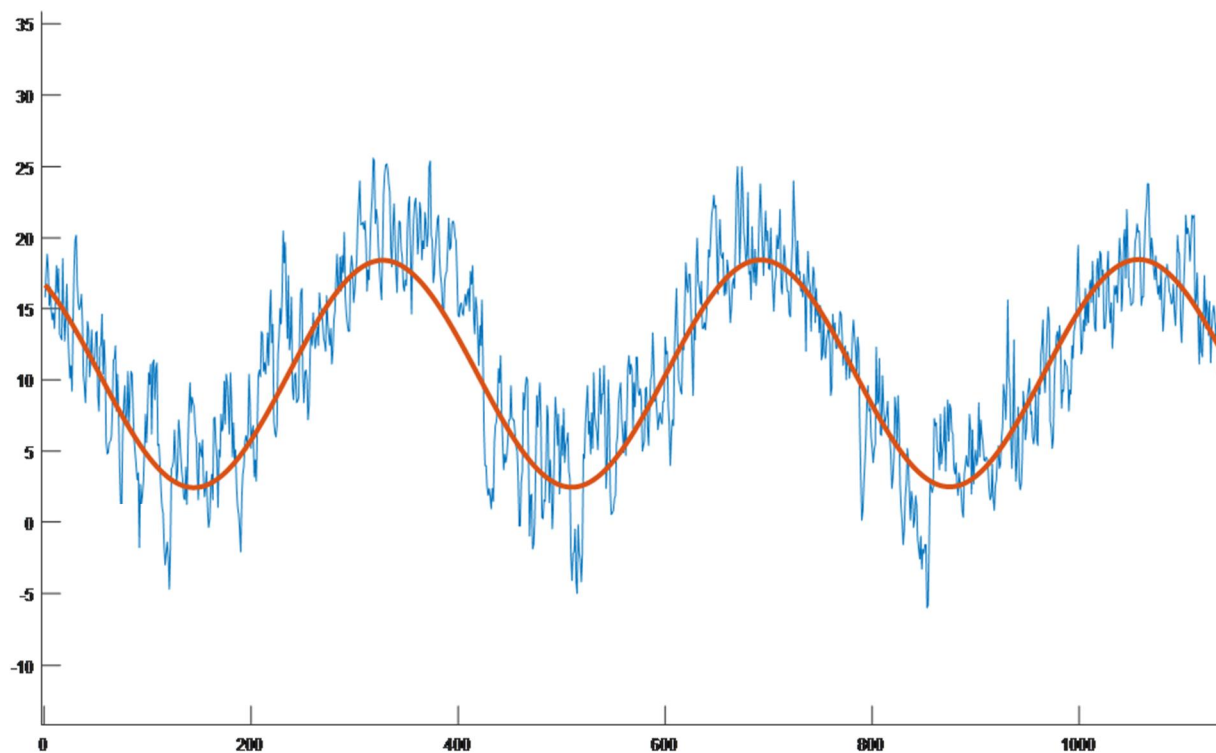


Figure 38: Fitting of seasonal function in the first three years [1948-1951]
Horizontal axis: days; Vertical axis: average temperature

¹⁶ Numbers are rounded on two decimal places

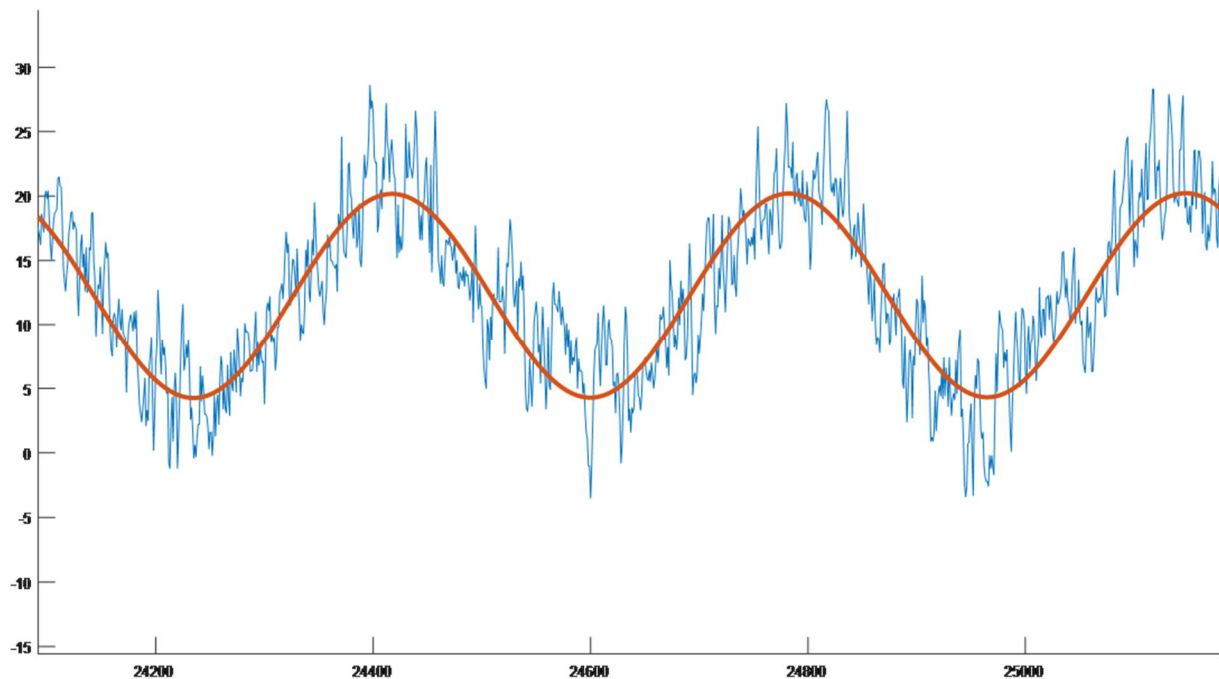


Figure 39: Fitting of seasonal function in the last three years [2014-2017]
Horizontal axis: days from the 1st of the September 1948; Vertical axis: average temperature

Sample autocorrelation function (fig. 40) shows strong correlation of de-trended and de-seasonalized data on its past values. This is a common situation in time series analysis. Partial autocorrelation function (fig 41) is very useful for AR model specification as it helps to identify significant variables, and lagged values in the time series model. Partial autocorrelation is a conditional correlation between two variables under assumption that some other set of variables is taken into account. The first three lagged values are significant and AR(3) model is suggested.

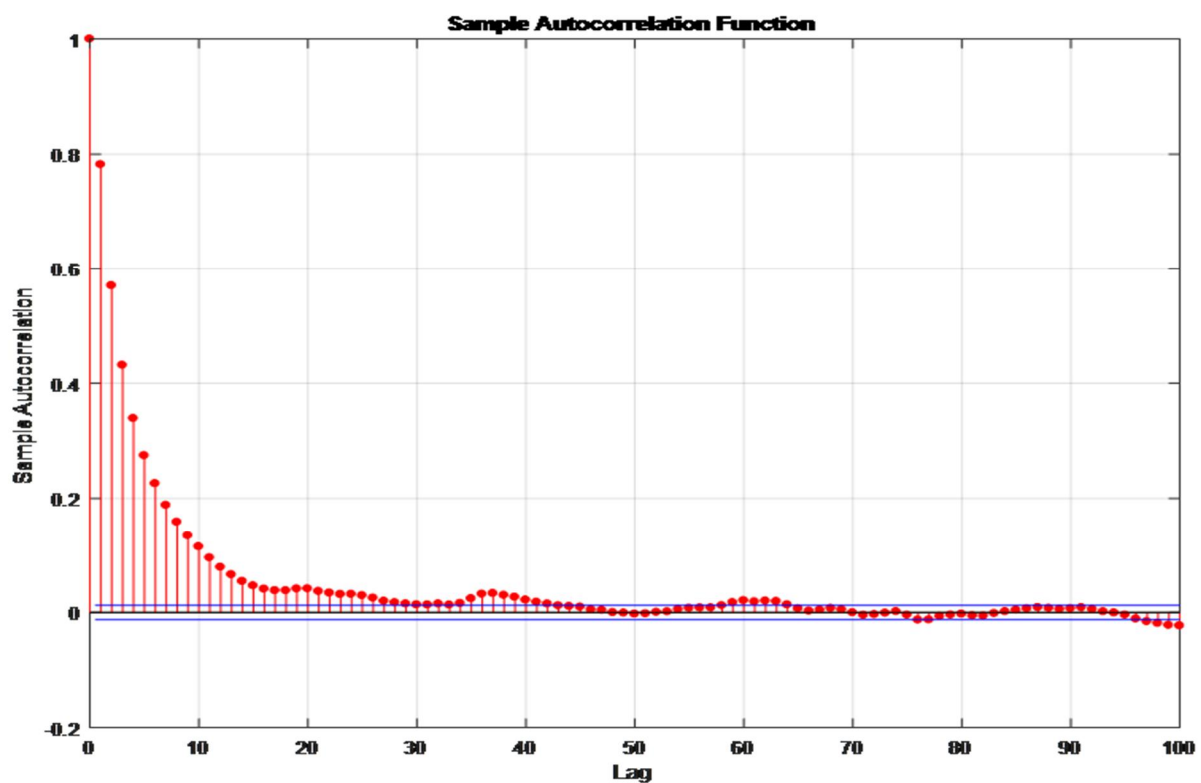


Figure 40: Sample autocorrelation function for de-trended and de-seasonalized data

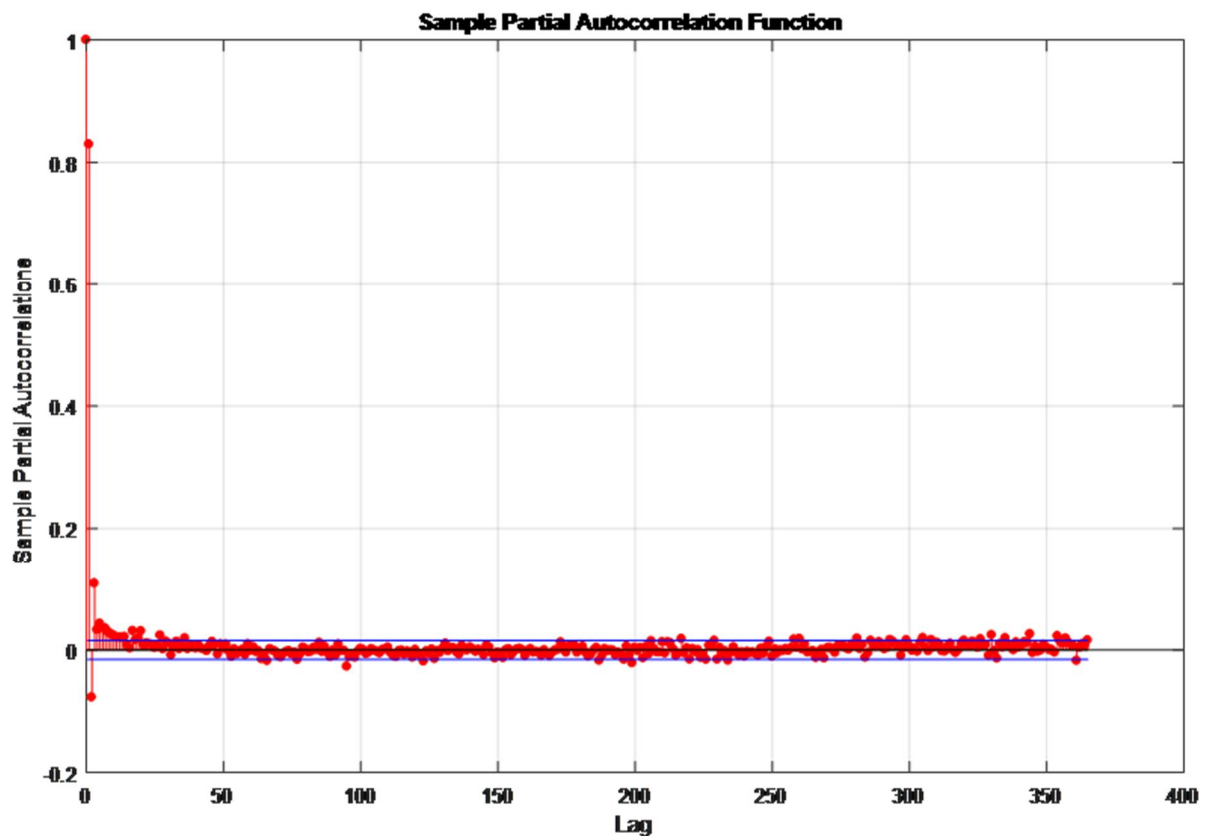


Figure 41: Partial autocorrelation function for de-trended and de-seasonalized data

Fitted parameters $\{a_1, a_2, a_3\}$ of AR(3) model (formula (28) on page 27) are $\{0.05, -0.15, 0.87\}$. Coefficient of determination is equal to 62 %. Figure 42 shows observed and predicted values from AR(3) model for sample period.

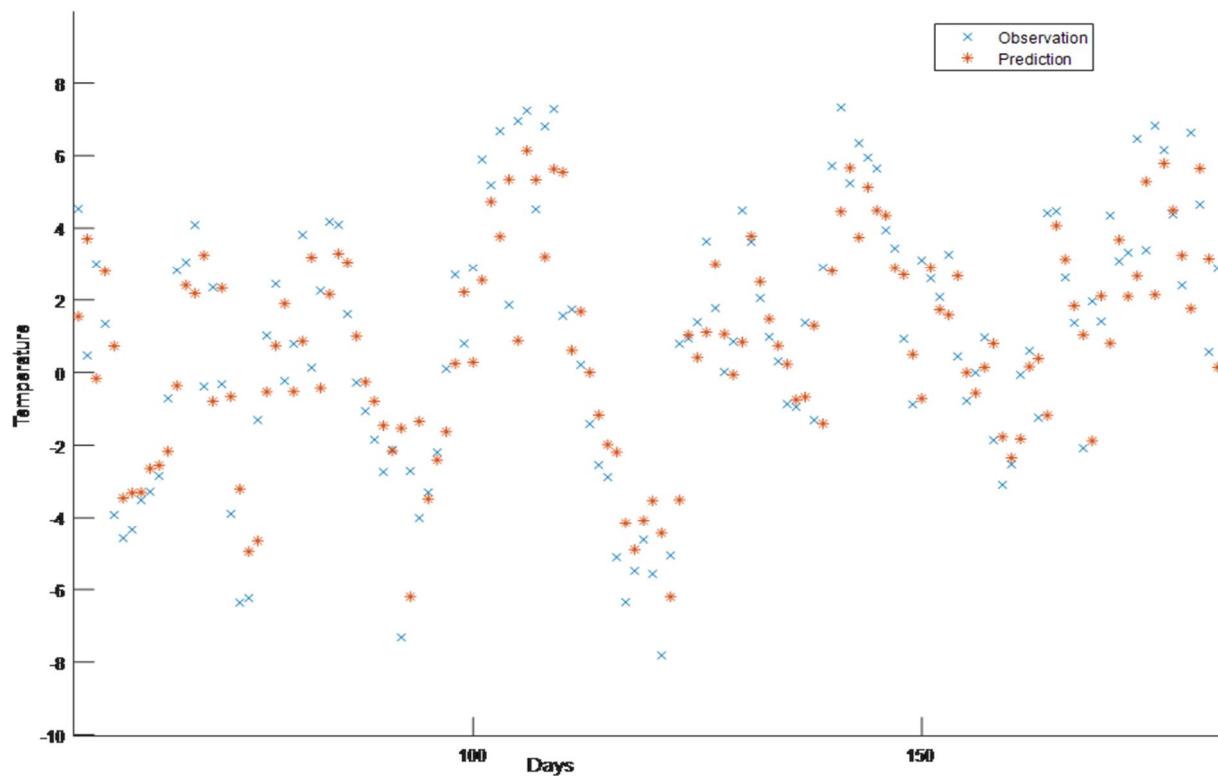


Figure 42: Observed and predicted values of temperatures filtered from seasonal effect.
Example from the first 180 days.

Figures 43 and 44 show autocorrelation function and partial autocorrelation function applied on residual data after AR(3) model application. One can notice that AR(3) model is suitable and there is no requirement of adding other lagged variables. Residual values are plotted in histogram on figure 45. The normality of residual data is noticeable.

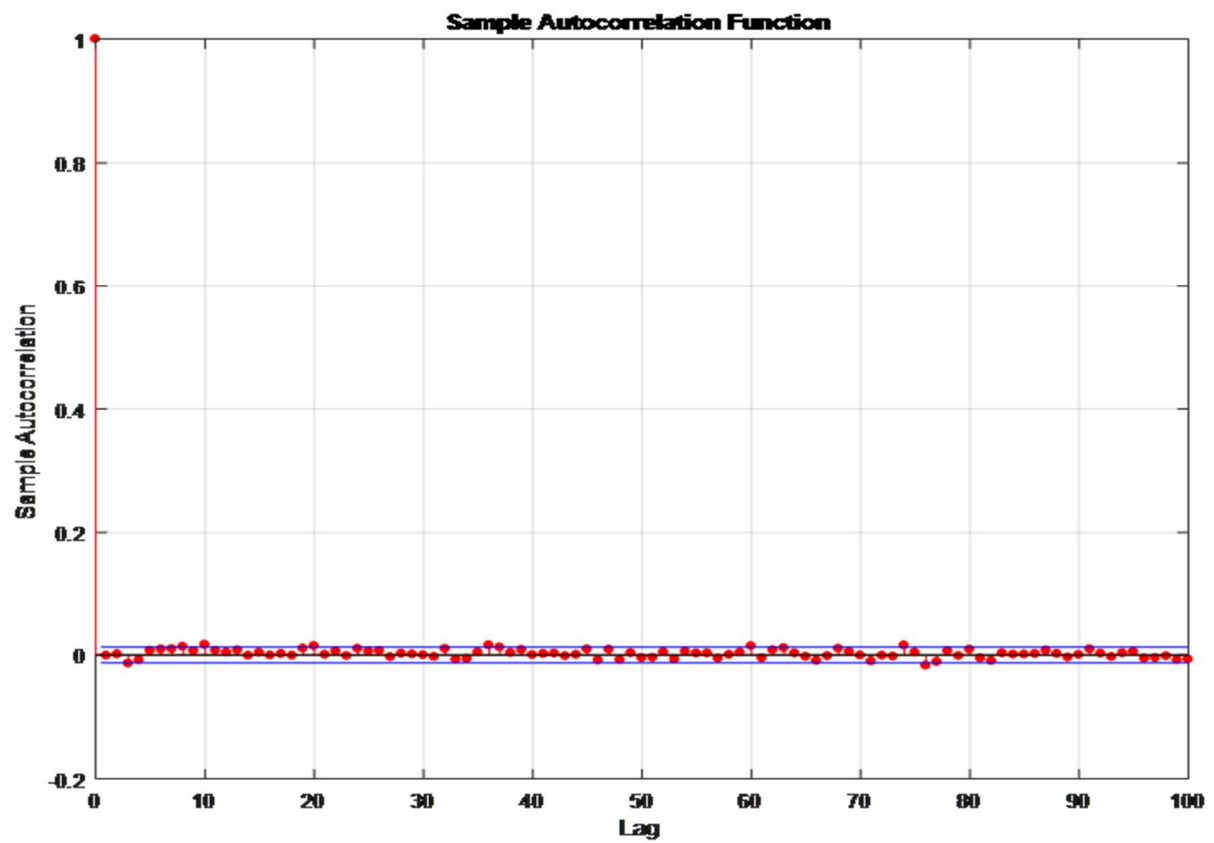


Figure 43: Autocorrelation function after applying AR(3) model

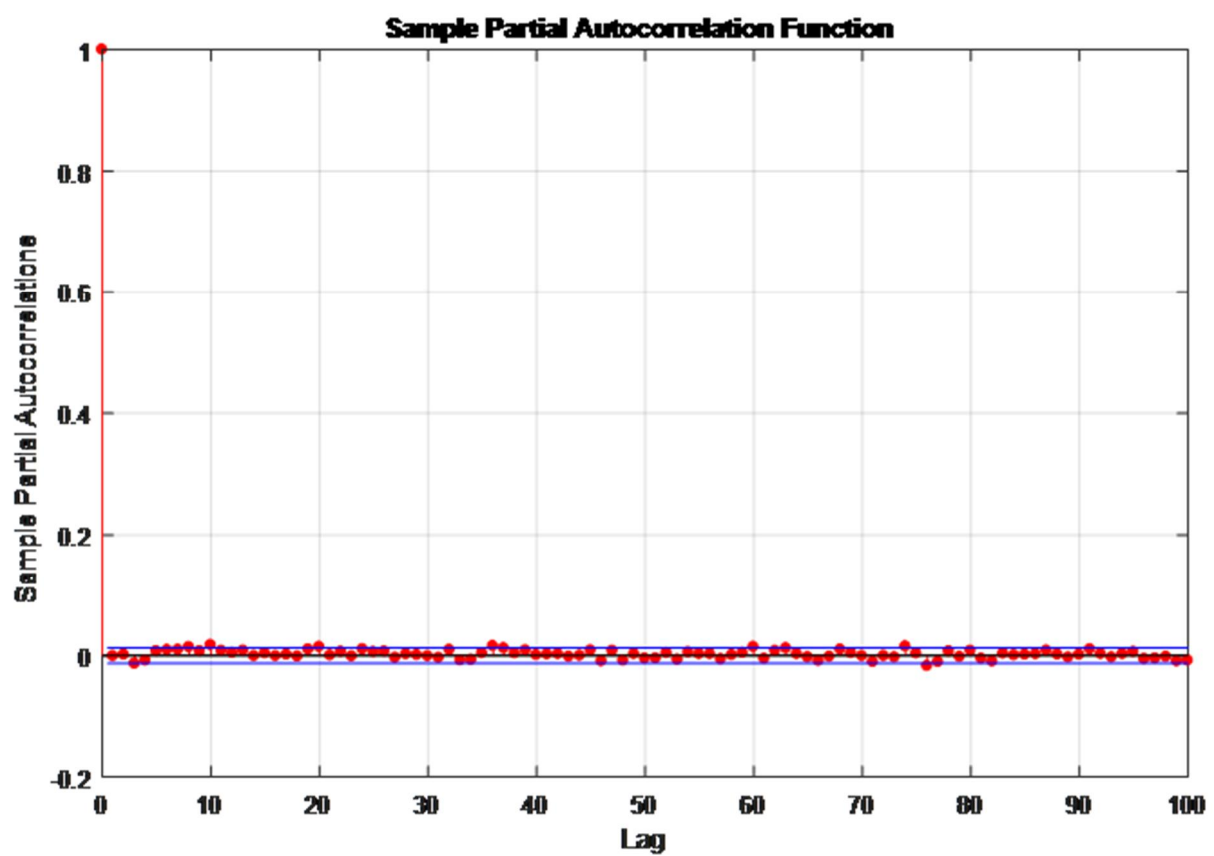


Figure 44: Partial autocorrelation after applying AR(3) model.

