Application of the generating costs analysis as a tool for energy planning and training

Fedor Veselov, Energy Research Institute of RAS

Workshop to Exchange Experience among Trainers on the IAEA's Models for Energy System Planning

Vienna, July 2017

ИНЭИ РАН

Recent experience in learning the energy planning

Courses of lectures for Master and MBA students

- **“System analysis in energy sector. Modeling the development of energy systems”**
  - as a part of Master program “Strategic management in the energy sector” at Higher School of Economics (National Research University)
- **«System modeling»**
  - as a part of Master program “System studies of the energy markets” at Gubkin Russian State University of Oil and Gas (National Research University)
- **“Power system planning”**
  - as a part of MBA program “Management on power industry” at Market Council/Financial University

Theory of the energy modeling and practical applications are the main part of these courses (also using MESSAGE and MAED as an examples of energy supply/demand formal representation or as a part of practical lessons)

Recent experience in learning the energy planning

Workshops, seminars and meetings with analytics and decision makers from energy companies and ministries.

- **Energy strategy to 2035**
- **General plan of power sector assets allocation to 2035**
- **Investment plans and strategies of generating companies**

Discussion of the modeling results in terms of capacity and generation structure, technological competition (short- or long-term) between the following options:

  - energy resources (fossil, nuclear and renewable)
  - types of generating plants
  - power plants and grid

Form the basis for successful training from the basic economic logic

Mathematics helps us to simplify the reality. But people are willing to trust the modeling results, only when they are understand the basic and simple economic logic of the modeling

It is very important for the researchers. They can use energy models effectively only when they understand how the exogenous cost and performance data are processed and converted into the optimal solution during the modeling procedure. And they can translate the results in the general economic language for decision makers.

It is very important for the decision makers. They must be sure that globally optimal solution usually coincides with their intuitive economic expectations or they must obtain simple and strong arguments to change their preliminary expectations about the results of technological competition

Usually it is not enough to say: “This is a model optimal solution”. People do not like a “black boxes”, even with the IAEA label (or any other international and consultant organization).

Give simple answers on simple questions before instead of resolving complicated problems later

People ask simple questions related to the modeling procedure and modeling results

- Economics of energy technologies. How to compare and rank them correctly?
- Impact of input data – how they can change the solution through the discounting and escalation of costs?
- Types of economic efficiency: social and commercial. What kind of efficiency is estimated in the model?
- What is the sense of objective function?
- And a more and more…

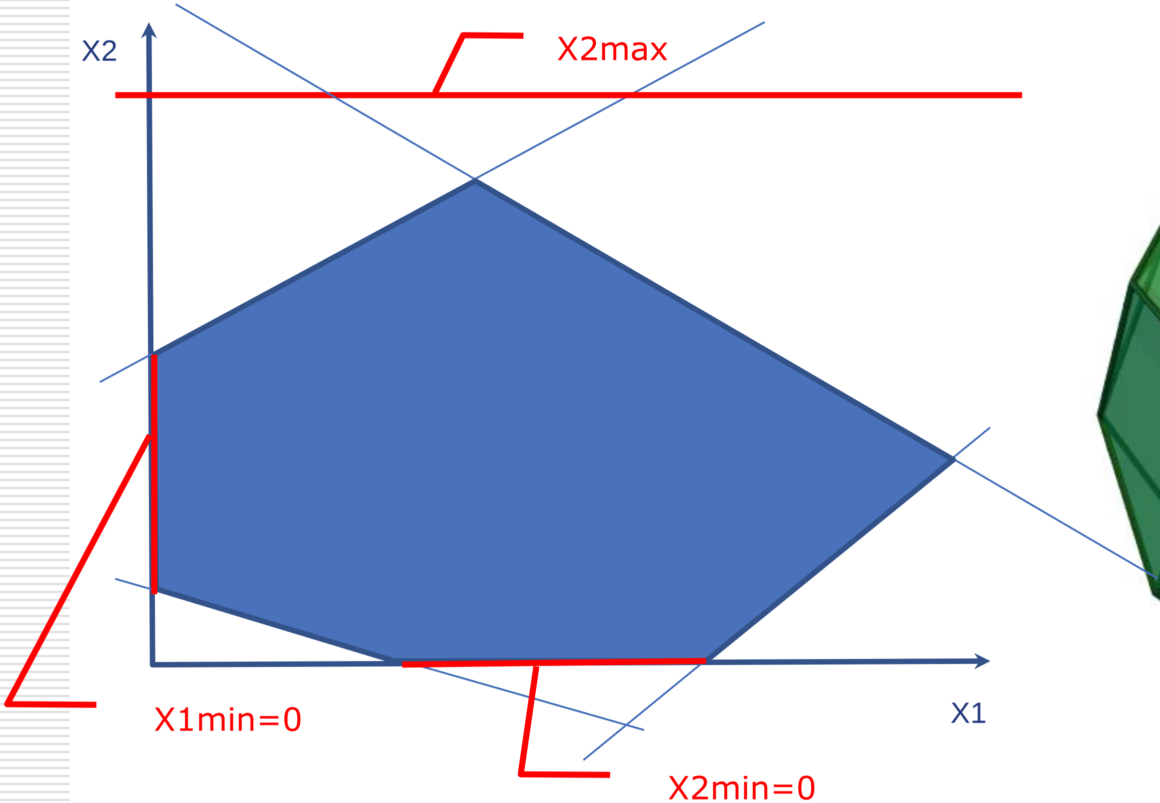
Most part of questions are related with economic comparison of generating options – how it can be illustrated, understood and simulated?