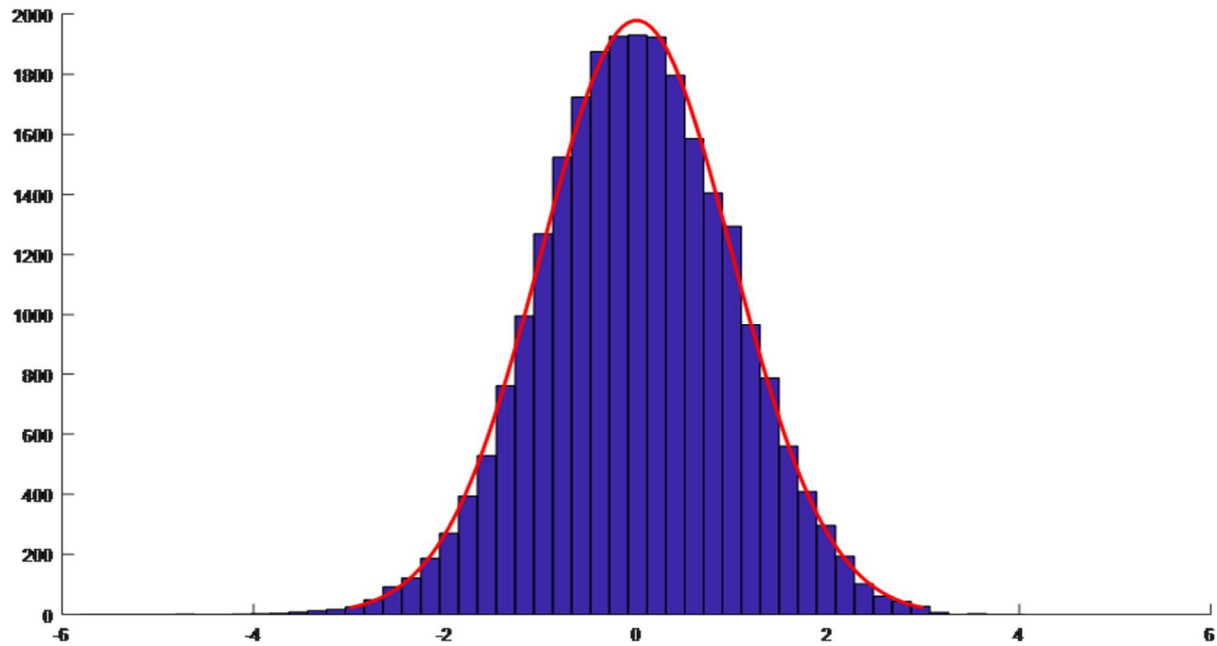


Figure 45: Histogram of normalized residuals after seasonal component, linear trend and AR(3) process were removed.

Figure 46 shows calculated variance of temperatures for specific day of the year. This is the proof of non-constant variance. High deviations are caused by two major facts:

1. The small amount of data. Only 69 temperatures are available for each day of the year.
2. Day-to-day temperature changes are high, using longer period (e.g. week) would decrease such high deviation.

Temperatures simulation takes into account the non-constant variance. Variance is modelled by 4th order truncated Taylor series (formula (30) on page 28), depicted by the red line. Fitted parameters $\{\beta_1 \dots \beta_9\}$ have values $\{4.43, 0.56, -0.20, -0.04, -0.07, -0.48, -0.38, -0.02, -0.13\}$.

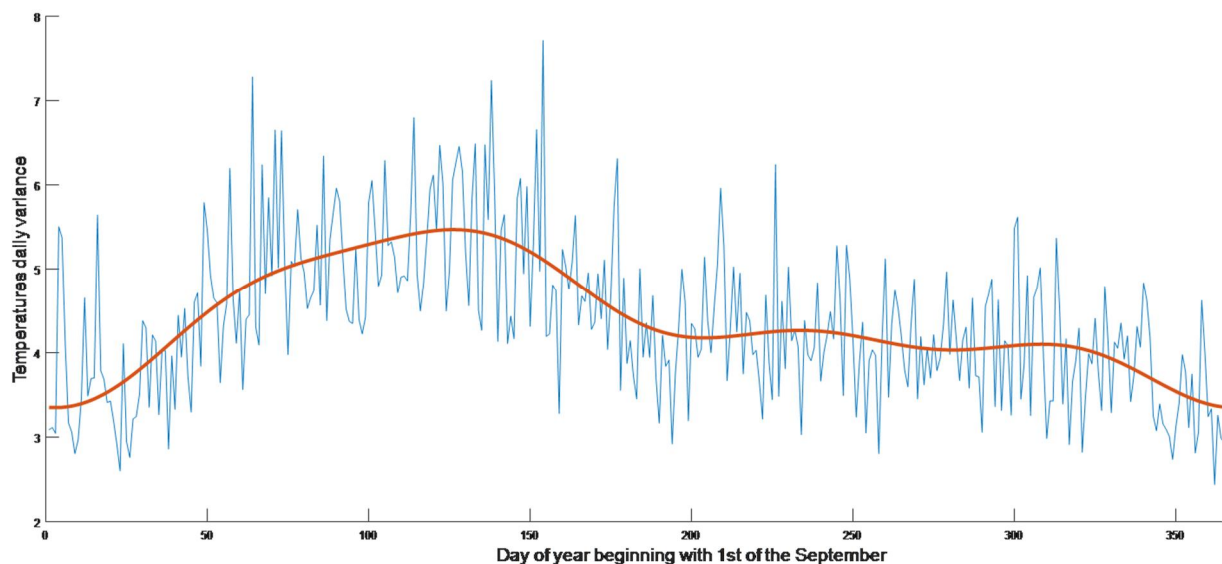


Figure 46: The blue line shows temperature daily variance and the red line is fitted truncated Taylor series function.

7.2 WEATHER OPTION VALUE

Option value can be understood as the mean value calculated from repeated simulations. Figures 47, 48 and 49 shows the temperature simulations for one year. Heating-degree-days for a specific period can be calculated from each individual simulation run.

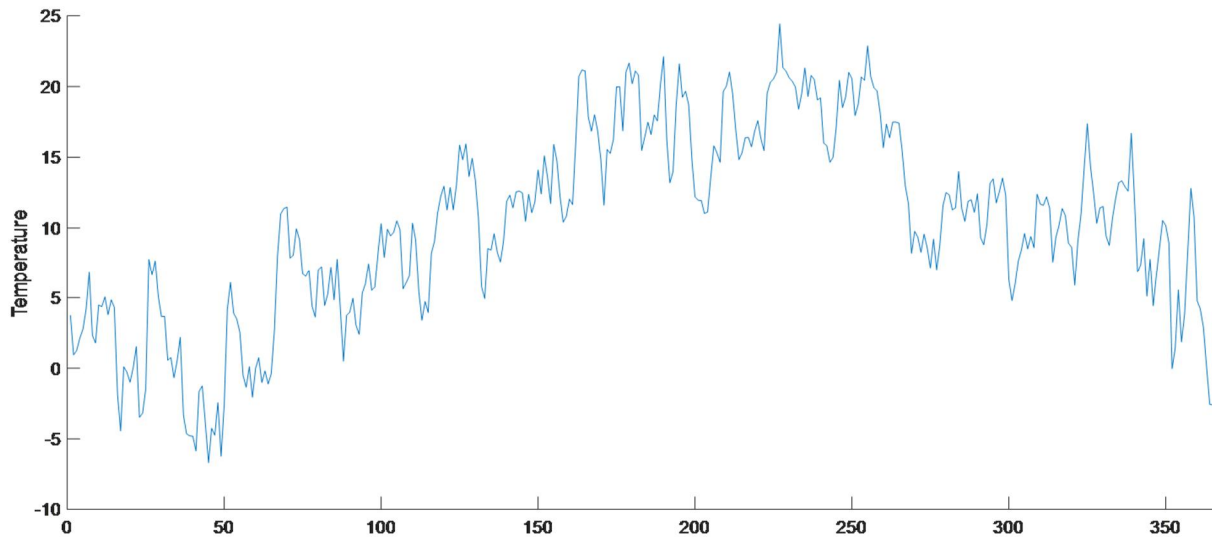


Figure 47: An example of one simulation beginning 1st of September

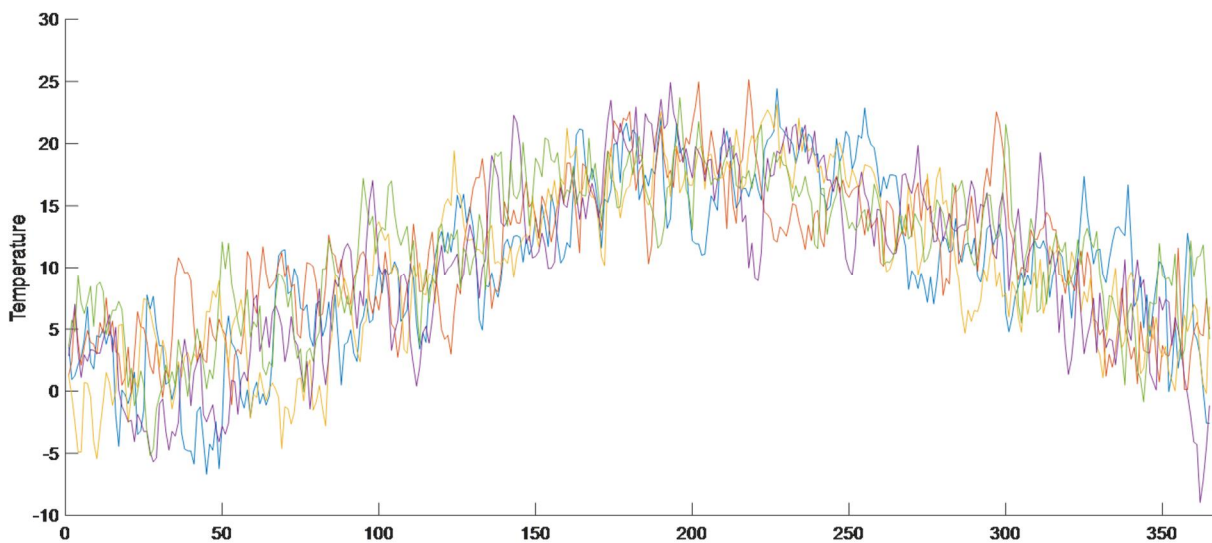


Figure 48: An example of ten simulations beginning 1st of September

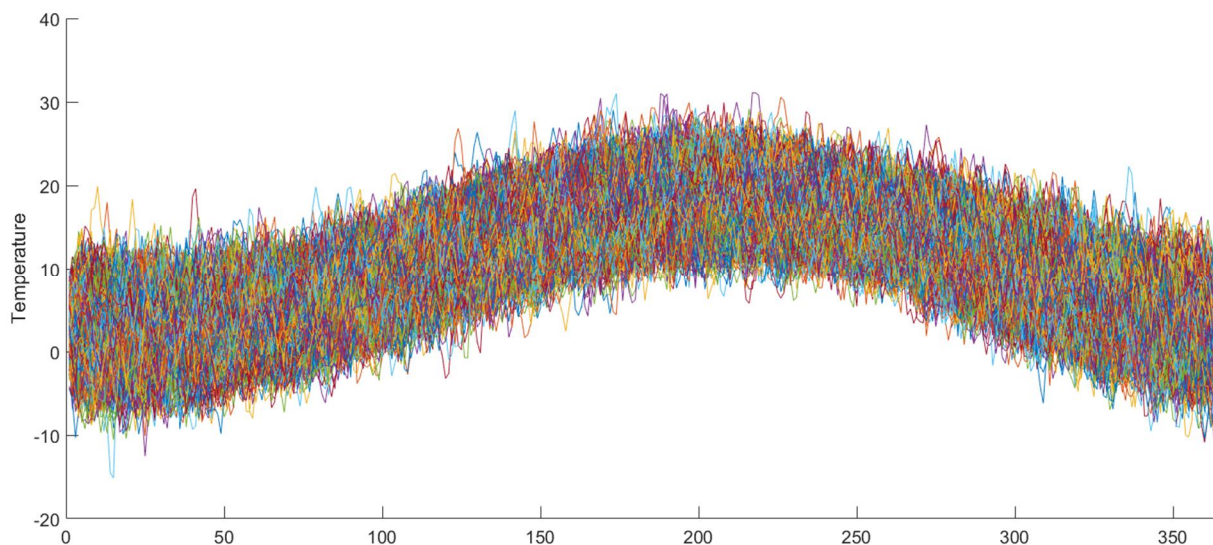


Figure 49: An example of 1000 simulation beginning 1st of September

If the HDD value for observed period is lower than the option strike price, call option has zero value. If the HDD value is higher than the strike price, call option value can be calculated as the difference between HDD value and the strike price. To obtain these result in monetary unit, this difference is multiplied by value of 1 HDD. Figure 50 shows the simulations result for call option with maturity of half-year, strike price equal to 1050 EUR and the discount rate equal to 0.5 %.

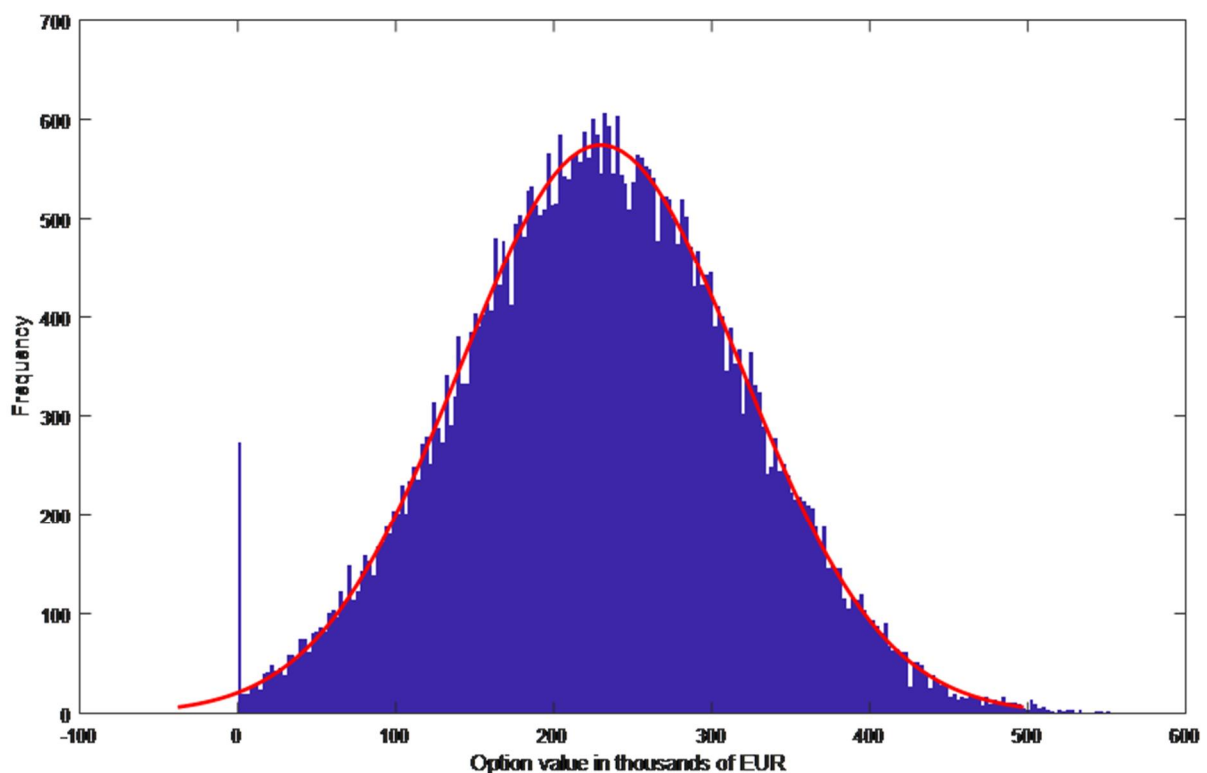


Figure 50: Call option value simulations results.

The start of simulation: 1st of September; Option value for period 1st of January – 31st of March.
Strike price: 1050 EUR; 1 HDD value: 1000 EUR; simulation runs: 50 000, discount rate: 0.5 %.

Option value distribution is almost normal. One can notice that frequency of zero value is high. This is caused by the fact that the option value is zero in cases where the difference between simulated HDD and option strike is negative. It is the only bias in option value normality. Specified call option has average value 230 550 EUR. In case where the simulated value would not be limited by zero, average

would have the same value as median 230 140 EUR since normal distribution has average value equal to median. The latter value is better for calculation of value-at-risk. The difference between these two numbers depends on the strike price. For call option, higher strike price leads to lower probability of option exercise and increase of zero value probability. The other important parameter is the standard deviation which is equal to 89 674 EUR and this value is slightly lower than it would be in case of non-zero value limitation (90 059 EUR). The value without zero limitation would be better for value-at-risk determination.

8 DISCUSSION AND FURTHER RESEARCH

This thesis brought insight on specific problems of economic effectiveness evaluation in power sector. Several various approaches were presented and pro-linked to specific tasks (deterministic, stochastic, single criterion and multicriterial). There are two ways for conducting future research:

1. Continuing of current research and its adaptation on new economical, technical, social and other relevant conditions.
2. Application of research outputs in different fields, similar tasks in power sector or other related industrial sectors.

Since European energy market integration is continuous process there are and will be many related challenging issues. Integration means unification of methodological approach, technical and economic problems that needs to be solved. To be more specific, for example massive penetration of electro mobility will lead to structural changes through whole power sector since it requires strengthening of distribution networks. This is strongly related to economic issues, tariffs structures etc. One of the biggest structural changes is growth of decentralized power production. This requires more flexible approach to power grid operation and management resulting in more sophisticated, smart approach. Production and consumption will be controlled on online basis with higher flexibility of control mechanisms. Big changes are related to the so-called demand side management where customers' consumption will be remotely controlled. To achieve this stage of development, a massive investment into infrastructure must be made. Mentioned issues bring many research opportunities.

Structural changes in European power sector are, among-others, driven by aims which are defined by five pillars of European Energy Union. Besides aforementioned energy market integration, structural changes depend on the security of supply policies, improvement of energy efficiency, reduction of emissions and technological innovation. European Union imports 53 % of its energy and the target of improving energy efficiency is set to 27 % by the year 2030. Target for greenhouse gas reduction is set to 40 % by 2030 and there is a strong intention of supporting low-carbon technologies. These changes open many research opportunities, including economic efficiency issues.

Research conducted on the issues from power sector can be partially applied in other sectors. Moreover, there are many interdisciplinary research questions. Research presented in this thesis is mainly connected with electric power sector. Many research outcomes, mainly in the area of market integration, can be also applied in gas sector. Currently, European gas market development is several years behind the development of electricity markets. Results of economic research from the power sector is, among others, used for forming of new legislation and strongly related regulation. Some principles of regulation are common through all network industries. Research performed for energy markets can be partially modified or applied on market with water or telecommunication services.

One of the major problem of European electricity markets is the fact that prices does not give proper signals for investors and consumers. Subventions are artificially decreasing electricity price from particular power sources. This situation begun with subventions of renewable power sources and finished with subventions of coal power plants considered as very non-ecologic sources. Current state of power sector became similar to the agriculture sector in Europe. Electricity market prices are biased and very high uncertainty makes long-term investments unattractive for private investors until they receive governmental guarantees. Improvement of support schemes must be done in order to achieve competitive environment attractive for private investments, maintain the sustainability of power sector and achieve the highest efficiency. This is very important field of future research that requires deep analysis and proposal of widely-accepted methodology which is currently missing. Changes in

power sector directly or indirectly affect many aspects of society and so-called externalities are another possible research opportunity.

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APPENDIX

INNOVATIVE DEFAULT PREDICTION APPROACH

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Innovative default prediction approach

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ABSTRACT

This paper introduces a new scoring method for company default prediction. The method is based on a modified *magic square* (a spider diagram with four perpendicular axes) which is used to evaluate economic performance of a country. The evaluation is quantified by the area of a polygon, whose vertices are points lying on the axes. The axes represent economic indicators having significant importance for an economic performance evaluation. The proposed method deals with magic square limitations; e.g. an axis zero point not placed in the axes origins, and extends its usage for an arbitrary (higher than 3) number of variables. This approach is applied on corporations to evaluate their economic performance and identify the companies suspected to default. In general, a company score reflects their economic performance; it is calculated as a polygon area. The proposed method is based on the identification of the parameters (axes order, parameters weights and angles between axes) needed to achieve maximum possible model performance. The developed method uses company financial ratios from its financial statements (debt ratio, return on costs etc.) and the information about a company default or bankruptcy as primary input data. The method is based on obtaining a maximum value of the Gini (or Kolmogorov–Smirnov) index that reflects the quality of the ordering of companies according to their score values. Defaulted companies should have a lower score than non-defaulted companies. The number of parameter groups (axes order, parameters weights and angles between axes) can be reduced without a negative impact on the model performance. Historical data is used to set up model parameters for the prediction of possible future companies default. In addition, the methodology allows calculating the threshold value of the score to separate the companies that are suspicious to the default from other companies. A threshold value is also necessary for a model true positive rate and true negative rate calculations. Training and validation processes for the developed model were performed on two independent and disjunct datasets. The performance of the proposed method is comparable to other methods such as logistic regression and neural networks. One of the major advantages of the proposed method is a graphical interpretation of a company score in the form of a diagram enabling a simple illustration of individual factor contribution to the total score value.

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1. Introduction

The term *magic square* (see Fig. 1) was firstly used in macroeconomics by a German economist and former minister of finance Karl Schiller (Medrano-B & Teixeira, 2013). A magic square is a diagram with four perpendicular axes on which are depicted country main macroeconomics indicators – gross domestic product (GDP), growth rate, consumer price inflation rate, unemployment rate

and a balance of trade to a GDP ratio (Fialová, 2006). The area of a quadrangle is used for a relative comparison between countries. The higher quadrangle area, the better economic performance of the examined country. The idea of economic performance evaluation based on the stated indicators was introduced by Nicolas Kaldor (born Miklós Káldor), Hungarian economist (Kaldor, 1971).

This chart (Fig. 1) is a special case of a spider (radar) chart, where the number of axes can be higher than four. The disadvantage is that the axes do not have the zero point in the intersection and a quadrangle area varies with a zero location on each axis. The example of another disadvantage is that the consumer price inflation rate below zero (deflation) is not desirable (Pontiggia, 2012), but the quadrangle area is growing in this case.

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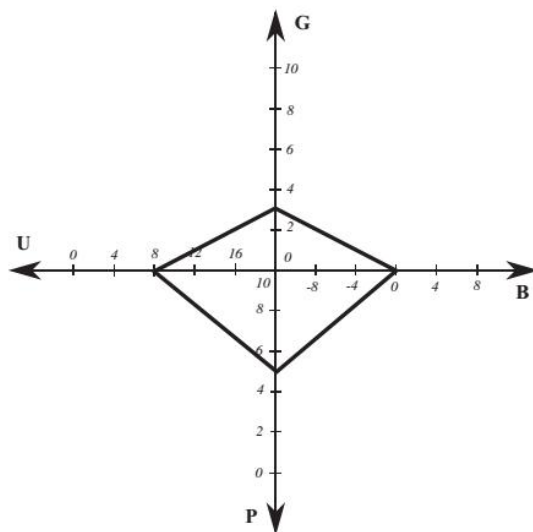


Fig. 1. Example of Magic Square (G - GDP growth rate, U - unemployment rate, P - inflation rate, B - trade balance), all numbers are in percentages.

A similar principle of evaluation and comparison can be used also in case of companies. There are several axes with performance indicators (Fig. 2). A company with a larger polygon area has better performance (is rated higher) than a company with a lower polygon area. To avoid the above stated disadvantages, all axes have the same origin (zero point) and the values are transformed to the numbers in a 0–1 interval according to “the higher, the better” principle. The final polygon area is used as a company score in the same way as Altman did in his original work (Altman, 1968).

An Altman's innovative approach lay in applying a discriminant analysis on the data and the use of multiple variables for predicting a company default. Many other approaches based on multivariate regression, well described in Bishop (2006), have been used since that time. Default prediction techniques are very important for the banks that need the risk estimation of debtors. Logistic regression is mostly used in a bank sector for the probability of default estimation and is recommended to use by BASEL2.¹ For the default prediction, researchers have focused mostly on machine learning (closely related to statistics) algorithms recently. A new feature selection (FS) boosting procedure (Wang, Ma, & Yang, 2014) was introduced. Feature selection eliminates features with small predictive power, reduces dimensionality of feature space and removes irrelevant data. Boosting is a machine-learning algorithm for reducing variance and bias in supervised learning. FS-Boosting combines these two approaches and results in an alternative method for bankruptcy prediction. Genetic algorithms are being improved. The author in Kozeny (2015) introduces a new fitness function based on a variable bitmask. Research in the field of support vector machines (SVM) also moved forward and the clustered SVM were used in credit scoring (Harris, 2015). The advantage of clustered SVM lies in good performance and low computational complexity. The improvement of machine learning algorithms or innovative approach in their usage are evident in current research, where adaboost (Heo & Yang, 2014) genetic algorithms (Gordini, 2014) and neural networks (López Iturriaga & Sanz, 2015) are being used in the field of bankruptcy prediction. The dynamic models considering the time

¹ Recommendations on banking laws and regulations issued by the Basel Committee on Banking Supervision.

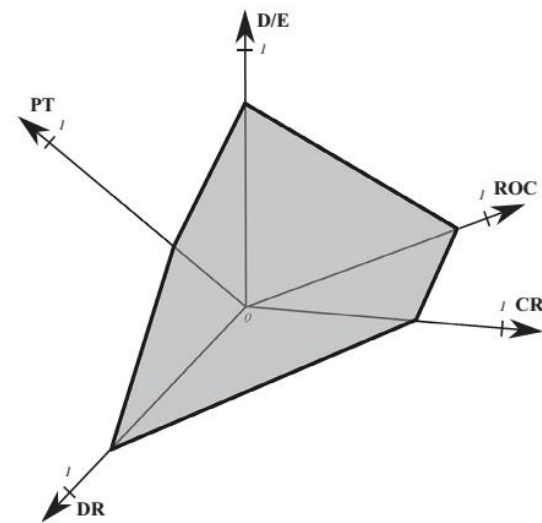


Fig. 2. Example of the diagram for the company. The grayed area represents a company score. (PT – payables turnover, D/E – debt to equity, ROC – return on costs, CR – current ratio, DR – debt ratio).

development of indicators are also represented by terminal failure processes (du Jardin, 2015). These models have better prediction performance in a long term. Improving prediction accuracy and identification of relevant predictive variables were two main objectives of the Least Absolute Shrinkage and Selection Operator (Tian, Yu, & Guo, 2015). Modern approach leads to often-complex technical improvements of machine learning methods.

A unique contribution of this paper is in the application and adaptation of macroeconomic approach (a magic square) in the field of company default prediction. The quadrangle is extended to a general polygon. In addition, the adjustment of angles between polygon axes, indicator weights and a scaling factor is innovative and here introduced parameters are easily imaginable in comparison to the parameters used in the above mentioned methods. The area of a polygon directly quantifies a risk factor in comparison to the magic square whose area could be used only for a relative comparison between countries. An easily adaptable system on different knowledge and databases provides a high-class approach for the bankruptcy prediction and overall economic company evaluation. Finally, yet importantly, a graphical interpretation helps in a quick orientation in the field of company risk factors and overall risk assessment.

An ideal scoring method evaluates each defaulted² company³ by a score value lower than any non-defaulted company. It leads to an ordering performance evaluation of the scoring method quantified by the Gini and Kolmogorov–Smirnov indices. Another possible method is to find out the score threshold value, which means that the companies with the score below this value are treated as default and the companies with score above this value are treated as non-default. Subsequently, the true positive rate (sensitivity) and true negative rate (specificity) can be calculated. The threshold value discovery is inescapable for the default prediction. The difference between this scoring approach and classification models such as logistic regression or neural network is that Gini and Kolmogorov–Smirnov

² The definition of the defaulted company varies. It can be either a company which is not able to fulfil its obligations in a specified time (e.g. 90 days) or a bankrupted company. However, it can be neglected as this paper aims at presenting a new scoring method.

³ A company is not defaulted in the time of evaluation.

indices will be used as an objective function as well as the measurement of a model ordering performance.

There are three groups of parameters affecting the polygon area (score).

- (1) Order of axes. The area of the polygon created by more than three indicators depends on the order of axes.
- (2) Angles between axes. It is not necessary that the axes are perpendicular like in Fig. 1. The only requirement is that the sum of all angles must equal to 360°. The polygon area varies with changing the angles between the axes.
- (3) Weight of indicators. Each indicator's value is between 0–1. The weight can be any non-negative number which the indicator value will be multiplied by.

The main goal of this work is to achieve a maximal Gini and Kolmogorov–Smirnov index value by changing the parameters. Another goal will be to find out the threshold value for the possibility of default prediction. This work also tries to find the answer on the following questions.

- (1) Does the order of axes have significant impact on Gini and Kolmogorov–Smirnov index values?
- (2) Is the performance of this scoring method competitive with other methods, such as logistic regression or neural networks?
- (3) Is it necessary to change all groups of parameters or weights, or the angles can remain constant?

The following scenarios will be evaluated.

- A. Order of indicators will be determined, other parameters remain constant.
- B. The weights will have the identical constant value. The order of the indicators and angles between their axes will be determined.
- C. The angles will have the identical constant value. The order of the indicators and their weights will be determined.
- D. All the parameters will be determined (order, weights, angles).

The process of data mining, data preparation and variables selection will not be covered due to the fact that it is a complex issue and it is not the aim of this paper. The indicators that enter the calculation are calculated from publicly available data.⁴ The proposed method will be trained and validated on disjunct datasets. Training in this context means to find out the values of parameters (order, weights and angles) that meet the constraints and achieve a maximal Gini (or Kolmogorov–Smirnov) index value. Validation is the process where the values of parameters obtained in the training phase are applied on the data that are not the part of the training dataset. Gini and Kolmogorov–Smirnov index values from training and validation phases will be compared. In case the drop of values between training and validation data sets will not be significant,⁵ one can say that the used method does not fit the training data and can be used in a general analysis. The results will be compared with other widely used methods.

⁴ There is plenty of data sources and information about the companies. Some countries (such as the Czech Republic, Slovakia and a few others European countries) have publicly available financial statements of all registered companies free of charge. There is also public insolvency register, debtors register and other free of charge or paid sources. Data gathering differs from country to country and depends on provided data exchange interfaces. This process is time consuming and requires advanced computer knowledge. Due to this fact, it is possible to order the aggregated data from specialized companies or institutions.

⁵ Significance is a relative term in this context and the difference in values will be compared with differences in other methods.

2. Methods

Data entering training and validation processes represents financial ratios from the financial reports (DR – debt ratio, D/E – debt to equity, ROC – return on costs, CR – current ratio, PT – payables turnover) and information whether a company defaulted in one year. The training dataset size is done by 459 observations with 33% of defaulted companies; a validation dataset has 2 661 observations with 2.5%⁶ of defaults. Financial ratios are input variables, and default information is a dichotomous target variable.

2.1. Performance evaluation

The scoring model performance will be evaluated by Gini and Kolmogorov–Smirnov indices. These two statistics are based on the measurement of model performance and accuracy not only within company evaluation, but generally in binary classification.

2.1.1. Gini index

A Gini index was firstly applied in economics as a measurement of inequality in income distribution. It was developed by an Italian statistician Corrado Gini (Gini, 1912) and it is usually defined mathematically from the Lorenz curve. The measurement of an income distribution inequality problem was further well elaborated by Dalton (1920).

The Lorenz curve in Fig. 3 says that the poorest 50% of population has 13% of all incomes. A company scoring model, where the companies are ordered by the score in a “lower is better” order (e.g. default probability), states that there was 13% of defaulted companies among 50% of non-defaulted companies. Generally, one can use sensitivity⁷ and specificity⁸ of any binary classification. The graph turns into a receiver operating characteristics (ROC) graph, in which the axes are swapped. Fig. 4 shows a cumulative accuracy profile (CAP).

A Gini index value for the calculation of income equality was defined as a proportion of an area A (an area between the diagonal and Lorenz curves) and the whole area under the diagonal (A + B), see Fig. 3. The extreme case when one person has all incomes leads to a 100% Gini value. For a scoring model assessment, the Gini index can be calculated (Irwin and Irwin, 2012) as a portion of the area between a random model line and a CAP curve and the area between a random model line and a perfect model line from Fig. 4. It is equivalent to 2AUROC-1 from the receiver operating characteristics⁹ and this value is the same as the area 2A in Fig. 3. Not only the Gini value, but also the shape of ROC and CAP curves are important.

The following equation demonstrates the Gini index calculation for the scoring model. Companies are divided into two sets (D – defaulted, N – non-defaulted). The Cartesian product of these sets is a set of score pairs. For each pair, when the element from a D set has a lower score than the element from N set, the contribution is positive,¹⁰ and vice versa. The result is then divided by the number of pairs. The meaning is that if all defaulted companies have a lower score than all non-defaulted companies, the model is perfect and the Gini index is 100%. The Gini will be equal or close to zero in case of a random model.

⁶ The real default rate in observed population. It looks like a very small portion but it is still 30 % of all defaults available. Learning from imbalanced data is a complex issue (He & Garcia, 2009) and a 33 % default rate in the training dataset was achieved by using a random subsample of non-default data.

⁷ True positive rate. Probability of a positive test if the condition is present.

⁸ True negative rate. Probability of a negative test if the condition is not present.

⁹ AUROC – Area Under Receiver Operating Characteristics.

¹⁰ Depends on an ordering logic – a higher score is better or lower score is better.

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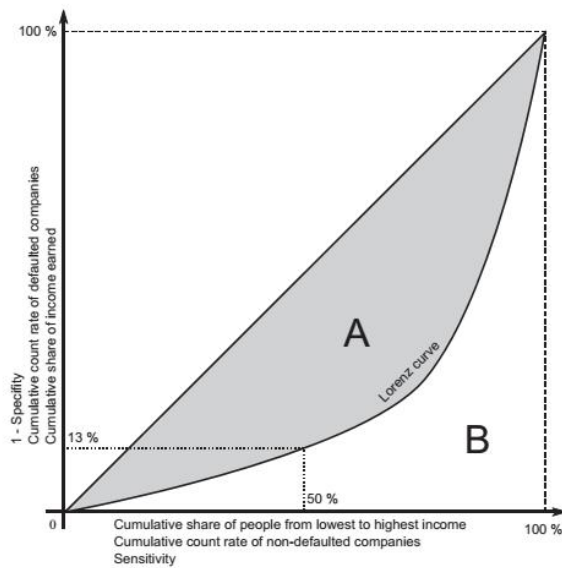


Fig. 3. Lorenz curve – the curve between areas A and B.

$$Gini = \frac{\sum_{(i,j): D_i < N_j} 1 - \sum_{(i,j): D_i > N_j} 1}{\#D \cdot \#N} \quad (1)$$

D – a score set of defaulted companies, N – a score set of non-defaulted companies, $\#$ – a number of elements in the set

2.1.2. Kolmogorov–Smirnov index

The Kolmogorov–Smirnov index is the maximum difference between two cumulative distributions. Fig. 5 shows the cumulative count rate of defaulted and non-defaulted companies ordered by a score. The Kolmogorov–Smirnov index value is represented by the maximum difference (a vertical gap) between the cumulative distributions graphs.

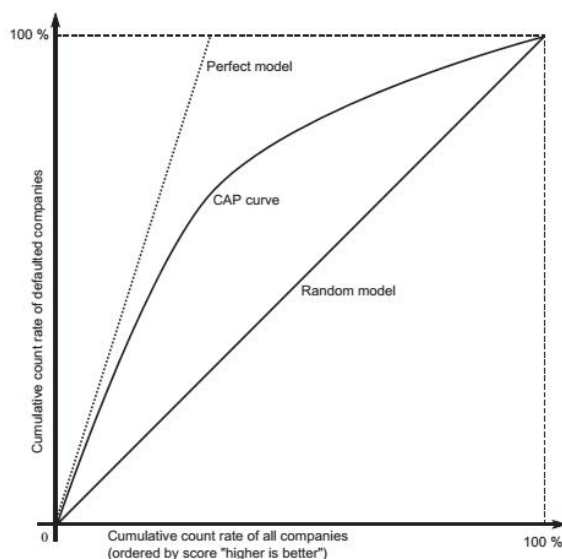


Fig. 4. CAP curve.

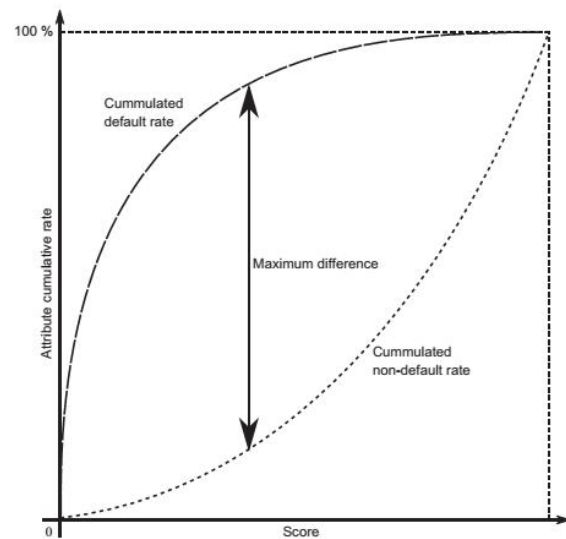


Fig. 5. Kolmogorov–Smirnov Index.

$$KS = \max |C_{D,S} - C_{N,S}| \quad (2)$$

$C_{D,S}$ – cumulated count rate of defaulted companies up to a specific score value

$C_{N,S}$ – cumulated count rate of non-defaulted companies up to a specific score value

The scoring model with high accuracy and predicting power has a higher Kolmogorov–Smirnov index value because defaulted companies have a lower score than non-defaulted companies. Most of the defaulted companies are cumulated in the area of a low score and non-defaulted companies are cumulated in the area of a higher score. For more detailed information about the usage of the Kolmogorov–Smirnov index in an ROC curve see (Bradley, 2013).

2.2. Financial ratios

Financial ratios were selected according to several criteria. The Gini index for the ratio was calculated to separate the variables with weak and strong prediction power. The correlation between the variables was also considered as it is not desirable to have strongly correlated input data. Financial ratios can be divided into the four groups: profitability ratios, liquidity ratios, activity ratios and debt ratios. The requirement was to have at least one ratio representing each group to achieve a complex view on the companies. More detailed information about the financial ratios and their selection and usage in a company failure prediction is described in Delen, Kuzey, & Uyar (2013), Xu, Xiao, Dang, Yang, & Yang (2014).

The debt ratio is a member of a debt ratio group formed by the debt-to-equity ratio, debt service coverage ratio, capitalization ratio, interest coverage ratio etc. It is the ratio between company total liabilities and total assets. The debt-to-equity ratio is the ratio between company total liabilities and equity. These two indicators are highly important in the default prediction because a high debt value has a significant impact on the ability of a company to service the debt.

The Return on Cost belongs to profitability ratio family. It is the ratio between the company profit and costs. This ratio expresses

how high profit was brought by each invested money unit. Other profitability ratios are return on assets, return on equity, return on capital and others.

The Current Ratio belongs to the group of liquidity ratios. Liquidity ratios measure the availability of cash (or high liquid assets) to cover the debt. The current ratio (also called the working capital ratio) is the ratio between current assets and current liabilities.

Accounts Payable Turnover Ratio, or simply the payable turnover, is a member of activity ratio group. It is the ratio between total revenues and payables. This indicator shows how many times per period the company pays its payable amount. The activity ratios measure the effectiveness of the resource utilization.

2.3. Scoring methods

The new proposed method was compared to the results from the Altman score calculation, logistic regression, neural networks and memory based reasoning. Logistic regression, neural network with three hidden units and memory based reasoning calculation were performed using an SAS software implementation. Above mentioned algorithms are explained in this section.

2.3.1. Altman score

The first widely used company scoring model was introduced by Altman (1968) who applied a statistical method of the discriminant analysis on a set of manufacturing companies. The result (Z-Score) is a linear combination of five financial statement indicators.

$$Z = 1.2T_1 + 1.4T_2 + 3.3T_3 + 0.6T_4 + 0.999T_5 \quad (3)$$

T_1 = Working Capital/Total Assets

T_2 = Retained Earnings/Total Assets

T_3 = Earnings Before Interest and Taxes/Total Assets

T_4 = Market Value of Equity/Book Value of Total Liabilities

T_5 = Sales/Total Assets

If the score falls below 1.8, it means that the company default is probable; the score between 1.8 and 3.0 is a gray zone and the companies with a score above 3.0 are not likely to default. The problem for the binary classification occurs in a large group of companies which fall into a gray zone. For purpose of calculations, these companies will be treated as non-defaulted.

The coefficients used in the Altman score calculation may differ between the economy sectors and countries. Here presented values are the results of the Altman calculation on the group of manufacturing firms.

2.3.2. Logistic regression

The logistic regression (Greene, 2003), often applied in economy, simply refers to the decision function represented by a sigmoid. The training refers to estimating the sigmoid parameters by a maximum likelihood approach.

2.3.3. Neural networks

There are several different types of artificial neural networks commonly used in a pattern recognition area (Bishop, 1995). The simplest neural network is a linear perceptron, for which a perceptron training rule with a training rate 0.1 was used.

Another very simple feedforward neural network with only one unit in the hidden layer was used. The training was performed by the Levenberg–Marquardt procedure (Bishop, 1995). This popular algorithm is used because of its relatively high speed and is highly recommended as a first-choice supervised algorithm by the Matlab Neural Network toolbox. Both the hidden and output neurons use

the sigmoid function. The mean squared error was minimized and the training was stopped after one training epoch representing all the training samples.

Slightly more complex feedforward network was the back propagation network with two hidden units (Bishop, 1995). For this network, the training was stopped after the number of training epochs had exceeded 50 or if the error gradient reached 10^{-6} . The back propagation algorithm with a momentum and adaptive learning rate was used. The momentum parameter was 0.95. The learning rate was initially 0.01 and was multiplied by factor 1.05 or 0.7, if the error increased or decreased more than by 4%, respectively. Another neural network used was the radial basis function network with 92 Gaussian basis function units. The calculation was also performed for the back propagation neural network and radial basis neural network with three hidden units. The learning rate was set to 0.1 and the momentum rate was equal to zero.

Finally, a support vector machine, which can be also understood as a neural network, was applied. A version with a linear kernel, whose advantage lies in a reasonable computational time, was chosen. Its training procedure uses quadratic programming to maximize so called margin around the decision boundary (Heijden, 2004).

2.3.4. Bayesian models

Bayesian classifiers use Bayes theorem to compute a posteriori probability of each class from conditional probabilities (likelihoods) and class prior probabilities (Duda, Hart, & Stork, 2000). The feature vector is further assigned into the class that maximizes a posteriori probability. The uniform prior probabilities were considered here. The true conditional probability distributions are not known and must be estimated from the training data. Several different types of this estimation corresponding to different types of the Bayes classifier were used:

- The Naive Bayes Classifier uses conditional independency of particular input features, which enables computing the total conditional density by a simple multiplication of separate conditional densities. The separate conditional densities were supposed to follow multivariate multinomial distribution which is appropriate for the categorical features.
- The Linear Bayes Classifier assumes normal conditional densities with equal covariance matrices, which leads to linear decision boundaries. The parameters of the normal densities are estimated using the sample means and a covariance matrix. For this classifier, an Adaboost combination of 40 linear Bayes classifiers was also used (Freund & Schapire, 1999). A weighted voting procedure was used to aggregate the weak classifiers.
- Quadratic Bayes assumes normal conditional densities with unequal covariance matrices, which leads to quadratic decision boundaries. The parameters of the normal densities are estimated using the sample means and covariance matrices.
- A Mixture of a Gaussians based Bayes classifier models the conditional density as a mixture of Gaussians. In the underlying experiments, the mixture of only two Gaussians is considered.

2.3.5. Decision trees

A C4.5 decision tree classifier was used with a pessimistic (top-down) pruning defined by Quinlan (1996). Splitting (creation of branches) was based on the change of the Gini index, which is a natural choice for the underlying task. If the change in the Gini index was less than a threshold, the split was not performed, which leads to smaller trees and can prevent overfitting.

A more complex decision tree-based method is the Breiman's decision forest, which averages the response from 50 decision trees, each trained on a bootstrapped version of the training dataset. In each node of the tree training, during the splitting procedure, only one randomly selected feature is considered (Breiman, 2001).

2.3.6. Memory based reasoning

Two particular memory-based classification methods were applied. First, the k-nearest neighbor classifier simply finds three training data instances that are the most similar to the testing instance and assigns the instance into the most common class amongst the three nearest neighbors. The Euclidean distance is used for similarity quantification, because it was observed to lead to good classification accuracies while keeping reasonable computational requirements (Marinaki, Marinakis, Doumpos, Matsatsinis, & Zopounidis, 2008).

Another memory-based method is the nearest mean classifier that assigns an observation according to its nearest class mean.

2.3.7. Evolutionary approach

Genetic algorithms (GAs) (Holland, 1975) are stochastic iterative optimization methods based on the principles of natural evolution. They maintain a population of candidate solutions, which are recombined and mutated to create a new generation of potential solutions. These solutions then compete with their parents and among themselves: better solutions survive to the next generation.

Genetic programming (GP) (Koza, 1992) is an extension to GAs. The purpose of GP is to evolve computer programs, mathematical expressions, and other similar structures. Grammatical Evolution (GE) (Ryan, Collins, & Neill, 1998) is a particular type of a GP algorithm allowing the user to prescribe the structure of all potential solutions (programs, expressions, etc.) with a context-free grammar (CFG).

The goal of the GE method is to evolve a function of five variables (i.e. the economic indicators of a company) so that it could be used as a company score (and later to predict a company default). Besides the five above-mentioned variables, the used CFG contains two constant terms (+1 and −1) and some operators and functions: addition, subtraction, multiplication, division, unary minus, natural exponential (e^x) and natural logarithm ($\ln x$).

The maximum depth of the derivation tree in the initial population was limited to 12. The population size of 1000 was used and the algorithm ran for 50 generations. Crossover, mutation, pruning and duplication probabilities were 0.8, 0.05 (per codon), 0.1 and 0.1. Wrapping the GE genotype was not allowed during the decoding process.

The experiment was executed twice, once with GINI as a fitness and once with a KS index. In order to lower the possibility of overfitting, the training dataset was split into two disjoint subsets, A and B, of an equal size. The split was random but preserving the class ratio (i.e. the halves of the first class and the second class separately). The evolution was performed by the fitness (GINI or KS) on a subset A, i.e. the selection and elitism work with respect to this measure. On the other hand, the so-called best-so-far solution was maintained with respect to the fitness on a subset B.

Since GE is inherently stochastic, the algorithm was executed 96 times per experiment, each time with a different seed of the pseudo-random number generator. Our results are presented in the form of statistics over these 96 runs, on both training data (the full training set) and the testing data.

3. Proposed method

The principle of scoring by this method lies in the computation of a polygon area as stated in the Introduction section. All the input parameters are financial ratios. These ratios can have the values from the interval $(-\infty; +\infty)$. The ratio values can be very high if the denominator in the ratio formula is close to zero. Due to this fact, the cut-off values were used to set the maximum ratio value. Then the values were standardized using Eq. (4) and normalized to a 0–1 interval by using logistic function (5). Standardization is a

Table 1

Results for the scenario A. The maximum and minimum values are marked in bold.

Order	Gini train	Gini validation	KS train	KS validation
12345	0.3984	0.2804	0.3268	0.2708
12354	0.4016	0.2888	0.3268	0.2735
12435	0.3992	0.2788	0.3170	0.2658
12453	0.4003	0.2893	0.3333	0.2758
12534	0.4021	0.2862	0.3203	0.2489
12543	0.3997	0.2806	0.3268	0.2509
13245	0.3994	0.2878	0.3301	0.2766
13254	0.4011	0.2801	0.3268	0.2585
13425	0.3986	0.2791	0.3301	0.2490
13524	0.4010	0.2833	0.3235	0.2570
14235	0.4009	0.2918	0.3268	0.2716
14325	0.4004	0.2845	0.3268	0.2509

process where the output data has its mean value equal to zero and the standard deviation equal to one.

$$z = \frac{x - \mu}{\sigma}, \quad (4)$$

z – standardized variable, x – ratio value, μ – arithmetic average, σ – standard deviation

$$a = \frac{1}{1 + e^{-z}}, \quad (5)$$

a – standardized and transformed ratio value, z – standardized ratio value.

The final polygon area calculation is described by Eq. (6), where the polygon is divided into N triangles and the area is the sum of the triangle areas.

$$S = \sum_{i=0}^{N-1} \frac{a_i \times a_{(i+1) \bmod N} \times \sin \alpha_i \times w_i}{2} \quad (6)$$

N – vertex count (equal to 5 in this calculation), a_i – value on i th axis, α_i – angle between consecutive axes, w_i – weight

The NMaximize function, which is the part of Mathematica software, was used to perform a maximization process. Model parameters (weights, angles, axis order) were changed in order to maximize the value of the Gini and Kolmogorov–Smirnov indices.

The simplest calculation scenario configuration was when the angles were equal to $360^\circ/5 = 72^\circ$, weights were equal to one and the order of parameters was changing. The order of parameters can be determined by cyclical permutations¹¹ from the order of five axes. There are 12 cyclical permutations $\{[1, 2, 3, 4, 5], [1, 2, 3, 5, 4], [1, 2, 4, 3, 5], [1, 2, 4, 5, 3], [1, 2, 5, 3, 4], [1, 2, 5, 4, 3], [1, 3, 2, 4, 5], [1, 3, 2, 5, 4], [1, 3, 4, 2, 5], [1, 3, 5, 2, 4], [1, 4, 2, 3, 5], [1, 4, 3, 2, 5]\}$ which were evaluated. The maximization was done for the Gini and Kolmogorov–Smirnov indices separately. Each calculation scenario resulted in two result sets. The calculations for other scenarios were analogous, but there were more changing variables. These scenarios were already described in the Introduction section.

4. Results and discussion

Table 1 shows the results for both Gini and Kolmogorov–Smirnov (KS) index optimizations in the scenario A (as presented in the Introduction section). It is obvious that the parameters order does not have a significant impact on the Gini and KS index values. The maximum and minimum values are highlighted. The difference between maximum and minimum values are 1.3% in case of Gini and 2.7% in case of KS indices.

¹¹ Cyclical permutations can be used because the score (a polygon area) for the axis order $[1, 2, 3, 4, 5]$ is the same as $[2, 3, 4, 5, 1]$.

Table 2

Results for scenarios B, C, D. The first part is the result of the Gini maximization and the second part is the result of the Kolmogorov–Smirnov index maximization.

Sc.	Order	Weights						Angles				Gini train		Gini validation	KS train	KS validation
D	12534	3.7	2.1	3.9	5.5	4.2	40.0	29.4	127.6	64.6	98.4	0.4148	0.3133			0.2979
B	12534	1	1	1	1	1	18.7	8.6	120.8	95.7	116.2	0.4163	0.3155			0.3006
C	12534	6.5	1.8	4.3	9.1	5.3	72	72	72	72	72	0.4146	0.3135			0.2841
D	14325	10.0	9.0	8.0	6.7	0.3	54.3	1.0	69.7	180.0	55.0		0.2938		0.3529	0.2998
B	13254	1	1	1	1	1	106.0	14.7	92.0	116.6	30.7		0.2884		0.3464	0.3028
C	12345	9.1	7.9	7.5	9.1	0.6	72	72	72	72	72		0.2863		0.3497	0.3080

The results (a validation part in Table 2) are close to each other, thus it is not necessary to search for the values of all three groups of variables (order, weights, angles), and one group can stay constant with the equal values. This is very important for the calculation time which was about several hours up to one day in case of the determination of all parameters. The maximization of the Gini index also leads to very good results for the KS index. This is obvious from Table 2, where KS values are the same in case of the Gini maximization and KS maximization. On the other hand, the maximization of the KS index does not lead to the highest possible values of the Gini index. The second part of Table 2 shows that the Gini index values are 2–3% lower than the values obtained by the Gini maximization.

The configuration with the parameter order [1, 2, 5, 3, 4], angle values (18.7°, 8.6°, 120.8°, 95.7°, 116.2°) with all weights equal to one is the best and results in 31.6% for the Gini index value and 30.1% for the KS index value.

Figs. 6 and 7 show the sensitivity and specificity based on a threshold level. The threshold is the score value that separates defaulted and non-defaulted companies. This threshold level can be set according to the requirements on a true positive rate (sensitivity) and true negative rate (specificity). This level does not affect Gini or KS indices. Increasing sensitivity means decreasing specificity and vice versa. The setup of the threshold value can also be used in other binary classification tasks.¹²

4.1. Comparison with other methods

Following table shows the comparison between the ordering performance of a newly proposed method with the methods where the calculation was performed by SAS software (see Table 3).

A brief comparison of other results achieved by Matlab software is shown in Table 4.

The best results for the grammatical evolution were achieved by maximizing the Gini index. The KS index maximization resulted in lower performance for both Gini and KS values similarly to the proposed method, where this behavior was also present. The median values from all runs are presented in Table 5.

It is obvious that proposed method performance is competitive to other methods.

4.2. Advantages and limitations

Advantages of the proposed method were partially discussed in the Introduction section. The main advantages are the graphical interpretation, exact risk assessment by the area of a polygon, easy orientation in the results and scalability to another set of tasks such as benchmarking. In addition, the proposed method also

¹² The problem can occur in such an interpretation where the score is represented by the default probability (e.g. in logistic regression). In this case, the logical threshold value should be 50 % and the companies with the default probability higher than 50 % should be interpreted as default companies, and those having the probability lower than 50 % as non-default companies. Despite of this, it is not necessary to be in compliance with this logical fact, and the threshold value can be moved to the level where the sensitivity and specificity are acceptable for the given task.

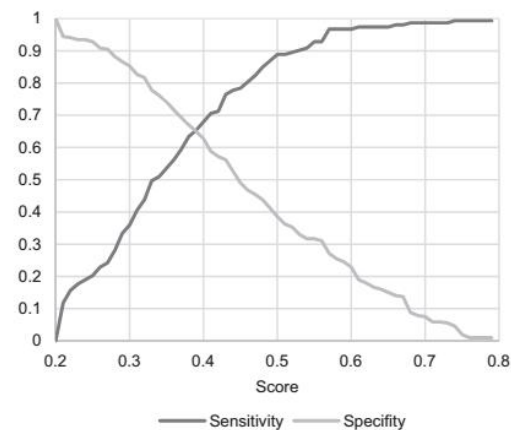


Fig. 6. Sensitivity and specificity, dependent on a threshold score value, calculated on a training set.

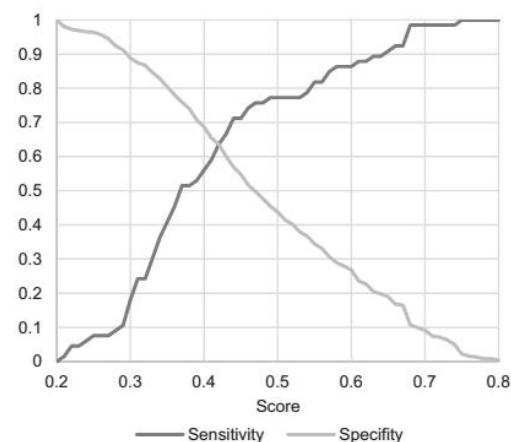


Fig. 7. Sensitivity and specificity, dependent on a threshold score value, calculated on a testing set.

Table 3

Comparison with widely used methods in the company default prediction.

Method	Gini train	Gini validation	KS train	KS validation
Proposed (Scenario B)	0.416	0.312	N/A	0.301
Altman	N/A	0.207	N/A	0.248
Logistic Regression	0.420	0.301	0.317	0.299
Neural Network (Back Propagation 3H)	0.454	0.291	0.337	0.292
Neural Network (Radial Basis 3H)	0.508	0.265	0.412	0.225
Memory Based Reasoning (K-Nearest Neighbors)	0.422	0.199	0.340	0.216

Table 4
Comparison with other classification methods.

Method	Gini train	Gini validation	KS train	KS validation
Linear perceptron	0.2507	0.1621	0.0065	0.0314
Neural Network (Back Propagation 2H)	0.3907	0.3076	0.3072	0.2644
Neural Network (Radial Basis)	0.7552	0.2032	0.5392	0.2043
Neural Net (Levenberg–Marquardt)	0.4129	0.3017	0.3203	0.3084
Support Vector Machine	0.3566	0.2594	0.3203	0.2579
Naive Bayes	0.4185	0.2869	0.3268	0.2706
Linear Bayes	0.4192	0.3043	0.3333	0.3069
Adaptive Boosting	0.3989	0.2681	0.3301	0.2979
Quadratic Bayes	0.4330	0.2702	0.3366	0.2835
Mixture of Gaussian and Bayes	0.4625	0.2316	0.3464	0.2855
C4.5 Decision Tree	0.2712	0.2036	0.2810	0.2537
Random Forest	0.3043	0.2020	0.2908	0.1919
Scaled Nearest Mean	0.4008	0.2853	0.3333	0.2658

Table 5
The results for the grammatical evolution.

Method	Gini train	Gini validation	KS train	KS validation
Grammatical evolution	0.4035	0.3023	0.3148	0.2869

simplifies the comparison of the results for different companies including the trends. Theoretically, the optimization process leads to an optimal solution, which can result in omitting some of the parameters. When the parameter weight is low, or the angle between the axes of two parameters is very small, one (or more) parameters can be excluded from the model without any significant impact on the model performance. The optimization process thus identifies the variables that do not contribute significantly to the quality of the model. The main drawback of the proposed method, when compared to other widely used approaches, is the absence of a reasonable optimization procedure in terms of computational complexity. The maximization of the Gini (or KS) index does not have an analytic solution, as each iteration requires e.g. sorting and the Cartesian product of discrete variables. Moreover, in this method are used many possible configurations. All these factors result in a relatively long computational time; e.g. our task calculations took approximately one day. On the other hand, the performance of our proposed method is very good and its results can be comparable to other best resulting methods.

4.3. Research contribution and limitations

The main research contribution of this approach is the design of a new methodology for the company scoring assessment. The advantages and limitations of this approach were discussed in the previous sections. Current research is focused on the improvement of currently used complex machine learning algorithms. The approach presented here is innovative since the method, which is standardly used in macroeconomics, was applied on corporations. One can argue that the polygon area is a specific scoring function and basically there is nothing new. On the other hand, this area cannot be represented only by an abstract number (score), but it can be easily expressed (illustrated), and therefore its usability is extended. The application of the model on a large set of companies can result in searching for specific patterns that can be found in the polygon shape. These patterns could be identified and the relation between them and company assessment could be examined. If the

relation were found, not only the score matters, but also the shape can help reveal the economic difficulties of the companies.

The main limitation of the proposed scoring model can be found in the optimization section, which can lead to a long computation time. Here presented model is trained on the random set of companies from the Czech Republic, and therefore it reflects the specific conditions of the Czech economy and Czech accounting standards. If the models presented here were used on the companies from other countries, the results can be biased or suboptimal. In this case, a training phase is ideal to run on the data from the country for which the model will be used primarily. This will result in creating the model specific for the country, where the observed companies reside. Another limitation can show up when the companies from different countries are compared. To get the comparable results, the training phase should run on the mixed set of companies from different countries, or the accounting financial data should be transformed to the same basis. Then, the accounting data specific for the appropriate country, must be converted to IFRS.¹³ Further issue to solve is a different tax environment and some other country specific differences.

5. Conclusions and future research

The proposed method is not a standard classifier but it can be used in a very similar way as the classification algorithms. The performance of the proposed method is comparable to logistic regression, various neural networks models, Bayes classifiers, evolutionary algorithms etc. The methods with the highest performance achieve Gini and KS index values around 30% for the validation data set. This number is not high and is lower than expected in real scoring models. This is caused by the fact that the data quality is not ideal and deep data pre-processing was not the aim of this paper. The important thing is that the newly proposed method is as good as the competitive methods for here described classification task. An indisputable advantage of the proposed method lies in visualisation inspired by the magic square, which is often used in comparison between economies of different countries. The contribution of the presented method consists in the fact that the result of the company scoring can be depicted also by a diagram which shows the strength of individual factors influencing the final score and overall performance. The future work can be focused on finding a diagram shape typical for particular economy sectors and comparing individual companies with this generalized sector diagram. Moreover, more detailed analysis of the input data can be performed with aim to construct more suitable indicators. The indicators used in this paper are standard financial ratios, which are well known, but their information value can be lower than the complex indicators. On the other hand, complex indicators will not be as easily understandable as well-known and widely used financial ratios.

The method presented in this paper is innovative, and therefore the future research can lead to many modifications of this method. It would be interesting to understand whether the polygon configuration is stable in time or whether it will have to be recalibrated in the future. If the configuration changes, it would be very useful to predict these changes and find out the dependencies of the parameter changes on another indicator, such as GDP growth, or, more generally, on the macroeconomic situation of the specific environments of the countries, where the examined companies reside. Another research can lead to industry sector specific models. The training dataset could be taken from a specific industry sector and the model could be more precise in the assessment of the companies from this sector. In addition, the company

¹³ International Financial Reporting Standards.

benchmark tools can be developed for a relative comparison of companies from the same sector. This can lead to some industry specific input variables (reliability of electricity supplies within power distribution etc.). The presented method can bring an important improvement in identifying the “gray zone” companies, which is similar to a gray zone e.g. in the Altman models. There is a group of companies that have their score close to the threshold value (introduced for the proposed method). The prediction of the default of these companies is not very reliable and deserves future investigation. Another future research can lead to creating a dynamic model, where the inputs will represent the changes of variables in time, and not their absolute values. This approach is dependent on the data of high quality because one company has to be monitored for a longer period.

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MODELLING OF NUCLEAR POWER PLANT DECOMMISSIONING FINANCING

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MODELLING OF NUCLEAR POWER PLANT DECOMMISSIONING FINANCING

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Costs related to the decommissioning of nuclear power plants create a significant financial burden for nuclear power plant operators. This article discusses the various methodologies employed by selected European countries for financing of the liabilities related to the nuclear power plant decommissioning. The article also presents methodology of allocation of future decommissioning costs to the running costs of nuclear power plant in the form of fee imposed on each megawatt hour generated. The application of the methodology is presented in the form of a case study on a new nuclear power plant with installed capacity 1000 MW.

INTRODUCTION

Nuclear power plants over their lifetimes produce not only electricity but also nuclear waste that has to be safely processed and disposed of. It is also necessary to properly decommission many parts of the power plant itself since internal equipment becomes contaminated with radionuclides despite the presence of a comprehensive system of nuclear contamination barriers. Only the so-called nuclear island of nuclear power plants (NPPs) is subject of decommissioning activities. The conventional parts of NPPs are dismantled in the same way as in the case of conventional steam power stations. A number of countries have opted for so-called deferred rather than immediate decommissioning in which case the decommissioning of the nuclear island is conducted following a significant time delay. In accordance with the polluter pays principle (PPP), it is essential that future costs be included in current costs of power generation by nuclear power plants.

METHODS

Decommissioning methods

Decommissioning of an NPP's nuclear island typically includes decontamination, dismantling, demolition of nuclear island constructions and technical facilities, treatment, storage, transport, neutralisation of waste originating during decommissioning, the installation of protective barriers and the implementation of the various measures required in terms of the assurance of radiation protection and ground work at the site aimed at the eventual release of the site for other uses (Figure 1).

The International Atomic Energy Agency (IAEA) has defined three standard decommissioning strategies⁽¹⁾. Immediate decommissioning, deferred decommissioning where the NPP is defuelled and locked for about 30–60 y and entombment decommissioning where radioactive contaminants are encased in a structurally long-lasting material until the radioactivity decays to a level that permits release of the facility from regulatory control.

The advantage of immediate decommissioning lies in the lower risk associated with the future decommissioning costs and the retention of the 'site memory' of operational staff working at the NPP. The advantages of deferred decommissioning, conversely, lie in the natural decrease in the activity levels of irradiated structures and technological components, a reduction in the risk of radioisotope penetration into the environment and the simplification of decommissioning procedures.

Decommissioning of NPPs and radioactive waste

Radioactive nuclear waste produced during standard NPP operation is either released into the environment (if its activity level is lower than legal limit) or stored in waste storage facilities located within the respective NPP complex until its radioactivity level and other physical properties do not allow further processing and eventual emplacement in the nuclear waste repositories. A further source of radioactive materials arises from neutron activation and contamination of normally non-radioactive materials such as the body of the reactor vessel and steam generator.

The principal activation products present in reactor materials upon shutdown are ⁵⁵Fe, ⁶⁰Co, ⁵⁹Ni, ⁶³Ni, ³⁹Ar, ⁹⁴Nb, ³H, ¹⁴C, ⁴¹Ca, ⁵⁵Fe, ¹⁵²Eu and ¹⁵⁴Eu⁽²⁾. In

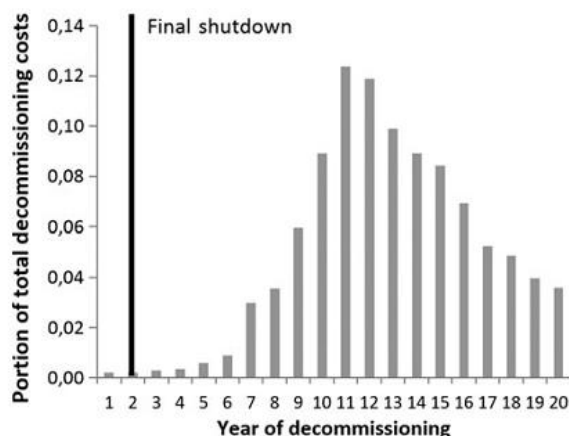


Figure 1. Time profile of decommissioning cost.

the case of steels, most of this activity decays over the following 50 y leaving longer-lived nickel, niobium and silver isotopes to dominate. As for graphite and concretes, short-term decay is dominated by ^3H , leaving the longer-lived ^{14}C , ^{41}Ca and ^{152}Eu isotopes to dominate in longer term^(1, 3).

The most abundant radionuclides still present in contamination residues 10–20 y following reactor shutdown generally include ^3H , ^{60}Co , ^{55}Fe and ^{137}Cs . After about 20–30 y, the most abundant radionuclides generally consist of ^{63}Ni , ^{137}Cs , ^{60}Co and ^{90}Sr . The long-lived transuranic actinides ^{241}Am , ^{238}Pu , ^{239}Pu and ^{244}Cm do not become significant parts of the radionuclide inventory until after around 100–200 y. Traces of ^{94}Nb are occasionally present, and ^{99}Tc and ^{129}I are generally not associated with residual contamination. However, it must be pointed out that fission product and actinide concentrations in residual contamination vary considerably from plant to plant^(4, 5).

As an example, it is interesting to consider ^{137}Cs and ^{90}Sr , and their impact on public health. Chemically, these elements have similar properties to stable Na and Ca. For example, according to UNSCEAR, the total ^{137}Cs contamination in the Czech Republic amounts up to several thousand kBq m^{-2} and was substantially higher following the Chernobyl accident.

Decommissioning cost

Assuming the specific value of NPP investment cost at $\sim 2000 \text{ EUR kW}^{-1}$ (as is the case of the Czech NPP Temelin), the amount of decommissioning cost can be estimated to be in the range of 15–20 % of NPP investment cost^(6, 7). The application of PPPs leads to a conservative approach to estimating decommissioning cost. The use of currently available technologies only can be assumed, and cost estimations should be based on the list of the various activities required and their current cost.

METHODOLOGIES USED FOR THE ASSURANCE OF DECOMMISSIONING FINANCING

Different countries employ a number of different PPP application methodologies with regard to the final disposal of spent fuel and the financing of NPP decommissioning. Naturally, this significantly complicates any evaluation of the competitiveness of individual NPPs when compared with other kinds of power plants as well as comparisons of the individual methods employed for financing of future activities related to the spent fuel disposal and decommissioning. The financing of radioactive waste disposal is discussed, for example, in⁽⁸⁾.

NPP decommissioning in selected countries

France applies the immediate decommissioning methods for its NPPs. The decommissioning cost estimation methodology is based on the ‘reference cost’ in contrast to the majority of other countries that prefer to employ individual analyses for each individual NPP. The reference cost value in 2010 stood at $291.28 \text{ EUR kW}^{-1}$ ($318.36 \text{ EUR kW}^{-1}$ including the cost of disposal of radioactive waste arising during decommissioning) and is periodically updated taking inflation into account (2 % since 2001)⁽⁶⁾. The total decommissioning cost of 58 pressurized water reactor (PWR) reactors was estimated at approximately EUR 19 802 million in 2010, and this estimate is also updated annually. The NPP operator is obliged to create a provision (in the form of secured and sufficiently liquid assets) to cover future cost of radioactive waste disposal and NPP decommissioning.

Sweden, as with France, has opted for the immediate decommissioning method; however, application is dependent on the availability of suitable disposal place, which, in the past, meant that in the case of already closed reactors at the Barsebäck NPP, the decommissioning method had to be changed to that of deferral. Current decommissioning cost estimates range from EUR 503 million (Oskarshamn) through EUR 552 million (Ringhals) to EUR 735 million (Forsmark)—see^(9–11). The NPP operator is obliged to pay fee to Swedish Nuclear Waste Fund (SNWF), which is intended to cover the costs of future decommissioning and radioactive waste disposal including that of spent fuel—from 2.18 to $2.62 \text{ EUR MWh}^{-1}$.

Switzerland, as with France and Sweden, also opted for the immediate decommissioning method. Two external funds have been established for the financing of decommissioning activities and radioactive waste management. Swissnuclear (expert commission) updates the decommissioning plan that includes an estimate of decommissioning costs every 5 y. Present decommissioning cost estimates range from EUR 758 million (NPP Leibstadt) to EUR 401

NUCLEAR POWER PLANT DECOMMISSIONING FINANCING

million (NPP Mühleberg)⁽¹²⁾. The so-called Stilllegungsfond (fund) will be used for the financing of future decommissioning cost (including the costs of disposal of waste created by decommissioning), and Entsorgungsfond will be used to finance the costs of radioactive waste disposal including spent fuel. NPP operators are obliged to pay fees into these two funds—value of fee is set on the annual basis and is not related to the volume of power generated. The decommissioning fee is based on the assumption of 50 y of NPP operation, 2 % inflation and 4 % nominal appreciation of the monies accumulated; annual payments to the Stilllegungsfond range from EUR 7.9 million (NPP Gösgen) to EUR 14.8 million (NPP Beznau I + II). There are currently two operational NPPs in the Czech Republic—Temelin NPP (2 × 1055 MW PWRs) and Dukovany NPP (4 × 500 MW PWRs), both of which have the same operator, CEZ a.s. The Czech decommissioning strategy is based on deferred decommissioning involving a 35–50 y safe enclosure period following the removal of spent fuel. The financing of decommissioning activities is managed through the gradual creation of a provision in the balance sheet of the NPP operator, which should be in the form of accumulated monies in a blocked account. The accumulated reserves can be used solely for the financing of decommissioning and related activities based on a validated decommissioning plan and the approval of SURAO (the Czech Radioactive Waste Authority). The decommissioning plan is updated every 5 y. Current decommissioning cost estimates are EUR 828 million for Dukovany NPP's 4 × 500 MW reactors (2012 prices) and EUR 540 million for Temelin NPP's 2 × 1055 MW reactors (2009 prices); 1 EUR is considered equal to CZK 27 (August 2014).

METHODOLOGY OF DECOMMISSIONING COST ALLOCATION INTO FEE

Approaches applied in different countries differ not only in the way in which future decommissioning costs are transferred to current NPP operational costs but also with regard to a number of other assumptions such as the extent of the period of NPP operation, assumptions concerning the appreciation in the value of the monies accumulated and the inclusion of estimates of inflation. Approaches also differ in the requirement when the total amount of financial sources is required (at the time of decommissioning or after the given number of years of NPP operation) or with the way how cumulated financial sources are treated—whether they stay at the balance sheet of NPP operator or are taken out into the special fund. All these approaches differ in the way how the risk related with the decommissioning financing is divided between the NPP operator and the society. For example, approach described in this article (i.e. fee

per MWh generated, separate fund managed by the state authority) enables to allocate decommissioning cost into the whole NPP lifetime (predictable and stable cost item). But in contrary, collection of the monies in special fund leads to their lower appreciation compared with the case when they would remain in NPP operator balance sheet.

There are two main issues concerning the adjustment of the funding system: the first involves estimating the amount of financing required in the future and the second the calculation of the fee charged per MWh of electricity produced to cover future decommissioning costs.

The future amount of funds required consists of the current estimated costs of decommissioning adjusted according to the price escalation factor. Later in the article, the term inflation will be used to cover the principle of price escalation:

$$FV = (PV - C_c) \times (1 + \text{inf})^{\Delta T} \quad (1)$$

where FV is the future value, PV is the present value of decommissioning cost, inf is the inflation rate (escalation rate), C_c is the already cumulated money and ΔT is the years until the decommissioning phase starts.

Monies are accumulated through a fee imposed on each MWh generated, and the future amount of these monies is described in the following equation:

$$FV = \sum_{t=1}^{\Delta T} (Q_t \times \text{fee}_t \times (1 + r_n)^{\Delta T - t}) \quad (2)$$

Q is the amount of electricity produced in MWh in year t , fee_t is the fee value in the year t and r_n is the nominal discount rate.

The nominal discount rate (which refers to the long-term average appreciation of accumulated funds) is estimated according to the yield rate of long-term government bonds (15 y and more).

The main principle is that the future value of accumulated financial funds must be equal to the future amount of decommissioning costs, the idea being that this condition will ensure that there are enough funds accumulated at the end of nuclear power plant operation to cover all related decommissioning costs.

The fee is increased by the rate of inflation each year:

$$\text{fee}_t = \text{fee}_0 \times (1 + \text{inf})^t \quad (3)$$

Equations (1–3) must be combined in order to calculate the actual fee, i.e. fee value in the 0th year:

$$\text{fee}_0 = \frac{PV \times (1 + \text{inf})^{\Delta T} - C_c \times (1 + r_n)^{\Delta T - t}}{Q \times \sum_{t=1}^{\Delta T} ((1 + \text{inf})^t \times (1 + r_n)^{\Delta T - t})} \quad (4)$$

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The utilisation of the real discount rate instead of the nominal discount rate simplifies the understanding of the calculations due to its meaning (see Equation 5), the real appreciation of monies that are accumulated in order to finance future decommissioning costs:

$$(1 + r_r) \times (1 + \text{inf}) = (1 + r_n) \quad (5)$$

where r_r is the real discount rate.

CASE STUDY

The case study presents the practical application of the aforementioned methodology⁽¹³⁾ using as an example the Temelin NPP, which was put into operation in 2001 and for which the operational lifetime is expected to be 50 y. Average gross electricity production amounts to $2 \times 7.5 \text{ TWh y}^{-1}$. Estimated deferred decommissioning costs (ending in 2106) EUR 270 million per block.

Calculated fees regarding the immediate and deferred decommissioning strategies are EUR 0.74 and 0.70 MWh^{-1} , respectively. The lower fee with regard to deferred decommissioning is the result of the influence of the non-negative real appreciation of allocated funds.

The appropriate determination of the real discount rate value plays a very important role in the calculations—the value is in the range of 0.2–1.2 % (a value of 0.5 % has been applied in the calculation). The financial investment of accumulated monies is restricted in a similar way to that of the investment of nuclear account funds allocated to the financing of radioactive waste disposal⁽⁸⁾. The calculated fee for immediate decommissioning varies in the range of EUR $0.83\text{--}0.56 \text{ MWh}^{-1}$, i.e. similar to the case of deferred decommissioning with a range of EUR $0.84\text{--}0.45 \text{ MWh}^{-1}$.

CONCLUSIONS

As the result of the extensive analysis of individual mechanisms applied to the financing of decommissioning in selected European countries, the authors came to the following conclusions:

- Even though all the systems employed in the various countries studied ensure the financing of future decommissioning costs, there are fundamental differences between the systems that render the direct comparison of the financial burden of electricity production from NPPs all but impossible.

- The fundamental risk of the potential failure of such financing systems is, in all cases, covered by the respective government; however, the extent of risk differs according to the given system/state.
- The systems compared vary considerably in terms of the volume of risk over time, the reason for which consists of differing timeframes in terms of the collection of funds over the lifetime of NPPs.

A new methodology that allows the inclusion of future decommissioning costs in the full costs of NPPs is hereby proposed, which requires that each and every MWh generated by NPPs is burdened with an adequate proportion of decommissioning costs. This will allow the harmonised comparison of the full production costs of electricity generated by NPPs in different countries under differing decommissioning schemes.

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RADIOACTIVE WASTE DISPOSAL FEES-METHODOLOGY FOR CALCULATION

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Radioactive waste disposal fees—Methodology for calculation

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HIGHLIGHTS

- Policy of radioactive waste management in the Czech Republic.
- Methodology for calculation of fees for radioactive waste disposal.
- Comparison of fee for radioactive waste disposal for selected countries.
- The most important factors influencing fee-case example of the Czech Republic.

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ABSTRACT

This paper summarizes the methodological approach used for calculation of fee for low- and intermediate-level radioactive waste disposal and for spent fuel disposal. The methodology itself is based on simulation of cash flows related to the operation of system for waste disposal. The paper includes demonstration of methodology application on the conditions of the Czech Republic.

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1. Introduction

Radioactive waste and spent fuel are generated in the Czech Republic as a consequence of the peaceful use of nuclear energy, health care, research and industry. In comparison to other hazardous waste, it possesses about one-hundredths of the mass of the total hazardous waste generated. Depending on the concentration of radionuclides and intensity of emitting radiation, radioactive waste is classified as low, intermediate or high-level waste (spent fuel), depending on the period of time required for decay, such as short-term and long-term (Czech Republic, 1997).

Currently, Czech Republic has four low- and intermediate-level radioactive waste (herein below referred to as LLW and ILW) sites

at disposal, namely: (a) Dukovany; (b) Richard; (c) Bratrstvi; and (d) Hostim, which was closed in 1965. The Dukovany repository was designed for management of low- and medium-level radioactive waste, which is generated by nuclear power plants. It is the biggest and most modern of all repositories in the Czech Republic and it meets construction and safety standards valid in advanced European countries. The repository is situated within the area of the Dukovany nuclear power plant. It has been in permanent operation since 1995. The Richard repository was built in the complex of the former limestone mine Richard II and has been available since 1964. Its primary purpose was to accommodate waste from institutions like hospital or research facilities. Finally, repository Bratrstvi was constructed by adapting a mining shaft, during which five disposal chambers were created and is entirely for the disposal of waste containing natural radionuclides. The facility was put into operation in 1974.

Physical flow of spent fuel is shown in the Fig. 1. Major part of this type of waste originates from nuclear power plants (State Office for Nuclear Safety, 2013). A small part of spent fuel and other high-level waste also comes from the ŘEŽ research institute.

There are two basic ways of spent fuel final disposal after its temporary storage: final disposal without or with fuel reprocessing.

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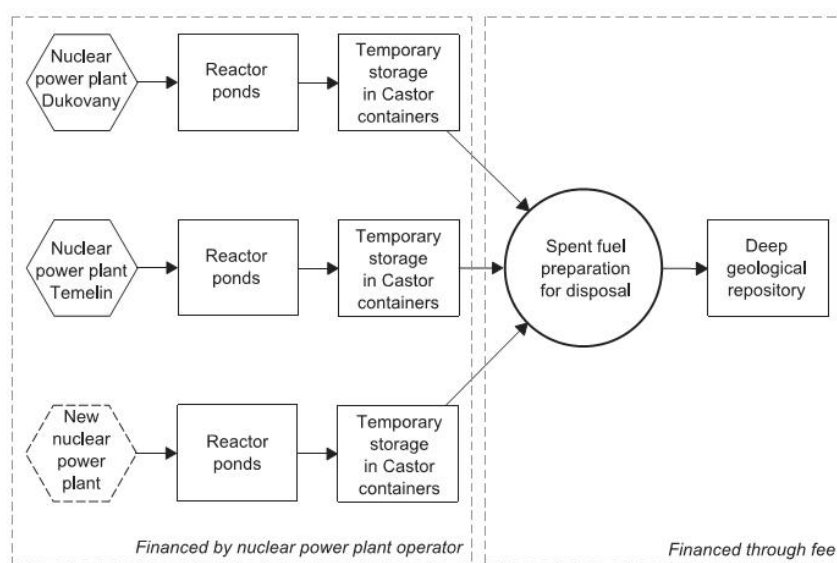


Fig. 1. Physical flow of spent fuel.

In the first case the fuel is prepared just for the final disposal (e.g. fuel is put into special containers). In the second case the fuel is reprocessed, leaving only a few percent as high-level waste. During this process the waste is chemically separated into uranium, plutonium and high-level waste solutions. These solutions usually contain a rich mixture of alpha, beta and gamma emitting radionuclides with half-time ranging from days to thousands of years. For examples we can state ^{14}C (5730 y; beta-), ^{41}Ca (1.03×10^5 y; electron capture), ^{59}Ni (7.6×10^4 y; electron capture + beta+), ^{63}Ni (100.1 y; beta-), ^{90}Sr (28.79 y; beta-), ^{94}Nb (2.03×10^4 y; beta-), ^{99}Tc (2.11×10^5 y; beta-), ^{129}I (1.57×10^7 y; beta-), ^{137}Cs (30.07 y; beta-), ^{239}Pu (24110 y; alpha, spontaneous fission) or ^{241}Am (432.2 y; alpha, spontaneous fission) (The Lund/LBNL Nuclear Data Search, 2013). Liquid high-level wastes are evaporated to solids, mixed with glass-forming materials, melted and poured into robust stainless steel canisters which are then sealed by welding. Highly active wastes are disposed in a similar way as spent fuel without reprocessing.

The Czech Republic, in accordance with the document NEA (2008), defines the final disposal of spent fuel in Deep Geological Repository (DGR) as the basic scenario and also does not assume spent fuel reprocessing. All the economic models include information only about the scenario without fuel reprocessing (RAWRA, 2011).

The cost of storage in reactor ponds and the cost of further temporary storage are the responsibility of the plant operators and are therefore not included in the fee calculation. Fee imposed on radioactive waste producers in Czech Republic covers only the costs of radioactive waste disposal in repositories.

2. Methodology

The task of the fee calculation is split into two relatively independent tasks:

- calculation of fee for ILW and LLW disposal in existing repositories,
- calculation of fee for future disposal of spent fuel in deep geological repository.

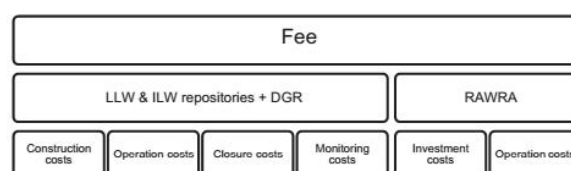


Fig. 2. Disposal fee usage.

The revenues (money inflows into a given system) consist of payments of waste producer and of appreciation (interest revenues) of the nuclear fund.⁵ Expenses include all current and expected expenses related to the operation and closing of repositories.

In the case of spent fuel the fee is related to the MWh produced. Waste producers pay at the same time as they derive benefit from the use of fuel, because amount of spent fuel produced is proportional to the amount of electricity generated (gross). This scheme ensures that sufficient money is available when needed. The system for spent fuel disposal is characterized by time disproportion between creation of the "money source" and utilization (generation of financial means precedes their utilization).

The disposal fee usage is described in the Fig. 2.

In case of a system for LLW and ILW disposal the fee is related to the volume amount of radioactive waste—standard 200 l drum (barrel).

LLW and ILW and spent fuel are stored in different kinds of repositories, and the cost of waste disposal differs significantly. Repositories have different expected lifetimes of operation and different structures of costs. Waste producers out of nuclear power utilize only repositories for LLW and ILW. Two different systems for radioactive waste disposal thus exist in effect:

- system for LLW and ILW disposal,
- system for spent fuel disposal (DGR repository).

⁵ Collected financial means on special, so called nuclear account in National Bank.

Fees for LLW and ILW disposal and spent fuel disposal are calculated separately to ensure full application of “polluter pays principle” and avoid cross-financing. Economic models reflecting all the expected future costs related to necessary activities needed for radioactive waste disposal are used to calculate fee values. Three groups of activities should be taken into account:

- costs related to RAWRA⁶ operation (these costs are fully transferred to radioactive waste producers),
- costs related to LLW and ILW repositories operation and closure,
- costs related to DGR construction, operation and closure (including site selection and all preparatory works).

Costs of RAWRA operation should be divided between these two systems e.g. according to the scope of activities managed in relation to individual systems. Economic models are based on simulation of future cash-flows reflecting expected lifetime of NPPs, power generated, costs related to repositories and RAWRA operation. Economic models have to include the value of money in a proper way (escalation of costs, appreciation of cumulated money).

2.1. Input data

The important task in fee calculation is identification of relevant input parameters for deep geological repository, LLW and ILW and RAWRA. This basically includes investment, operational costs, monitoring costs and time constants. Cost of DGR relates to expected operation of currently existing NPPs (lifetime, volume of power generated) and assumptions on construction of the new power blocks.

Sources of input data

- State energy policy of the Czech Republic.
- Conception of radioactive waste and nuclear spent fuel management (including the way of NPP decommissioning).
- Reference project of deep geological repository.

2.2. Scenarios for fee calculations

Fee value is influenced especially by the following parameters:

- operational lifetime of currently existing NPPs and volume of power generated,
- construction of new NPPs and time schedule of operation,
- cost of DGR construction and operation,
- expected appreciation of cumulated financial sources,
- RAWRA operational costs.

Other parameters of fee calculation play a minor role as is documented in sensitivity analysis. Existing Czech NPPs were put into operation in 1983–1987 (NPP Dukovany) and 2001 (NPP Temelin) and they are expected to be under operation for at least 40 years. Construction of new power blocks is being discussed and international tender for its construction is even currently opened. Thanks to high uncertainty of future electricity price and high economic risk related to construction of new NPPs, it is expected that the final decision will be postponed. Despite this uncertainty, the current version of Czech Energy Policy assumes continuation in nuclear power utilization and with the construction of new

power blocks. Based on this 3 basic scenarios of future NPPs operation can be discussed⁷ (Czech Republic, 2012):

- no new power blocks and 40 years of current blocks operation (assuming power generation equal 30 TWh annually)–DGR operation until 2110,
- new power blocks substituting currently existing NPPs and 40 years of current blocks operation (assuming power generation in new blocks equals 25 TWh annually)–DGR operation until 2150,
- no new power blocks and extension of currently existing NPPs to 60 years of operation–DGR operation until 2120.

Cost of DGR construction (2050–2064), operation (since 2065) and closure can be estimated to be between 70 and 110 billion CZK⁸ in 2012 prices (RAWRA, 1999, 2011, 2011). Different assumptions of NPP operation (40 or 60 years, new power blocks) influence both operation and construction costs of DGR and also the closure time. Dukovany repository from LLW and ILW is being expected to be under operation until 2090 (2110). Monitoring for 300 years is expected after repository closure.⁹ Economic models (both for LLW and ILW system and for DGR) should cover their operation, closure and also monitoring period after the closure.

Discount rate will be estimated from the yield of long-term (15 years and longer) governmental bonds. This approach respects very limited investment options for money stored on “nuclear account”. Appreciation of these funds was in the range of 2.5% and 3.0% in the last six years¹⁰ (RAWRA, 2012, 2013c). The real discount rate plays the dominant role (Eq. 6). Inflation in this equation has the meaning of price escalations of decisive future expenditures related to waste disposal and repositories operation. Its value is related to the development of prices of construction work and industrial producers. All other components play a negligible role (e.g. wages, etc.). Assuming limitations on investment of cumulated money into financial instruments, one can assume the nominal appreciation to be only slightly above mentioned price escalations in the long term. Real discount rate is assumed in the range of 0.2%–1.2%.¹¹ Improperly high value of real discount rate value would cause high contribution of appreciation on collected money to the future financial sources collected with the consequence of inadequately low fee value (high risk of lack of money to cover future expenditures).

RAWRA operational costs including investments (R&D etc.) range in the level 4–5 mil. EUR annually (RAWRA, 2012, 2013c).

Example of LLS and ILW production from NPP operation for the scenario of 40 years of NPP operation and no new NPP is documented in Fig. 3. The Czech Republic conception (RAWRA, 2011) assumes the so-called deferred decommissioning which influences significantly the

⁷ Assumptions on power generation in currently existing NPPs reflect current situation after repowering in the last years aimed at increase of installed power and reliability of operation. Power generation of new NPPs reflects the scenario from Czech Energy Policy.

⁸ 2.5–4.0 bn EUR or 3.5–5.5 bn USD according to exchange rate from December 31, 2013.

⁹ Repository Richard for ILW and LLW is expected to be closed at the time of DGR opening (2065).

¹⁰ This is in accordance with return from governmental bonds (see <http://www.investing.com/rates-bonds/czech-republic-government-bonds>).

¹¹ Financial model covers the period of 100 years at least. Assuming no new NPP, money collection from the operation of currently existing NPP will continue to 2040 (2060), while the decisive expenditures related to the DGR construction and operation will occur in the period 2050–2064 and 2065–2110 (2120) respectively. One can assume that Czech Republic economy will converge to the economy power of Western European EU member states. That is why it is possible to work with stable conditions for price escalation and money appreciation assumptions similar to conditions of the most developed EU countries.

⁶ Radioactive Waste Repository Authority – state organization ensuring safe disposal of radioactive waste in the Czech Republic.

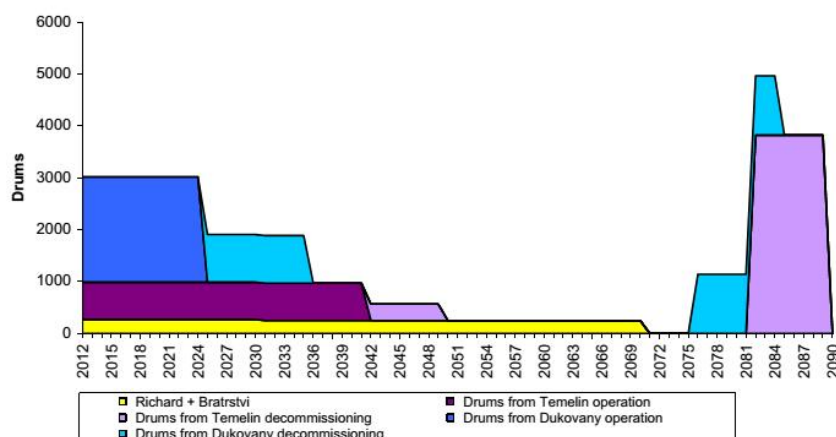


Fig. 3. LLW and ILW production.

profile of waste origination. LLW and ILW waste from potential new NPP is expected to be stored in DGR.

2.3. Methodology background

The main aim of the fee calculation methodology is to:

- Comply with “polluter pays principle” – all the costs related to the system for radioactive waste management should be borne by subjects who profit from nuclear power and other technologies utilization.
- Ensure proper value of financial sources at the moment of their requirement – according to expected activities within the system of radioactive waste management.
- Respect in proper way special characteristic of the task and very long time horizons – compared with standard investment task and their cash-flow profiles, financing of system for radioactive waste disposal has basically reversed the cash-flow profile. In case of this project, financial sources are cumulated first (e.g. during operation of NPP) and they are used (invested) in the future e.g. for construction, operation, closure and monitoring of DGR. This unique cash-flow profile influences the meaning of discount rate.

Application of “polluter pays principle” in fact requires allocation of all future costs related to the radioactive waste disposal to the operation cost of radioactive waste producers. This means that collection of the needed financial sources should be related to the volume of the waste production. In case of NPP, fee is related to the volume of power generation; in case of other waste producers it is related to the volume of generated LLW and ILW. This is based on the opportunity cost principle that repositories have finite capacity. Each volume unit of radioactive waste consumes permanently a part of its capacity. In case of spent fuel, there are two major factors influencing fee value – volume of waste production which is basically proportional to NPP service lifetime and total power generation. Significant portion of DGR costs is independent of volume of spent fuel disposed. Thus it makes sense to relate calculation of proper fee value to the power generation, which can be for instance influenced by increase of NPP energy efficiency¹² and reliability of operation.

¹² It can be documented on the example of the Czech nuclear power plant Dukovany and Temelin. Investments into non-nuclear part of NPPs enabled

The calculation of fees is based on basic principles of financial analysis of the project (Brealey et al., 2011) and is calculated assuming long-term financial balance between revenues and expenses (cost). The basic criterion of investment project financial analysis is Net Present Value (NPV).

$$NPV = \sum_{t=0}^T CF_t(1+r_n)^{-t} \quad (1)$$

where

r_n nominal discount
 T project assessment period
 CF_t cash-flow in year t (difference between cash inflows and outflows).

Nominal discount has the meaning of opportunity costs of invested money¹³ in standard financial project analysis. In many cases the task is not to evaluate economic effectiveness of the project for its given conditions but to find the minimum price (fee, etc.) to reach a required level of project economic efficiency¹⁴ (Vávřová and Knápek, 2012). Minimum price is calculated based on the binding condition $NPV=0$, which means that the investor realizes rate of return from his investment equal to the discount rate used for NPV calculation. NPV equal to zero represents the balance between the present value of all future project-related expenses and the present value of all future incomes (revenues) generated by the project. The task of fee calculation is thus aimed at finding the value of fee at the first year of analyzed period, so that NPV of all future money inflows and outflows would be equal to zero. Cash-flow in year t is calculated according to the formula

$$CF_t = c_{\min,t} Q_t - E_t \quad (2)$$

where

$c_{\min,t}$ fee in year t [CZK/drum, CZK/MWh]
 Q_t physical volume of waste produced in year t [drum, MWh]
 E_t expenses (cost) in year t .

(footnote continued)

significant increase both of installed power and of power generation; e.g. NPP Dukovany increased installed from 4×440 to 4×510 MW and total power generation from both NPPs increased from 24.7 TWh in 2005 to 30.2 TWh in 2012.

¹³ Return on alternative investments of a given investor.

¹⁴ As an example of this approach one can mention calculation of feed-in tariffs for power generated based on renewable energy sources to ensure adequate rate of return from the investment.

Fee defined as the minimum price ensures full financing of all future expenditures related to radioactive waste disposal and also includes time value of money (in terms of appreciation of collected money through fee).

Discount rate (r_n) has different meanings, contrary to standard investment projects—discount rate has meaning of the return on money cumulated. Money cumulated during operation of facilities (like NPP) is usually collected on special bank accounts with specific conditions for their investment into financial assets.¹⁵ Cumulated money brings nominal return from its investment. Real rate of return (6) from money cumulated contributes to covering future expenditures related e.g. with the DGR construction, operation and closure.

Calculation of minimum price requires projection of future cash flows of a given project or the system. Proper cash flow projection requires creation of the economic model reflecting all the conditions of project realization or system operation. General rules for economic model creation are discussed e.g. in Knápek et al. (2011).

With respect to the special status of RAWRA (RAWRA, 2013b) that is responsible for operation of repositories and for radioactive waste disposal (no taxes paid, no depreciation, no provisions) the basic equation (1) can be transformed using Eq. (2) into the following equation:

$$\sum_{t=1}^T fee_t \times Q_t \times (1+r_n)^{-t} + C_c = \sum_{t=1}^T E_1 \times (1+inf)^{t-1} \times (1+r_n)^{-t} \quad (3)$$

where

fee_t	nominal specific fee in the year t [CZK/drum] or [CZK/MWh]
r_n	nominal discount [–]
T	assessment period [years]
C_c	cumulated money at the beginning of the assessment period.

Left-hand side of Eq. (3) consists of cumulated revenues from fees paid by waste producers and of real appreciation of money on the nuclear account. Right-hand side of the equation consists of the present value of all expenses caused by the system for waste disposal.

The used methodological approach works with nominal values of revenues and expenses. The fees will be calculated for the starting year 2013. Annual increase by inflation is assumed (or when fee is increased in a longer period e.g. 3–5 years steps, average increases should correspond to the inflation during this period). The following equations demonstrate derivation of the fee in the starting year (fee_1) assuming annual increase by inflation. In this case, fee in the starting year is calculated as the ratio of sum of discounted system expenses to physical volume of waste:

$$fee_t = fee_1 \times (1+inf)^{t-1} \quad (4)$$

where

fee_1	specific fee in starting year [CZK/drum] or [CZK/MWh]
inf	expected long-term inflation rate [–]

$$fee_1 \times \sum_{t=1}^T Q_t \times \frac{(1+inf)^{t-1}}{(1+r_n)^t} = \sum_{t=1}^T E_1 \times (1+inf)^{t-1} \times (1+r_n)^{-t} \quad (5)$$

$$(1+r_r) \times (1+inf) = (1+r_n) \quad (6)$$

$$fee_1 = \frac{\sum_{t=1}^T E_1 \times (1+inf)^{t-1} \times (1+r_n)^{-t}}{\sum_{t=1}^T Q_t \times (1+r_r)^{-t} \times (1+inf)} \quad (7)$$

¹⁵ Investment should be in compliance with Atomic Act.

where

r_r real discount.

Inflation in formulas has the meaning of price escalation of decisive expenditures related to repositories construction, operation and closure.

Assessment period in general should include physical lifetime of all components of the system for radioactive disposal, including defined period of physical monitoring after repositories closure.

Events¹⁶ prior to the year during which the fee is calculated for are considered in the nuclear account value (item C_c in formula (3)) in the beginning of assessment period.

3. Results and discussion

In case of NPP two different systems for radioactive waste disposal should be financed and two different fees theoretically should be calculated. For practical reasons, fees for LLW and ILW disposal from NPPs could be included in calculation of general fee covering financing of both systems (case example of Czech Republic).

This can be done in the following two steps:

- Calculation of separate fee for the financing of LLW and ILW and identification of expected money inflows from LLW and ILW disposal in operation and decommissioning period, including money inflow time profile (it is assumed here that LLW and ILW are disposed immediately when they occur and simultaneously waste producer pays fee for their disposal).
- Expected money inflows from NPPs LLW and ILW disposal are then included in the model for calculation of fee to finance spent fuel disposal as a separate expense item.

This approach ensures proper inclusion of needs for financing for LLW and ILW disposal generated from NPPs into one general fee imposed to power generation in NPPs. This approach also enables proper inclusion of LLW and ILW coming from facilities out of nuclear power. Inclusion of financing of LLW and ILW from NPPs into one fee respects also the fact that cumulative requirements for financing of NPPs LLW and ILW disposal are a very small portion of the total fee imposed on NPPs. It can be estimated assuming input values discussed in Sections 2.1 and 2.2 that total costs related to LLW and ILW disposal account for only ~6% of the total costs of radioactive waste disposal including spent fuel (in present value).

Discount rate value plays a crucial role in fee calculation. Thanks to the very long time period, relatively small changes of its value significantly impact the fee value due to the fact that a significant part of cumulated financial sources in the future results from cumulated money appreciations. The difference between nominal discount rate (having the meaning of money appreciations through their investing into financial assets¹⁷) and expected long-term average inflation plays a decisive role. The impact of money appreciation on fee value can be documented on the figures for the Czech Republic. Assuming input data and assumptions discussed in Section 2, one can estimate fee value (for spent fuel and LLW and ILW disposal) for different appreciation scenarios as follows:

- 0.3% – fee value 2.73 EUR/MWh,
- 0.75% – fee value 1.95 EUR/MWh,
- 1.25% – fee value 1.28 EUR/MWh.

¹⁶ Amount of waste already generated, amount of money already accumulated.

¹⁷ In case of Czech Republic fees paid by radioactive waste producers are.

Different countries apply different philosophies of financial sources collection to cover future costs related to NPP decommissioning, spent fuel, and LLW and ILW disposal. France has separate fees ensuring financing of decommissioning and radioactive waste disposal (fee value for waste disposal is 1.4 EUR/MWh (ASN, 2013)). Sweden introduced a different system where each NPP is assigned an individual fee value covering future costs related to the decommissioning, spent fuel and LLW and ILW disposal. Fee value range is 2.2–2.7 EUR/MWh (Kärnavfallsfonden, 2013). Switzerland policy is based on two fees (Switzerland, 2003). The first is aimed at financing decommissioning and disposal of LLW and ILW from decommissioning (1.6 EUR/MWh), and the second fee should finance disposal of spent fuel and LLW and ILW from operation (6.4 EUR/MWh). The mentioned fee values are basically comparable with fee value imposed on nuclear power in USA, which is currently 1 USD/MWh (DOE, 2013). Each country uses different methodologies for fees calculation, and fees have different meanings and cover financing of different aspects of decommissioning, LLW and ILW and spent fuel disposal. Collection of financial sources to cover decommissioning and waste disposal usually did not start at the time when NPP started their operation, which means that necessary financial sources should be collected during remaining operational lifetime of NPPs. Expected costs of DGR which reflect unique conditions of individual countries also significantly influence fee value. Appreciation of cumulated financial sources also significantly impacts the fee value – countries have different regulations regarding possible financial investments for cumulated money. All these factors complicate any simple comparison of fee values between different countries. Each comparison should be based on an understanding of the country's methodology details.

4. Conclusion

The article presents a comprehensive methodology for calculating the fee for storage of radioactive waste. It also takes into

account technical aspects like fuel recycling cost, amount of waste production in conformity with the future energy production plan and price of the work connected with safe deposition of nuclear waste. The economic part is coping with a long time horizon and a staged procedure of waste disposal. A continuation of this work will include developing models based on this methodology and making specific calculations for RAWRA. We expect that our calculated fees will be applied in the Czech Republic.

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NEW APPROACH TO BROWN COAL PRICING USING INTERNAL RATE OF RETURN METHODOLOGY

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New approach to brown coal pricing using internal rate of return methodology



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HIGHLIGHTS

- We showed that brown coal is the substitute for black coal only at the time of the investment decision.
- We compiled the model used in a calculation of the economically justified price for the productive and extractive component.
- The resulting economically justified price is on a par with the current black coal price.
- The proposed methodological approach is applicable to solve similar tasks not only in the energy sector.

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ABSTRACT

Brown coal is one of the dominant local strategic raw materials in Europe, used, to a large extent, in the power-generating industry. The current situation, where the price of gas and electricity precludes the efficient use of gas sources, leads to the extraction of older sources, chiefly brown coal ones. In tandem with a turning away from nuclear power, brown coal is experiencing a renaissance and the issue of brown coal price setting is, and will be, relevant. This paper deals with a proposal of a new method for determining the base price, consisting of defining the reference fuel chain for electricity and heat production based on brown coal. It builds on the notion that the degree of risk of the involved parties should be reflected in the modified amount of revenue per capital invested. The resulting price is then an economically justified price which encourages a respect for the specific features of the market in question and set the base price of the commodity in a way that is acceptable for both the extractive and the productive components of the fuel chain.

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1. Introduction

The issue of brown coal price setting is determined by the highly specific nature of the market, which – unlike the other energy commodity markets – is local, not regional (such as the overwhelming majority of the natural gas market) or global (such as oil, black coal and uranium markets). The reason for this arrangement is the fact that compared to the other energy raw materials the energy content of brown coal, in proportion to its volume, is significantly lower than that of oil or natural gas. Oil has the highest energy density with a calorific capacity of 40–45 GJ/t, translating to 35–40 GJ/m³. Natural gas, composed primarily of methane, has an energy density equalling one thousandth of that of oil, 35–45 MJ/m³, at atmospheric pressure. Its

energy density can be increased by compressing natural gas a hundred times to 100 bar. At the same time, natural gas can be liquefied at –162 °C to achieve a calorific capacity about half of that of oil. In contrast, bituminous coal has a calorific capacity of 20–30 GJ/t, with a wide variation depending on its ash content. Brown coal then has a significantly lower calorific capacity, sometimes even less than 10 GJ/t [1].

The local nature of this commodity is also evident in the differing definitions of brown coal in the world. The definition methodologies differ across countries and organisations [2]. Different methodologies are applied in the USA (ASTM – American Society for Testing and Materials), Germany (DIN – Deutsches Institut für Normung) as well as within the UNECE (United Nations Economic Commissions for Europe). The methods differ in both the classification of coal of various calorific capacities (the UNECE defines 6 types of coal in its entire range, the DIN defines 11 types), and in the definition of the internationally applied term lignite. The UNECE defines ortho-lignite (up to 15 kJ/kg) and meta-lignite (up

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Table 2

Coal key parameters. source: [4–6].

	Brown coal sorted	Brown coal – energetic	Black coal
Calorific value	17–20 MJ/kg	9–17 MJ/kg	19–35 MJ/kg
The content of volatile matter	45–60%	45–60%	10–40%
Ash content	5–15%	20–50%	5–25%
Water content	25–35%	20–50%	3–10%
The sulphur content	0.5–2%	0.5–4%	Below 1%

Note: Higher quality brown coal (in Czech conditions known as sorted coal) is exclusively used for households and smaller heating plants. Its reserves are very limited and are expected to be depleted in app. 10 years) – see e.g. [7].

plant, while respecting all the costs associated with the production. The disadvantage of this method is that it disregards the cost side of brown coal extraction, meaning that the risk undertaken by the extraction and production components of the fuel cycle is not reflected at all. However, should the fuel chain not be vertically integrated, that need not necessarily be a disadvantage. The methodology for pricing black coal used in Poland [19] determines the price based on the relationship between the calorific value, ash content and sulphur content, in the coal being evaluated and the reference coal. However, this approach again fails to deal with the reference price setting, and is therefore not applicable to determining the price of brown coal.

In India, the prices of coal are set centrally by the government by means of a price resolution, defining 17 price brackets depending on the combustible heat [20]. The coal market in China has been through an interesting development [21,22]. Following a price regulation for this commodity, there was a two-tier price, where part of the coal was sold at the regulated price and part at the market price, and today the price is determined by the market and the government has only retained the capacity to enter the market temporarily with the probable intention of influencing the coal price. This is chiefly due to the regulated electricity price. Not even these major coal-mining countries have thus far dealt with brown coal pricing, although they do make a considerable use of it. This is primarily because these countries are still developing, and the primary issue is not the price of a commodity but the satisfaction of the demand for energy. At the same time, the government owns the mineral resource, so it need not always make an economic profit.

The Czech Republic is one step further in this respect. The country has privatised the coal reserves and there are private mining corporations which are currently addressing the difficulties of setting the price of brown coal for long-term contracts reaching expiry. There is a proposed methodology for pricing brown coal [23] based on the assumption of long-term inter-changeability of different fuels. It is founded on the notion that heat generation incurs various investment, operating and environmental costs with each type of fuel. The relationship between the different fuels expressed how much more “useful” a unit of energy in a given fuel is compared to another fuel. Based on calculations, the discussions have considered the range of approx. 0.65–0.8 of the black coal price. The chief advantages of this methodology are its simplicity and tie with a tradable commodity.

The disadvantage is its limited functionality in electricity generation. This limitation is due to the different pricing of heat and electricity. Different fuels may not always be swapped “arbitrarily” (e.g., due to insufficient raw material base), or the additional induced investment would be so high that they would effectively preclude the shift to a different fuel (e.g., insufficient gas pipeline capacity, limited access to railway transport, etc.). The price deduction based on the price of commodities traded on the stock exchange does not take into account the local nature of brown coal. For example, the low prices of shale gas in the USA, which have caused an increased supply of black coal on the European market, have decreased the price on the European stock exchange.

Ironically, if this method was applied, brown coal would lose its drawback, but also its advantage as a local raw material. This methodology has come up against a major objection by consumers in the Czech Republic. Nevertheless, at least one long-term contract has been concluded for brown coal supplies at a price of 0.65 ARA starting from 2022 [24].

According to the authors, none of the methodologies published can be applied as the universal, generally transferrable method. Those that do deal with the base price fail to respect the differing degrees of the risk undertaken by both the supplier and the consumer.

The authors believe that the price of brown coal should not primarily be derived from commodities traded on the stock exchange that are of limited substitutability, but rather that it should reflect the specific situation on each market and the value chain in electricity and heat production and supply as much as possible, while also ensuring a “fair” division of the profits generated by the entire chain.

3. Proposal of a new method for brown coal pricing

The pivotal idea of the proposed method for brown coal pricing is the premise that within a single value chain (heat and electricity generation based on brown coal), all the major involved entities, i.e., the extractive and productive components, should realise the same revenue per capital invested. The entrepreneurial risk for both the entities is essentially identical, since they are mutually tied to the consumption/supply of brown coal and the associated deliveries of heat and electricity. The profit from the entire fuel chain should therefore be divided in proportion to the capital invested, whereby the degree of risk undertaken by each of the entities would be reflected.

The method proposed follows 1 GJ in the fuel throughout the chain. In the extractive component, it follows all the costs associated with its production. In the productive components, it takes into consideration the efficiency of the electricity and heat production, based on which the revenues from the final product of the entire chain can be subsequently determined. After that, it considers all the costs to the productive component in relation to the production of electricity and heat from the 1 GJ in the fuel. Thanks to the value chain defined in this way, we can determine the permissible range of the brown coal price. It is defined by 2 limit prices, namely:

- **Minimum cost price** from the point of view of the mining company at the foot of the mine, respecting the required revenue per capital invested and all the costs associated with the extraction.
- **Maximum permissible price** from the point of view of the heating/power plant at the foot of the plant, respecting the required revenue per capital invested and all the costs associated with the production of the final product.

The minimum cost price is calculated using NPV methodology (simulation of cash flows with the help of the economic model of

the reference project from the binding condition $NPV = 0$ (for details see [25]). The minimum cost price assures the investor of the required rate of return on the capital invested. The maximum permissible price is such a price of coal that assures the competitiveness of power and heat on the market while also assuring the required return on the investment. If the minimum cost price is lower than the maximum permissible price, a platform range for business negotiation exists. Conversely, when the investor cannot meet the required rate of return from the investment this (assuming there is no subsidy) leads to the project being rejected. A similar approach can be found in many economic tasks, e.g. one can mention the determination of feed-in tariffs for RES support for power generation, (here the minimum cost price is higher than the maximum permissible price and support should change the position of these two values, e.g. by investment or operational subsidy).

The following cost items have to be subtracted from the size of the minimum cost and maximum permissible price range:

- Costs of transporting the coal from the point of extraction to the point of consumption.
- Fee for mineral mined, and all local fees and taxes.

The costs of transporting the coal may be borne by either the extractive or the productive component of the value chain, which is why it has to be borne in mind that the inclusion of this item in the budget of the extractive/productive component alters the final product (coal at the foot of the mine versus coal at the foot of the plant). This cost should be included in the calculation with respect to the local attributes of the market in question. It is typical of the Czech setting that the consumer pays for the transportation.

The fee for the mineral mined, and all local fees to the State represent how much of the profit from the value chain is appropriated by the State, being the owner of the mineral being mined. Where the State is the owner of the extractive component, there is a question of how to cope with these items, which the State may essentially set as it chooses, thus “artificially” increasing its share in the profit generated.

The price range defined in this way, then, provides a platform for negotiation between the two parties. This enables the “fair” setting of the resulting price of coal so that the percentage revenue per capital invested is equal for both the key companies. This price can be defined as the just economic price for both the fuel chain components. It must be noted here, too, that this price is the base price and can be further adjusted and indexed based on the qualitative properties of each delivery of coal (inspiration can be taken from the Polish model [19]). The whole methodology is shown in Fig. 1).

The proposed methodology is therefore based on the assumption that the profit is divided in proportion to the capital invested. The resulting price can then be defined under the condition:

$$C_t(r') = C_v(r') \quad (1)$$

where r' is identical return per own capital.

$$C_t(r) = \frac{O_t \times T_{zt} \times [n_{st} + a_t(r)]}{Q_{pal}} + N_{pt} + N_{dt} + N_{vyd} \quad (2)$$

where

- $C_t(r)$ is the resulting brown coal price for the extractive component of the fuel cycle [EUR/GJ],
- r is required return per own capital,
- O_t is the average depreciation during the service life of the extractive component [EUR],
- n_{st} is the constant operating costs of the extractive component [%],

- $a_t(r)$ is the proportionate annuity for T_{zt} at the given equal return r per own capital [–],
- T_{zt} is the average service life of the extractive component [years],
- Q_{pal} is the annual amount of energy delivered in the fuel by the extractive component [GJ],
- N_{pt} is the specific other variable costs of the extractive component [EUR/GJ],
- N_{dt} is the specific costs of coal transportation of the extractive component [EUR/GJ],
- N_{vyd} is the specific costs of the mineral mined [EUR/GJ].

$$C_v(r) = Q_{vyr} \times (1 - k_{vst}) \times C_{tep} + E_{vyr} \times (1 - k_{vse}) \times C_{el} - n_{iv} \times [n_{sv} + a_t(r)] - e_{CO2} \times C_{CO2} - N_{pv} - N_{dv} \quad (3)$$

where

- $C_v(r)$ is the resulting brown coal price for the productive component of the fuel cycle [EUR/GJ],
- Q_{vyr} is the amount of thermal energy produced from 1 GJ of coal [GJ/GJ],
- k_{vst} is the own heat consumption coefficient [%],
- C_{tep} is the heat price [EUR/GJ],
- E_{vyr} is the amount of electrical energy produced from 1 GJ of coal [MW h/GJ],
- k_{vse} is the own electricity consumption coefficient [%],
- C_{el} is the electricity price [EUR/MW h],
- n_{iv} is the specific investment [EUR/GJ],
- n_{sv} is the constant operating costs [%],
- $a_t(r)$ is the proportionate annuity for T_{zv} at the given equal return r per own capital [–],
- T_{zv} is the average service life of the productive component [years],
- e_{CO2} is the specific CO2 emission from 1 GJ of coal [t/GJ],
- C_{CO2} is the price of an emission permit [EUR/t],
- N_{pv} is the other variable costs of the productive component [EUR/GJ],
- N_{dv} is the specific costs of coal transportation of the productive component [EUR/GJ].

The basic assumption is that we use annual data. Values used in the calculation are given in Appendix B. Eqs. (2) and (3) contain the annuity for the time of the assumed economic service life at the required revenue (for example, 10%), thus yielding the aforementioned minimum cost or maximum permissible price of brown coal. The appendix lists the procedure for calculating the resulting price conforming to Eq. (1).

4. Case study

To apply the principle of our methodology, it is necessary firstly to define the reference fuel chain. In the instance of brown coal pricing there are two participants – the extractive component (mine) and the productive component (power plant or cogeneration plant). Our case study results were used as the system basis for solving business disputes over brown coal pricing (preferably used by the mining companies and also provided to the Czech Regulatory Office). That is why we used data not for the specific power or cogeneration plant or for a specific mining company but the data reflecting the reference (typical conditions).

In our case study we used the data for a mine from the mining companies business plans intended to launch a new phase of brown coal mining in the Czech Republic. This essentially refers to opening up a new mine de facto on a “greenfield”. The data for the productive component reflects the results of the extensive primary data collection and represents a “typical” cogeneration

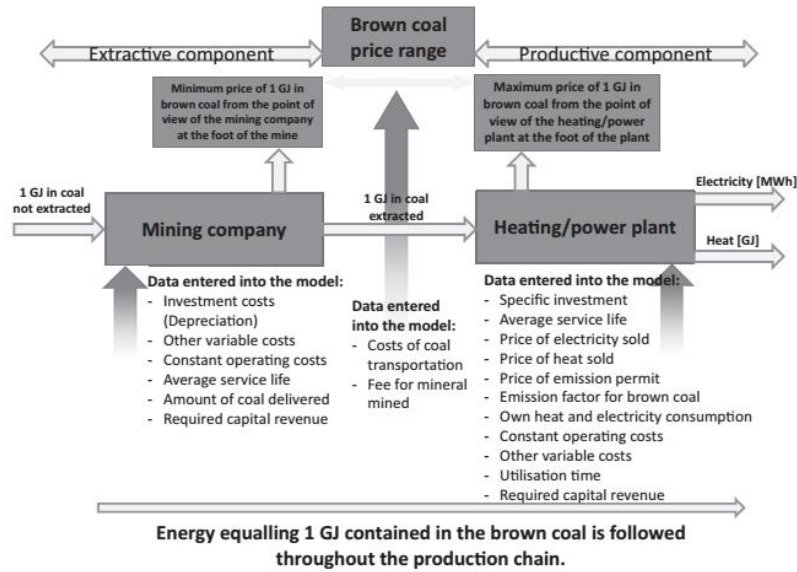


Fig. 1. Reference fuel cycle.

plant in Czech conditions (essentially in the range of 10–100 MW of installed power). All the data used to calculate the resulting brown coal price are in Appendix B. The typical price range of brown coal delivered by the mining companies from 2008 to 2012 (mostly based on long term contracts signed in 90 s) was from EUR 1.35/GJ to EUR 2.1/GJ. These prices have reflected the previous situation on the energy market (i.e. the structure of the branch in the 90 s, business conditions of the 90 s, the negotiating position of the parties in the 90 s, when the privatisation of mining companies had not been completed etc.) and have led to the unequal economic position of the subjects in the vertically integrated brown coal fuel chain.

Using Eq. (2) we got the minimal cost price (from the point of the extracting company). This minimal acceptable price for the mine respects all the costs associated with the extraction and the (minimum) required revenue per capital invested, divided by the annual amount of energy delivered in the fuel.

$$C_r(r=0, 1) = \frac{18568200 \times 50 \times [0.036 + 0.1]}{95200000} + 0.964 + 0.031 = 2.32 \text{ EUR/GJ} \quad (4)$$

Consequently many contracts for the supply of brown coal close to the lower price range (1.35 EUR/GJ) covered in principle only the variable operating costs of mines but did not provide funding for the acquisition of new assets required to continue operation.

Vice versa the maximum permissible price for the cogeneration plant reflects the profit from sales of electricity and heat per GJ minus all the costs (fixed and variable associated with the production of electricity and heat and the required revenue per capital invested, divided by the annual amount of energy consumed in the fuel – see Eq. (3):

$$C_v(r=0, 1) = 0.63 \times (1 - 0.03) \times 10.42 + 0.06 \times (1 - 0.07) \times 38.59 - \frac{1930 \times 0.06 \times 1000}{3700} \times [0.03 + 0.11] - 0.1 \times 1.27 - 0.308 - 0.579 = 3.12 \text{ EUR/GJ} \quad (5)$$

The range between these two prices represents the interval for business negotiations. Eq. (1) defines the splitting of the economic benefits within this interval so that the rate of return for both parts of the integrated value chain (i.e. the mine and cogeneration plant) would be equal. This is demonstrated in Fig. 2.

The resulting permissible coal price for a 10% rate of return for both parts of the value chain range was from EUR 2.32/GJ (minimum cost price from the mining company's perspective) to EUR 3.12/GJ (maximum permissible price for the cogeneration plant). The task is to find a coal price between these two values so that the rate of return for both parts of the (integrated) value chain would be the same. Application of Eq. (1) (with reference to Appendix A) leads to EUR 2.53/GJ which gives a 12.2% rate of return for both.

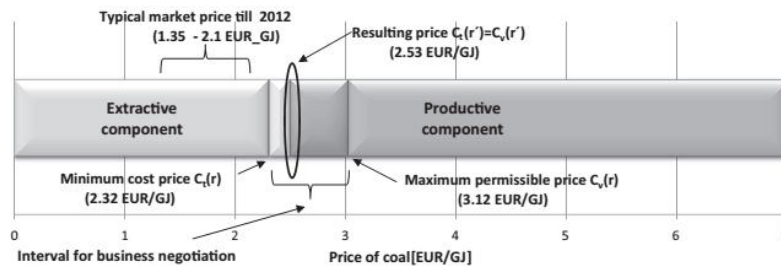


Fig. 2. Dividing the economical profit of the value chain.

5. Results of case study and discussion

The principle of the method is that the final product (i.e. electricity and heat) is the same regardless of whether the brown or black coal is burned. Due to the given principle of the method it has to result in pricing energy in brown and black coal at a similar level (assuming similar investment costs related with the given type of coal utilisation for power and heat production). The difference in the valuation of brown and black coal then mainly reflects differences in variable costs related to the use of given coal type (e.g. transportation costs, desulphurization, waste handling).

If the resulting maximum permissible price with zero required revenue is lower than the minimum cost price, the proposed method would lead to no solution. In this case, the input data would have to be revised, as it would mean that no profit is generated throughout the value chain.

The resulting price 2.53 EUR/GJ in presented case study, under mentioned conditions, is much closer to black coal price than was and still is. Typical spread between black and brown coal price in the Czech Republic was more than 100% (in 2008 even close to 300%). This may indicate that sources combusting brown coal realised in last years relatively high specific profit compared to specific profit of the mining companies. In the contract for coal supplies at a price of 0.65 ARA starting from 2022, mentioned above, the price for 2013 is set at EUR 1.5/GJ. This price gradually approximates the stock exchange price of black coal [24].

The case study presents not only the application of the methodology but also gives a look to the reality of the Czech Republic. Long term contracts for the brown coal delivery in the Czech Republic are currently being expiring and the new contracts started to be subject of extremely complicated negotiations between private owners of coal mines and coal fired cogeneration and power stations. Application of the developed methodology can contribute to find the balance between the interests of extraction and productive component of value chain and thus can have utilisation either by Energy Regulator or by Office for the protection of the competition.

5.1. Sensitivity analysis

In the next part, we performed sensitivity analyses to identify the values entered that have the greatest effect on the resulting price. For the extractive component, the resulting price is most sensitive to the coal delivered, the depreciation rate and the average service life. The relative sensitivity analysis was calculated as the coefficient of price elasticity for each of the parameters used in the calculation. So the formula used for the relative sensitivity analysis was:

$$rs = \frac{\frac{\max Y - \min Y}{(\max Y + \min Y)/2}}{\frac{\max X - \min X}{(\max X + \min X)/2}} \quad (6)$$

where rs is relative sensitivity, Y is the dependent variable and X is the independent variable on the selected interval (see Fig. 3 for sensitivity analysis of coal producer).

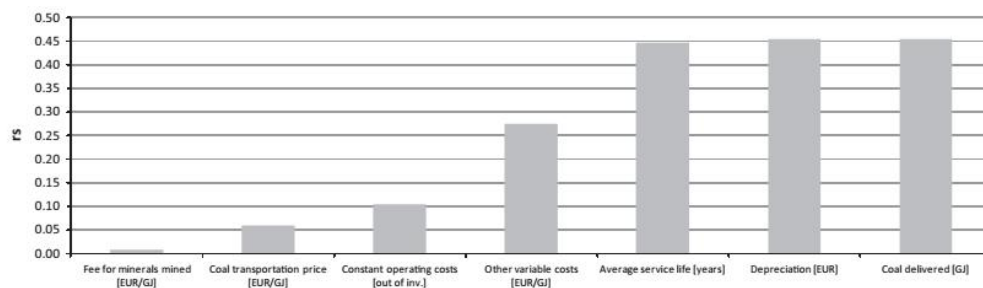


Fig. 3. Relative sensitivity of input data for the coal producer.

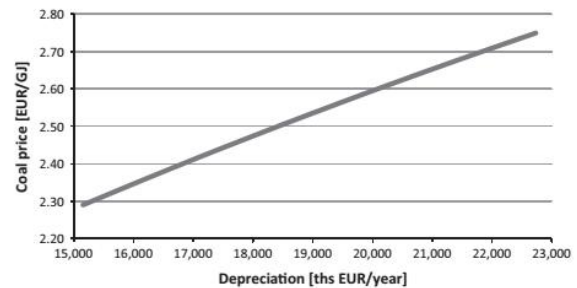


Fig. 4. Coal producer's sensitivity to depreciation.

Relative sensitivity gives the percentage change in calculated coal price in response to a one percent change in the relevant input parameter.

Since the coal delivered and the average service life is determined by the mine deposit, the setting of the depreciation rate is the most important in terms of calculation accuracy. The value of depreciation used in the model is related to the annual output of the extractive component of 5500 thousand tonnes.

It has already been mentioned that the data for the extractive component originate from business plans for a new mine de facto on a "greenfield". We regard this as proper because the situation would be distorted if we used the current values at a time where a considerable part of the equipment is written off. The consequence of the non-economic operation with poor maintenance and frequent investment is that it might lead to a higher proportion of the divided profits. On the other hand, if we entered the depreciation rates for a particular mine, the resulting price would almost certainly decrease. In which case, the price should then be calculated separately for each miner and electricity/heat producer pair, respecting their particular cost items. That, however, would result in an inconsistency in the proposed methodology because the non-economic operation and the long distance from the mine would paradoxically be an advantage for the consumer, whilst non-economic extraction would be an advantage for the miner. The source and the mine on a "greenfield" are therefore the only methodologically permissible options (see Fig. 4 for sensitivity analysis of coal producer to depreciation):

The input data for the productive component are the most sensitive to the heat from 1 GJ (efficiency) and the heat price. The reference calculation used a relatively high efficiency based on the reference plant, which, however, respects the current requirements for efficient operation. The heat from 1 GJ was set to 0.63 GJ and the heat price to EUR 10.42/GJ. The heat price used is sufficiently conservative, as the average heat price from coal sources from the primary distribution system in the Czech Republic is EUR 11.86/GJ. For example, we can also set the required efficiency of the source based on the requirements for efficiency

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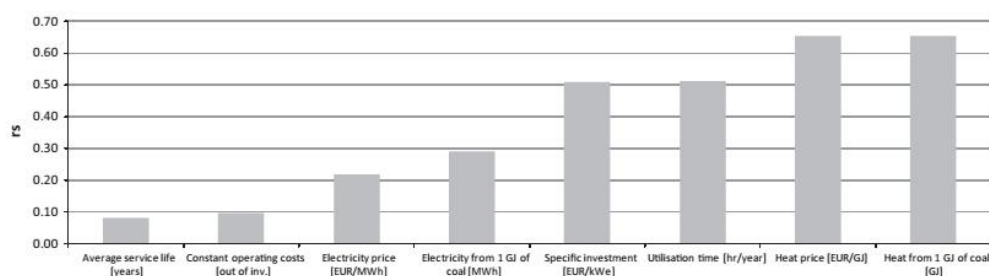


Fig. 5. Electricity and heat producer's relative sensitivity to most important input data.

utilisation of primary energy resources under the current EU energy policy, thus motivating the producers further towards more efficient technologies. The difference between coal and heat price is primarily given by the plant's efficiency. In addition, the heat price absorbs cost items and profit specified in Eqs. (2) and (3) (see Fig. 5 for sensitivity analysis of electricity and heat producer):

In our case of model verification, we defined the electricity and heat producer as a combined heat and power (CHP) plant with a prominent heat production. This is in line with the current trend of efficient utilisation of primary energy resources. We also regard it appropriate for ineffective condensation production to bear the economic consequences of a non-economic operation. The economically justified price of coal, set in a way that all the parties involved in the transformation process realise equal revenues, makes it possible to conclude long-term contracts in which neither party will be advantaged. All the involved parties will thus gain assurance for long-term investment planning.

When seeking the price of a primary energy resource, it has to be borne in mind that the final product of a heating plant is heat and electricity (typically only electricity in a power plant). We can say that the prices of these final products will be reflected in the prices of the inputs for the transformation process, i.e., notably the price of the primary energy resource. The technical and economic intensity of the transformation process has an effect on the size of the price that would be acceptable under given market conditions. If for any reason the price of electricity and heat is low, so will the demand for the primary resource. This means its market price will also be low as long as there is a relevant market for this primary resource. Theoretically, the market price of the primary resource and the price of the primary resource derived from the final production price should then be identical. That would hold under ideal conditions with no market distortions caused by any type of tax, support for selected types of resources, or other influences.

5.2. Other possible application of the methodology

The case study in chapter 3 represents the application of the developed methodology in solving the typical business dispute using the typical reference data in the case of brown coal pricing in current Czech conditions. The methodology can be applied anywhere, wherever the technically integrated system is separated into individual business entities and in the absence of a market environment and when the given commodity has no direct substitute in the short run. So it can be used (upon retrieving the specific data) as the general methodology whenever one has to solve business disputes in the technically integrated chain (where one of the commodities in the chain is not subject to free market trade) with different legal entities owning and operating individ-

ual processes within the chain (even if there are more than two entities). The methodology is applicable also in cases where more than two independent legal entities exist within the given value chain.

Another application of the developed methodology can be found, for example in the case of heat delivery from the district heating systems where a technically integrated system is split into individual parts owned and operated by different companies having different owners with different interests – bearing in mind that heat from district (centralized) heating systems is also the local commodity without a “general” market. Another possible application of the methodology is market analyses when an international investor enters new territory (e.g. brown coal mining branch, centralized heating systems, etc.). This is currently the situation where there is a desire to consolidate district heating systems entities by changing shareholders and who are in many cases interested in multinational companies. These applications are in fact based on the same principle as brown coal pricing. The methodology can also help solve similar problems arising from privatisation.

6. Conclusions

Brown coal is not a standard market commodity, which is shown in Table 1. The production of black coal is more than six times greater than that of brown coal, but the global trade in black coal is more than 170 times greater. In comparison to its substitutes, brown coal has a lower energy density. Once one combines this with current prices, the reason for its absence from the stock exchange becomes clear. Transportation costs make the use of brown coal economically inefficient when it is beyond a reasonable distance from the quarry site. Typical transportation costs can be estimated at around 0.4–0.6 EUR/GJ, 100 km [26].

So, in the case of brown coal, the calorific value is substantially lower and transport costs are, in proportion, significantly higher, thereby increasing the cost of brown coal for power plants. Moreover, brown coal power plants have a typically lower efficiency. So they need to transport more coal which inevitably adds to transport costs.

Owing to their different parameters, brown and black coal can be substitutes only at the time of the investment decision. The expected plant service life is, in fact, currently standardized to 40–50 years. This implies the need to ensure a certain fuel base for this period. That means to provide economic incentives to the mine owner to invest in the development of the mine and it is therefore necessary to ensure a fair share of the profit.

There is currently no publicly accessible and agreeable methodology for the pricing of brown coal that would be acceptable to both the extractive and the productive components of the fuel chain. After privatisation, when the power plants had been sepa-

rated from the mine owners, this is the default task which remains unresolved. Current low electricity prices put pressure on the solution to the problem. As has been mentioned above, brown coal is not a standard market commodity. Taking that into consideration, creating stable and transparent brown coal pricing rules is very important.

The proposed methodology determines a reference base price of brown coal, which may facilitate a simplification of the negotiation of new contracts and may be used by regulatory bodies in deciding on disputes between the extractive and the productive components of the fuel chain. Our methodology is not designed as an input output model. It distributes an internal profit in the value chain, which gives a fair price signal and also gives an impulse for long-term development and investment decision making. The fair price signal itself reflects the external macro-economic data.

The necessity of solving the issue of “objective” pricing methodology for brown coal has begun to emerge in the Czech Republic in years 2009–2012. Then long-term contracts between mining companies and independent cogeneration plants begun gradually expiring. Brown coal is not a market commodity and in principle is non-substitutable by other fuel commodities (without significant investments). For this reason it is problematic to set the brown coal price so that the productive and extractive component adequately participates in the division of economic effects arising from the use of brown coal. The absence of a generally accepted methodology in some cases even led to series of business disputes potentially threatening heat supply in district heating systems (DHS).

The principles of this methodology can be currently used by mining companies as the basis for new contract negotiations. It can be also used to solve arbitrations that have arisen from the fact that the generally accepted methodology had not exist.

The proposed methodological approach is applicable to solving similar tasks where technically integrated systems are separated into individual business entities (possibly with different business strategies) and in the absence of a market environment. Heat delivery from (so-called centralized) district heating systems serves as a good example. These systems are characterised by the chain of heat production (typically an independent cogeneration plant) – heat distribution (primary and secondary heat grid) and by retail. Here it is necessary to solve the same problem, i.e. how to split the “chain” profit throughout the individual entities participating in the chain. This task is similar to that of brown coal pricing because of the local nature of heat delivery and consumption. This task is also one of the most economically, technically and even socially sensitive challenges which is under discussion and research at present. The advantage of this methodology is the fact, that it is internationally portable in the cases mentioned above. So it can apply beyond the Czech Republic used wherever the technically integrated system is properly separated.

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Appendix A

In this section, we derive a simplification of the calculation of the brown coal price. Starting from Eq. (2), the resulting price of brown coal for the extractive component of the fuel chain can be rewritten as:

$$C_t(r) = k_{0t} + k_{1t} \times a_t(r) \quad (\text{A.1})$$

where k_{0t} and k_{1t} are constants independent of r :

$$k_{0t} = \frac{O_t \times T_{zt} \times n_{st}}{Q_{pal}} + N_{pt} + N_{dt} + N_{vyd} \quad (\text{A.2})$$

$$k_{1t} = \frac{O_t \times T_{zt}}{Q_{pal}} \quad (\text{A.3})$$

The constant k_{0t} is in fact the specific operating cost to the extractive component of the fuel chain, and the constant k_{1t} represents the specific investment costs to this component. Eq. (3) can be rewritten analogously for the resulting price of brown coal for the productive component of the fuel chain:

$$C_v(r) = k_{0v} - k_{1v} \times a_v(r) \quad (\text{A.4})$$

where k_{0v} and k_{1v} are again constants independent of r :

$$k_{0v} = Q_{vyr} \times (1 - k_{vst}) \times C_{tep} + E_{vyr} \times (1 - k_{vse}) \times C_{el} - n_{iv} \times n_{sv} - e_{CO2} \times C_{CO2} - N_{pv} - N_{dv} \quad (\text{A.5})$$

$$k_{1v} = n_{iv} \quad (\text{A.6})$$

In this case, the constant k_{0v} equals the specific operating profit from 1 GJ in the coal (earnings before interest, taxes, depreciation and amortization – EBITDA) and the constant again represents the specific investment costs to the productive component. After substituting for the annuities and simplification, Eq. (1) yields the resulting equation for identification of the return r :

$$(k_{0t} - k_{0v}) \times r + k_{1v} \times [1 - (1 + r)^{-T_{zv}}] + k_{1t} \times [1 - (1 + r)^{-T_{zt}}] = 0 \quad (\text{A.7})$$

It is obvious that, with the exception of special cases of combinations of the constants, this equation has to be solved numerically. A similar conclusion holds for the case of using continuous interest rather than composed interest, where again the following equation is solved numerically:

$$(k_{0t} - k_{0v}) \times r + k_{1v} \times (1 - e^{-T_{zv} \times r}) + k_{1t} \times (1 - e^{-T_{zt} \times r}) = 0 \quad (\text{A.8})$$

Generally, we would now have to discuss for which parameters the above equations have real positive roots. Since we know that the constants in these equations have a clear economic foundation and meaning, it is enough for the existence of a real positive r that all the constants k are non-negative. This condition is always met for the constants k_{0t} , k_{1t} and k_{1v} . If the constant k_{0v} is negative, there is no point solving the problem, because the productive component of the fuel chain is inefficient even with a zero coal price. After the return r is identified, the resulting price of brown coal is determined based on Eqs. (2) or (3).

Appendix B

Data are derived from statistically processed database of heat supply and mining companies in the Czech Republic. Price level corresponds with the year 2013 (see Table B.1).

Appendix C

(See Table C.1).

Table B.1

Numerical values used to solve Eqs. (1)–(3).

Productive component		Extractive component	
Electricity price Cel [EUR/MW h]	38.59	Depreciation Ot [EUR]	18,568,200
Heat price Ctep [EUR/GJ]	10.42	Average service life Tzt [years]	50
Heat from 1 GJ of coal Qvyr [GJ/GJ]	0.63	Required return per own capital r	0.1
Electricity from 1 GJ of coal Evyr [MW h/GJ]	0.06	Other variable costs Npt [EUR/GJ]	0.964
Own electricity consumption kvse [out of electricity produced]	0.07	Constant operating costs nst [out of inv.]	0.036
Own heat consumption kvst [out of heat produced]	0.03	Coal delivered Qpal [GJ]	95,200,000
Other variable costs Npv [EUR/GJ]	0.308	Fee for minerals mined Nvyd [EUR/GJ]	0.031
Specific investment [EUR/kWe]	1930		
Average service life Tzv [years]	40		
Required revenue r	0.1		
Constant operating costs nsv [%]	0.03		
Utilisation time [hr/year]	3700		
Price of emission permit CO2 [EUR/GJ]	1.27		
CO2 emission from 1 GJ of coal CO2 [t]	0.1		
Specific costs of coal transportation of the productive component [EUR/GJ]	0.579		

where niv = specific investment/(Utilisation time/1000/Evyr).

Table C.1

Nomenclature.

°C	The degree Celsius
ARA	Amsterdam, Rotterdam, Antwerp (black coal price)
ASTM	American society for testing and materials
CHP	Combined heat and power
CTU	Czech Technical University
DHS	District heating systems
DIN	Deutsches Institut für Normung
EBITDA	Earnings before interests, taxes, depreciation and amortization
EU	European Union
EUR	Euro
GJ	Gigajoule
kg	Kilogram
kJ	Kilojoule
km	Kilometre
m ³	Cubic metre
MJ	Mega joule
Mt	Million tonnes
MW h	Megawatt hour
NPV	Net present value
RES	Renewable energy sources
t	Tonne
UNECE	United Nations Economic Commissions for Europe
USA	United States of America

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BIDDING ZONES RECONFIGURATION - CURRENT ISSUES

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Bidding Zones Reconfiguration – Current Issues

Literature Review, Criterions and Social Welfare

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Abstract— The aim of this paper is to introduce methods of solution regarding current issues of electricity markets integration in Europe. The focus is pointed on bidding zones overview and bidding zones reconfiguration process in general, meantime the situation in central Europe will be analysed more deeply.

Bidding zone can be defined as an area without internal business congestion. It means that transaction can be completed between any two points inside this area and electricity can be transferred without requirement of transmission capacity allocation. Bidding zones borders in many countries are the same as the political borders because countries were more isolated in the past than in present time. This situation is changing with the increase of international cooperation. Countries like Czech Republic, Slovakia, Poland, Hungary and France are examples of bidding zones that are identical with political borders. On the other hand, there is a single bidding zone that includes Germany, Austria and Luxembourg (DE-AT-LU).

The most scrutinous issue of bidding zones configuration covers DE-AT-LU zone where the problems with internal congestion occur and correspondingly affect surrounding bidding zones, especially Czech Republic and Poland. Transmission capacities inside this zone are insufficient. Electricity flows through neighbouring grids and constrains transmission capacities for local market participants. This article presents criteria that might be used for bidding zones reconfiguration with the main accent on social welfare concept applicability. Social welfare is a wide term which is investigated in this paper under bidding zones reconfiguration problem. (*Abstract*)

Keywords—bidding; zones; reconfiguration; electricity; markets

I. INTRODUCTION

European energy market has progressively developed and integrated since the liberalisation introduced by the First Energy Package in 1996, and it currently passes through the third Energy Package which was proposed by the European Commission in September 2007, and adopted by the European Parliament and the Council of the European Union in July 2009.

The key principles of the third package include third party access and ownership unbundling which stipulate competitive

conditions on the market. Previously essential energy facilities (electricity networks and gas pipelines) were usually owned by companies who also produced and supply energy. Third party access means that anybody wanting to supply electricity or gas to customers or to distribution companies to supply in the area should give the access to these companies in order to let them transport their energy. The underlying terms and conditions of the third party access principle should be fair and reasonable and are supervised by national regulators. However, the European Court has ruled that the concept of the third party access only relates to the access to the system and it does not cover related issue – connection which is governed by the National Law. The principle of unbundling means that certain functions that were in the past offered by single companies have to be parcelled out, and, in a particular, the function of transmission has to be separated and operated independently from all the other parts or functions of the vertically integrated energy companies. This principle provides independence of Transmission System Operators (TSOs) and Distribution System Operators (DSOs) ensured by European legislation. For TSOs the unbundling rules are rather strict, the European Commission has emphasized structural/ownership unbundling: the transmission pipelines or networks should in fact be owned and operated by a completely separate entities with their own resources, management, executive and it should be no relationships between these TSOs and any other part of the energy supply or production business.

In order to consider the current and future status of the transmission network there were implemented bidding zones – network areas within which market participants can offer energy (in the day ahead, intraday and longer-term market time frames) without having to acquire transmission capacity to conclude their trades.

Currently not all of bidding zones coincide with a natural country boarder. Germany, Austria and Luxembourg constitute one single bidding zone, that cause a problem of closed capacities that cannot reach in the required amount neighbouring countries, such as Czech Republic, Poland and Slovakia. That is why there is a crucial necessity in developing criteria that will help to identify amended bidding zone and then to reconfigure it meeting all the market and social requirements.

For the sake of completeness, nodal pricing should be mentioned, however it is not applied on Pan European level. Nodal pricing approach comes from the idea that electricity price can be calculated based on real electricity flows for each point in electricity grid. This approach results in many nodes with individual electricity prices. There will be price differences within individual countries that are actually not usual for customers and that will lead to big changes on European market.

II. BIDDING ZONES ORIGIN

Transmission pricing in market environment was the issue in US electricity market in the beginning of the 90s. The pioneer in this field was professor William Hogan from Harvard University. He published paper [1] dealing with contract networks addressing the problem of loop flows and congestion in electricity transmission system. System for trading of transmission capacities at market based prices was introduced in [2] and the methodology and preliminary results were published in [3]. Difficulties with transmission prices for improperly configured bidding zones are described and demonstrated in [4]. The issue of prices distortions in the zonal configuration where zones are free of congestion are discussed in [5]. Hogan's publications regarding competitive electricity market design [6] and nodal and zonal congestion management [7] play important role in the development of US electricity market and can be useful for European case.

III. BIDDING ZONES IN EUROPE

Bidding zones theory development was based on the US electricity market development. Papers regarding European market development are connected with the literature mentioned in the previous paragraph and reflect actual issues of bidding zones implementation in Europe.

The creation of bidding zones in specific countries is covered in following sections. The emphasis is put on central Europe because of issues regarding DE-AT-LU bidding zone reconfiguration. However, northern Europe and Italy are also covered because these countries have experience with bidding zones configuration and can be used as the source of relevant information.

A. Northern Europe

The number of bidding zones in Norway is not fixed and can be changed according to the development of transmission grid or in case of grid failures. The exact configuration of bidding zones in Norway is based on detailed analysis of the transmission lines. TSO submits to Nord Pool Spot quarterly in-depth analysis with 5-year outlook. All changes in bidding zones configuration are proposed in maximum advance. [8]

Sweden was divided into four bidding zones in 2011. This process was based upon decision of European Commission that resulted from appeals of market participants in Denmark. Swedish TSO had 18 months for implementation of bidding zones since European Commission decision. Swedish case is only explicit information about the required duration of zone splitting process. [9] One of the objection raised regarding European Commission decision was that it would jeopardize

some already signed long-term financial and supply contracts. Commission noted that market participants in electricity markets are exposed to all kinds of risks, and general change of regulation, namely, the introduction of bidding zones, is merely one example.



Fig. 1. Bidding zones in Northern Europe [10]

B. Italy

Bidding zones in Italy were introduced in 2006 and their origin is in heterogeneous nature of Italian power grid. Italy is divided into 6 geographical bidding zones; however other virtual zones exist. For more information see [11].



Fig. 2. Bidding zones in Italy [12]

C. Central Eastern Europe

Bidding zones borders in Central Eastern Europe are the same as countries' geographical borders with the exception of DE-AT-LU bidding zone. DE-AT-LU bidding zone was established in 2005, but the process of its legal origin is not almost described. This bidding zone was created without any coordination with neighbouring countries. The curiosity of DE-AT-LU bidding zone is the presence of scheduling mechanism for electricity flows inside of the bidding zone. The reason is that transmission capacities within the zone

(north - south direction) are insufficient. The proof of this statement can be found on Austrian Power Grid operator web page [13] where intraday trading stops occur very often because of critical loads flow. Insufficiency of network capacity within DE-AT-LU bidding zones results in power flows through neighbouring zones, mainly Czech and Poland. This situation is documented in TSO reports [14], [15]. Independent report about this issue was prepared for European Commission [16]. Solution was also proposed in this report.



Fig. 3. Bidding Zones in Central Eastern Europe [12]

The main issue is that market participants from neighbouring grids (mainly electricity traders) cannot use transmission capacities from/to DE-AT-LU zone because these capacities are taken by unscheduled electricity flows. These market participants are not compensated and they are discriminated because of unequal market conditions. Moreover, Czech, Polish and Slovak TSOs do not get paid for this unscheduled flows as the source and sink areas are in the same bidding zone. In other words, these flows are treated as intra-zonal power flows.

IV. POWER FLOWS

Over the last decade, the European transmission grid structure has changed a lot due to its expansion and changes of legislation coming out of the Third Energy Package. Along with these changes new challenges for the market connected with loop flows and transit flows came. Such power flows limit normal operation of existing energy-exchange bidding zones making market coupling ineffective. Within a bidding zone, market participants are able to exchange energy without allocation, so there no major congestions resulting from transactions through bidding zones [17].

Current solutions for the electricity market provide scheduled market flows and corresponding prices derived from the bids and offers from market participants within a certain bidding zone which borders usually coincide with the national ones. However, in the electricity grid, there are substantial fluctuations of scheduled power flows from the actual or so-called physical flows since the situation on forward, the day ahead and even intraday energy market hardly ever reflects the reality. Such deviations between set or scheduled flows and actual flows are defined as unscheduled flows.

Transit and loop flows are the particular case of unscheduled flows affecting additional costs (external) on the host area in case the grid is overloaded with the flow and cannot operate properly. These power loop flows occur when a certain country is not able to facilitate internal grid infrastructure to handle with new generation (eg. wind), and so the power is transported via neighbouring countries' grids and then back into a different part of the producing country [18].

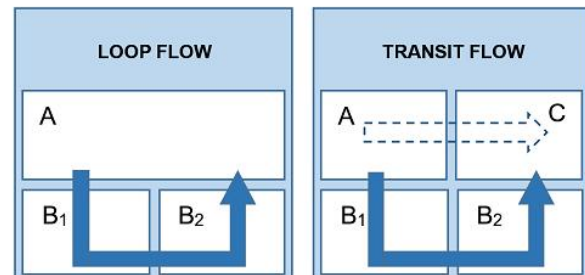


Fig. 4. Unscheduled flows responsible for additional costs in adjacent grids

The problem of loop and transit flows is becoming more and more common for countries which are developing new generation objects with large amounts of installed capacity, but do not advance existing grid infrastructure to make it able to transfer energy output to demand areas. One of such countries is Germany with its vastly developing wind generation. Increased demand for energy caused the necessity of additional generation, but the grid transmission system within the country does not allow its transferring, so it is implemented via eastern neighbouring countries such as Poland, Czech Republic and Slovakia, which correspondingly suffer from overloadings. Slovakia has no direct connection to DE-AT-LU zone, however unscheduled flows flow via Czech Republic, Poland, Slovakia, Hungary to Austria.

Thus, the transit and loop power flows problem represents the crucial issue of the European energy market. Therefore, proper handling of the challenges for some bidding zones suffering from loop flows should be developed in order to provide their delimitation and flow-based market coupling with sufficient price signals (adequate reflection to the physical grid) and energy balance.

V. CRITERIA FOR BIDDING ZONES RECONFIGURATION

Most of the criteria for bidding zones reconfiguration can be understood as a set of tools which can be used for modifications in current bidding zones configuration. They can be also used for assessment of bidding zone effectiveness. The most of the criteria result from a guideline on Capacity Allocation and Congestion Management (CACM) [19]. This guideline, however, does not exactly define criteria. It only defines some rules that should be taken into account when reviewing existing bidding zones configuration.

A. Congestion Rent

According to [20] congestion rent is "the amount collected by the owners of the rights to the transmission line. In a one-line network these rights would typically pay the owners an

amount equal to the line's capacity times the difference between the prices at the two ends of the line. In the case of a load pocket, this is the difference between the internal price and the external price. Congestion rent is a transfer payment from line user to line owner, as using the line has no actual cost." Equation (1) represents the calculation of congestion rent. $P_{\max} - P_{\min}$ is the difference in marginal prices and Q is power flow.

$$CR = (P_{\max} - P_{\min}) \times Q \quad (1)$$

B. Remedial Actions

The Remedial Action means, by ENTSO-E, are defined as: "a measure activated by one or several System Operators, manually or automatically, that relieves or contributes to relieving Physical Congestions. They can be applied pre-fault or post-fault and may involve costs" [21].

Two main and mostly used measures within the remedial action, with direct payments to secure the service, are Countertrading¹ and Redispatching². However, there could be also other measures that are connected with direct costs. There are also costless³ actions such as reconfiguration of transmission grid (e.g. shut down of transmission line).

The objective function, as a subject of optimization, is defined only as the sum of all costs caused by remedial action. The optimum variant is logically the one with lower overall costs.

C. Difference in Marginal Prices

Difference in electricity marginal prices between two interconnected nodes (zones) signalizes the congestion on lines between these nodes. Two adjacent nodes can be grouped into one zone if there is no congestion between them or there can be set the limit on the congestion level (or difference in marginal price). The second option leads to increasing of redispatch costs and violates the principle of bidding zone definition. However, it can be chosen in case of specific geographic condition (islands, mountains, etc.).

There are spot prices and long-term contracts prices. Spot prices are mostly created by sources with available short-term capacities that respect immediate demand (good example can be the August 2015 with high temperatures limiting power generation and conventional power plants in contrary to extremely high demand for power consumption for air conditioning). Marginal price can be understood as the marginal price of long-term and short-term contracts.

Maximizing of marginal prices differences leads to bidding zones formation and weighted sum of marginal prices (e.g. by capacity or power flows) can be used as a criterion function.

¹ Countertrading means a Cross Zonal energy exchange initiated by System Operators between two Bidding Zones to relieve a Physical Congestion

² Redispatching means a measure activated by one or several System Operators by altering the generation and/or load pattern, in order to change physical flows in the Transmission System and relieve a Physical Congestion

³ Energy losses are neglected

On the other hand, marginal prices difference can be used as a constraint in social welfare optimization.

D. Price Volatility

Price volatility is calculated as standard deviation of prices in zones (or nodal prices) during specified period. Price volatility can be used for zonal formation similarly to marginal price, but only as a supplementary criterion (or constraint) because price volatility can be the same for two regions with different average price value.

This approach was applied in WSCC (Western Systems Coordinating Council) region in US.

"The objective of the analysis was to identify geographic zones within which the variance is small relative to the variance between the zones. A simple difference-of-the-means test was applied to the hourly data to test the probability that the two zonal samples were, in fact, part of a single sample. Within each of the hypothesized zones a further analysis was undertaken to identify any bus values that were outliers (i.e. further than two standard deviations from the mean) and to question whether this might indicate that these buses should be moved from one zone to another". [3]

"Applying these two criteria and visually inspecting the hourly probability plots for each scenario, it was possible to combine four zones into two zones (in the Northwest and in Arizona) thus reducing the number of zones in the WSCC from 17 to 15. Interestingly, no individual buses were moved from one to another zone as a result of this process". [3]

E. Transition Costs

Transition costs have different nature compared to other components of social welfare calculation. These costs are non-recurring. To compare transition costs with other components of social welfare calculation we need to determine the time frame for the evaluation. The definition of the relevant time horizon is complicated due to the fact that all other factors influencing structure, scope and effectiveness of the power market should remain approximately stable. Thanks to uncertain character of power market development in EU (also thanks to unfinished discussion about the future continuation of energy only market idea), these one-time costs should be compared in maximum five-year horizon for other social welfare components determination. This time frame is at the moment supported with the fact that many of the currently defined EU goals are set-up to the year 2020 (renewable energy sources goals, climate policy goals, CO₂ allowances, etc.). Direct comparison (without definition of evaluation period) of one-time costs with cost item occurring annually would lead to inadequate decisions. Assumption of five-year period for comparison of different bidding zones options make sense also from the fact of relatively high inertia of market participants decision making (possibility to react both on supply and demand sides to changes in power market).

F. Social Welfare

Social welfare maximization (in terms of energy market) can be defined as the maximization of consumers and producers surpluses regarding redispatch and countertrading

costs. In general, larger bidding zones lead to higher social welfare in case bidding zones formation conditions (such as no internal congestion) are fulfilled. General way of social welfare calculation in case of one exporting and one importing region with defined transmission capacity for cross-border trade is calculated as the sum of consumers' and producers' surpluses, congestion revenues decreased by congestion costs.

VI. SOCIAL WELFARE DISCUSSION

Social welfare is the concept based on evaluation of all possible effects resulting either from some action (e.g. creation of new interconnecting capacity between two regions) or consumption of given commodity or service. According to the economic theory, social welfare is a measure of well-being of the entire society. In relation to given action or commodity (or service) consumption social welfare can be understood as the sum of effects resulting from the consumption. It can include direct and indirect economic impact.

Direct economic impact is relatively easy to determine (e.g. decrease of power prices in power importing country if electricity price in power exporting country is lower). Also costs of redispatch fall into this category.

There are indirect economic impacts for which it is impossible to directly evaluate their values. They should be determined using models testing differences between situation with action and without action (e.g. construction of new interconnector between two regions or keeping the current state). These indirect impacts can include among other:

- Increase or reduction of business companies' competitiveness (e.g. current allocation of energy intensive industries does not necessarily follow allocation of power generation capacities. Germany can serve here as the good example with so-called Northern region with the excess of generation capacity compared to the power consumption and with Southern region with the excess of demand over consumption).
- Increase or decrease of trade possibilities for wholesalers with electricity (e.g. reconfiguration of bidding zone with congestions causing loop flows in other, zone has symmetric impacts to the wholesalers in both zones but with different sign).
- Increase or reduction of the economic welfare (part of the social welfare) of households as the increase or decrease of disposable income.

There are indirect impacts which are part of social welfare definition. These impacts are typically regarding not only the market participants (i.e. consumers, producers and TSOs), but also the third parties or entire society. One can mention impacts such as:

- Changes in total environmental impacts (greenhouse gas emissions, emission of conventional gaseous pollutants, solid wastes etc.) related with the power generation as the result of changes in merit order power generation fuel mix used.
- Energy reliability, security, and the impact to energy policies of individual EU member states and of EU.

VII. DISCUSSION

Many authors discuss two different terms – economic welfare and social welfare. The term economic welfare is based on the logic of market equilibrium between supply and demand. If all the cost related with the given commodity (here electricity) are born by the suppliers and all the benefits are on side of consumers, the market equilibrium will result in largest possible economic surplus (i.e. economic welfare). If other subjects (not buyers) benefit from the electricity consumption or if subjects other than sellers bear the cost of electricity production, transmission, the total welfare should be defined as the so-called social welfare. Definition of social welfare thus includes also the benefits and costs of third parties, which are not directly included in market transactions. In many cases, it is very hard to identify and evaluate in monetary terms these effects on third parties and therefore reduction to economic welfare is often made.

There are a lot of criteria that could be used as a basis for bidding zones reconfiguration. The problem of these criteria is their unclear definition, calculation or application. The examples of these criteria can be market depth, clearing prices, electricity production based on specified technologies, CO₂ emissions, adverse effects and many others.

We think that the best way is to use simple, well-defined criteria that are easily applicable. Various criteria application has impact on social welfare and therefore one can at least observe this impact. We think that bidding zones should be primarily reconfigured on congestion basis. It means that congestion should be the primary criterion for bidding zones formation. Other criteria such as remedial actions and congestion rents are strongly correlated with underlying physical congestion and can be used as a secondary measure. For example, remedial actions are used due to the congestion and when congestion is minimized, remedial action will be also minimized. This will lead to social welfare increase. Transition costs are one-time costs and we think these costs can be neglected in long term because if the reconfiguration process is designed properly, it will not require high additional costs in future.

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ELECTRICITY MARKETS INTEGRATIONS – WHAT IS THE CURRENT STATUS AND FUTURE OUTLOOK OF BIDDING ZONES RECONFIGURATION?

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Electricity Markets Integrations – What is the Current Status and Future Outlook of Bidding Zones Reconfiguration?

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Abstract — The aim of this paper is to summarize the current status of the EU Electricity Market Integration, especially address the highly discuss issue of Bidding Zones Reconfiguration, analyse proposed criterions for the potential reconfiguration and also discuss possible future development.

Speaking of Bidding Zones Reconfiguration the mainly discussed issue is the German-Austria-Luxemburg trading zone (DE-AT-LU) where the problems with internal congestion occur and correspondingly affect surrounding bidding zones, especially Czech Republic, Slovakia and Poland. Transmission capacities inside this zone are insufficient and unscheduled electricity flows through neighbouring grids and constrains transmission capacities for local market participants. This has resulted, among others, into installation of phase shifting transformer at Czech-German and Polish-German borders. There is therefore an urgent pressure to solve this situation and most promising and investigated option is to split the DE-AT-LU zone in to two and even the Germany's power grid regular address all 4 Germany TSO to prepare the introduction of capacity allocation on the border with Austria. On the other hand, there are arguments that go against this and they support the idea of even larger bidding zones (further integration) rather than division of current bidding zones (that is especially the case of DE-AT-LU zone). These arguments are mainly based on the liquidity of the market. If divided there is also a problem of current traders' open positions on derivate contracts (within DE-AT-LU zone these contracts are estimated at over €20 bn.).

This article is therefore investigating the whole process of proposed splitting process with the focus on presented criterions that should be used to find the optimal configuration. The special focus is paid to the applicability of social welfare as one of the “unclear” criterion that has the potential to strongly influence the whole decision making process.

Based on the analyses we can conclude that the main approach to the process of reconfiguration is solid however, the results will strongly depend on the final settings (limiting values) of individual criterions and final weights of each criterion. Without this information, the whole process can be rightfully opposed by any involved participant. (Abstract)

Keywords: bidding; zones; energy; markets; social; welfare

I. INTRODUCTION

A. Problem Description-current situation

The integration of European Electricity Market is on ongoing process. It has been effectively started by the First Energy Package (1996) and the main aim was to develop common effective market platform. Unfortunately the market integration has also shown some drawbacks. One of the biggest problems has been identified within the Central East Europe (CEE). Businesses operation on the electricity market in the CEE Europe Region, mostly in geographical location of Czech Republic and Poland, meet the problem of insufficient electricity transmission capacities on the border with Germany. [1], [2] Available transfer capacities are severely limited especially due to the influence of so-called loop-flows (flows within the Germany-Austrian (DE-AT) bidding zone, which flow through the transmission system of neighbouring countries). This situation is caused mainly by following reasons:

- very high generation capacities based mainly on intermittent RES located in the northern part of Germany,
- lack of transmission capacities from northern part to southern part of Germany (where are located significant consumption capacities),
- Energiewende program that will result into full phase out of nuclear power plants in Germany [3], which will lead to intensification of distribution of electricity generation and consumption.

The affected business entities (electricity traders) are currently losing business opportunities and their losses are not compensated [4], [5]. Loop-flows are unscheduled power flows and currently are almost not a subject to payments for usage of transmission system. This situation is caused mainly by insufficient transmission capacities in Germany. However construction of new power transmission lines has long delay (especially thanks to the fact that the major parts of new transmission lines must be put underground) and the forecasted cost will be significantly higher (up to four times more).[6]. This means that current situation will not be solved (from the technical point of view) in the short term period.

The most promising and effective solution of this problem can be seen in splitting of Germany-Austrian bidding zone into several smaller bidding zones. Current situation is profitable for participants from Germany-Austrian bidding zones because cheap electricity from wind power plants from

northern Germany can be transferred to southern Germany and Austria without payment for transmission fees. Whole Germany-Austrian bidding zone benefits from lower electricity prices. If this zone were divided, there would become a difference in electricity price between new zones (e.g. northern and southern Germany) [7]–[9]. This price difference would be caused by requirement of transmission capacity allocation and related costs. Czech and Polish transmission system operators would obtain revenues from transmission capacity utilization. Moreover, companies (mostly electricity traders) from Czech Republic and Poland could take place in capacity allocation mechanism and they could have opportunities of trading abroad.

On the other hand there are also efforts from the electricity traders to maintain the current configuration of DE-AT bidding zone. The main concern is the negative effect of zonal splitting to forward market liquidity, wholesales market power and retail competition. The European Federation of Energy Traders (EFET) issued, among others, an investigation [10] describing what happened in Sweden after splitting into smaller bidding zones in 2011 from the electricity traders point of view. Even though Swedish Energy Market Inspectorate stated that the reconfiguration had not any major negative effects, EFET argues that based on the hard data evidence from Sweden there, in fact, were negative effects in terms of the amount of future contracts traded on Nasdaq as well as the drop in the liquidity. Based on this evidence EFET strongly suggest that economic consequences have to be taken into account.

This situation can serve as a great example of contradictory views on current discussion about DE-AT bidding zone reconfiguration. Therefore it is obvious that even though the technical criterion will play significant role in the potential splitting process, economic and social criterion must be taken also into account - the right question is how and to what extent.

B. Historical Background

Bidding zones theory was developed in 90s in US by [11]–[16] as the consequence of power grid congestion (insufficient electricity transmission capacities). Market liberalization and integration process in Europe begun significantly later.

Bidding zone can be defined as an area without internal business congestion. It means that transaction can be completed between any two points inside this area and electricity can be transferred without requirement of transmission capacity allocation. Bidding zones borders in many countries are the same as the political borders because countries were more isolated in the past than in present time. This situation is changing with the increase of international cooperation. Countries like Czech Republic, Slovakia, Poland, Hungary and France are examples of bidding zones that are identical with political borders. On the other hand, there is a single bidding zone that includes Germany, Austria and Luxembourg. [17]

Germany-Austrian (DE-AT) bidding zone was established in 2005, but the process of its legal origin is not almost described. We assume that DE-AT bidding zone does not fulfil condition for being full independent bidding zone. The main reason is that DE-AT zone cannot be understood as "copper plate" due to the congestion of transmission lines. ACER (Agency for the Cooperation of Energy Regulators) has adopted a legally non-binding opinion to split the German-

Austrian single bidding zone. However this opinion could not start the splitting process (especially when Austria is strongly against) therefore the comprehensive bidding zone review is being done by European Network of Transmission System Operators (ENTSO-E). It should be finished by the end of 2017 and if it supports the break-up ACER, according to declaration of head of wholesale markets at the European Commission, should be responsible "to define a new split model against the wishes of Austria".[18]

Once the splitting process is started there is also a question how to settle current open positions of electricity traders. It is estimated that these positions on DE-AT border are worth up to €20 - 25bn. According to [18] there are three potential options:

- "The introduction of new futures products specifically for Germany or Austria, with existing positions rolled into the new ones."
- "The introduction of a system price – as is used in the Nordic and Italian markets – which would be used to settle against, and would be generated by trade in the two separate price zones."
- "An "adjustment" of the existing Phelix futures to reflect the price zone split."

The whole process is therefore lying on the results of above mentioned bidding zone review. It is obvious that the main focus is will be on defining critical grid elements that violate the "copper plate" principle. To do that the whole European electricity grid has to be modelled and therefore the following section is devoted to the main principles of electricity flows calculation as a primary manner for the identification of congested grid elements.

II. CORE IDEA

The main reason for bidding zones reconfiguration is congestion of power lines resulting in unscheduled power flows in neighbouring grids. Central European power grid was recently modelled in [2] and results present congested power lines. Comprehensive review of bidding zones definitions, history, development in Europe and criteria for reconfiguration, were introduced in [17] and its brief summary was presented in introductory section.

There are several issues related with calculations of power flows, identification of unscheduled flows and identification of critical branches.

1. Power flows in grid are usually decomposed using Kirchhoff laws, however other method "Natural Flows" (NF) was used in material [19]. It is necessary to compare results of power flow decomposition (PFD) to NF.
2. The other issue is finding relevant and critical power grid elements required for power flows calculation. European grid is large and using all elements would lead to very complex calculation. Rational aggregation and simplification will be needed.
3. To be able to find relevant grid elements, their load and congestion has to be reported in meaningful way. Load of the grid elements is changing in time. Critical load can last short or long time, it can occur rarely or frequently.

Based on above specified issues, part of this article will be devoted to description of grid element load and selection of relevant elements for further analysis.

III. GRID ELEMENT LOAD DESCRIPTION

The aim is to find a set of statistics and tools that accurately describe the load of the elements while being simple to understand, compute, and interpret.

In the statistical representation of the elements load, we assume that we will have a time series of physical flows on grid elements. To describe the situation on an element, we propose a combination of the following statistics.

1. Arithmetic mean or other measure of central tendency (modus, median). Describes the predominant direction of electricity flow. In case of zero average, we can use median or modus. If there were a situation when the average and the median were zero, it can be concluded that there is no predominant flow direction.
2. Standard deviation. It is possible to estimate the changing intensity of the flow of the element.
3. Maximum and minimum flow value.
4. Variation coefficient. It is defined as the ratio of standard deviation and arithmetic mean. This is a standardized standard deviation, making statistics comparable between calculations on lines with different capacities. The problem may occur in situations where the average is close to zero, because the value of the coefficient may be high. In this case, we can use absolute flow values.
5. Quantiles (10%, 90%, possibly others) and the quantile in which the sign of the flow changes (if it changes). This characteristic provides information on the statistical distribution of flows. It can serve to determine the likelihood of changing flows.
6. The number of changes in the sign of the flow over a period.
7. The number of exceedances of the predetermined flow threshold value on the element. Circular flows cause flow fluctuations on the network element, and we can identify how often this fluctuation occurs when the threshold value is set correctly.

IV. RELEVANT GRID ELEMENTS SELECTION

In this section, we focused on appropriate selection of relevant elements for loop flow analysis. In our opinion, it makes sense to monitor the frequency and intensity of flows occurring on a network element. An undesirable state can be understood as exceeding a set flow limit on an element.

1. The limit can be defined as:
 - a. The percentage of the nominal load.
 - b. The percentage of the load in a base scenario.
 - c. The percentage of the difference between nominal load and load in a base scenario. This approach is appropriate if we assume that loop flows are not harmful if there is free capacity for them on specific grid element.

- d. The standard deviation (or its multiple) from the average value of the load in a base scenario.

2. Evaluation of limit exceeding:

- a. Simple (binary) cross-border information.
- b. The extent of the limit exceedance (absolute, relative).
- c. Duration of the limit exceedance.
- d. Intensity of the limit exceedance as the combination of exceedance extent and duration. We may also consider the product of the power and duration, i.e. energy, which flew through grid elements if limit was exceeded.

3. Determine the occurrence of undesirable states, e.g. period of year (number or percentage of 8760 hours per year) in order to consider grid element as relevant in further calculations.

Similarly, N-1 rule violation could be monitored. The number of hours (or percentage) of 8760 hours per year in which the N-1 rule was violated can give us also good information about relevancy of specific grid elements. The only problem is the data availability, because we would need large amount of data besides power flows. We think that the appropriate combination of suggested approaches can be used to select relevant elements for loop flow analysis. Specific combination of above-mentioned approaches (rules) can be found after deeper statistical analyses of reasonable amount of data.

Identification of relevant grid elements is only first (but very important) step towards the setting of criterion for bidding zone reconfiguration. However it is already known that the final decision will be made upon set of criterion with different weights. The most of the criterion result from a guideline on Capacity Allocation and Congestion Management (CACM) [20] and are:

- Congestion Rent
- Remedial Actions
- Difference in Marginal Prices
- Price Volatility
- Transition Costs
- Social Welfare

Detailed description of above mentioned criterion is discussed in [17]. From our point of view the most "problematic" criteria is the social welfare.

V. SOCIAL WELFARE APPLICATION AND CONCLUSION

One of the most robust economic criteria is the social welfare. As defined in [17] the social welfare "is the concept based on evaluation of all possible effects resulting either from some action (e.g. creation of new interconnecting capacity between two regions) or consumption of given commodity or service. According to the economic theory, social welfare is a measure of well-being of the entire society. In relation to given action or commodity (or service) consumption social welfare can be understood as the sum of effects resulting from the consumption. It can include direct and indirect economic impact."

Unfortunately, there is no unequivocal definition of social welfare and calculation of social welfare is very often (particularly in bidding zones reconfiguration) simplified to calculation of economic welfare. Economic welfare is defined

as sum of consumers' and producers' surpluses and in the context of bidding zones was described in [21]. Prices of electricity have strong impact on whole society because electricity is used widely and industrial production is very sensitive on electricity price. Economic welfare calculation does not include secondary (indirect) impacts on society and it is assuming homogenous region (e.g. Central Europe or Central and Eastern Europe). The other problem is purchase power in countries with different economic development [22]. Increase or decrease of electricity prices by one euro has different impact on German residents and Czech residents. This discrepancy should be reflected in social welfare calculation [17].

Even though the social welfare definition is still unclear, there are efforts to include social welfare criterion into current decision processes. We do not cast doubt on the main ideas of social welfare as a solid criterion, but we do believe it is necessary to continue discussions and research regarding achievement of clear definition including methodology for identification and calculation of all necessary inputs. Moreover, according to correlation between Social Welfare, Congestion Rents and Remedial Action criteria, it is possible to conclude that any optimization using Congestion Rents and Remedial Action criteria should lead also to increasing of social welfare.

Based on the materials that have been already published regarding the proposed criterion for bidding zones evaluation, we do believe that the best way is to keep all criteria as simple as possible with very unequivocal definition. Only in such case, results can be taken as a solid foundation for future reconfiguration of bidding zones in CEE region.

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