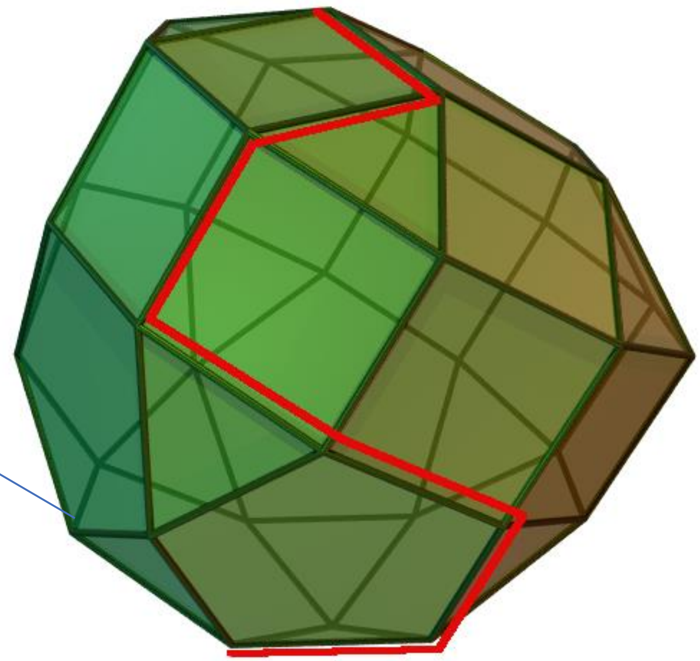
Give simple answers on simple questions before instead of resolving complicated problems later

Give the explanation of the modeling choice as simple as possible, like a graphic explanation of the linear programming problem

for 2X case

or for 3X case





Staged approach to the generation capacity structure forecasting

Screening analysis of the typical decisions of existing plant rehabilitation and new construction options (selection of the preferred generating technologies)

Modeling tool – spreadsheet calculator of discounted costs of construction, operation and decommissioning	Criterion – per kWh discounted generation costs for each technology (LCOE, EGC)

It may be FINPLAN or simple spreadsheet calculator

↓

System evaluation of energy balanced and economically efficient variants of power sector development (optimization of scales for preferred generating technilogies)

Modeling tool – long-term optimization model of power sector integrating all generating technologies and grid expansion (fuel supply as an option)	Criterion – minimum of total discounted costs of forecasted balance requirements supply in the planning period (+aftereffects in 15 years)

It may be MESSAGE or WASP

↓ ↑

Assessment of investment resources and financial conditions

Modeling tool – financial models of the electric power sector, its segments and energy companies	Criterion – concordance with the macroeconomic limitations (by prices and investments) and minimum industry/corporate financial viability requirements

Source: ERI RAS

Cost-based screening analysis of energy technologies

The vales of the levelized cost of electricity (LCOE) is generally used for economic ranking of the technologies:

$$LCOE = P_{MWh} = \frac{\sum(Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t) * (1+r)^{-t}}{\sum MWh\ (1+r)^{-t}}$$

P_{MWh}	=	The constant lifetime remuneration to the supplier for electricity;
MWh	=	The amount of electricity produced in MWh, assumed constant;
$(1+r)^{-t}$	=	The discount factor for year t (reflecting payments to capital);
$Capital_t$	=	Total capital construction costs in year t;
$O\&M_t$	=	Operation and maintenance costs in year t;
$Fuel_t$	=	Fuel costs in year t;
$Carbon_t$	=	Carbon costs in year t;
D_t	=	Decommissioning and waste management costs in year t.

Source: IEA/NEA Projected Costs of Generating Electricity 2015 Edition

Why the electricity is discounted?!

The general economic sense of LCOE is that its value represents the constant price of electricity ensuring the payback of the technology during its lifetime (T).

LCOE is the minimum constant revenue required per 1 MWh for the zero NPV

Revenues | Costs

$$NPV = \sum_{t=1}^{T} P_{el} \cdot W_t \cdot (1-\alpha_{own.needs})/(1+d)^t - \sum_{t=1}^{T} (Capital_t + Fuel_t + O\&M_t)/(1+d)^t = 0$$

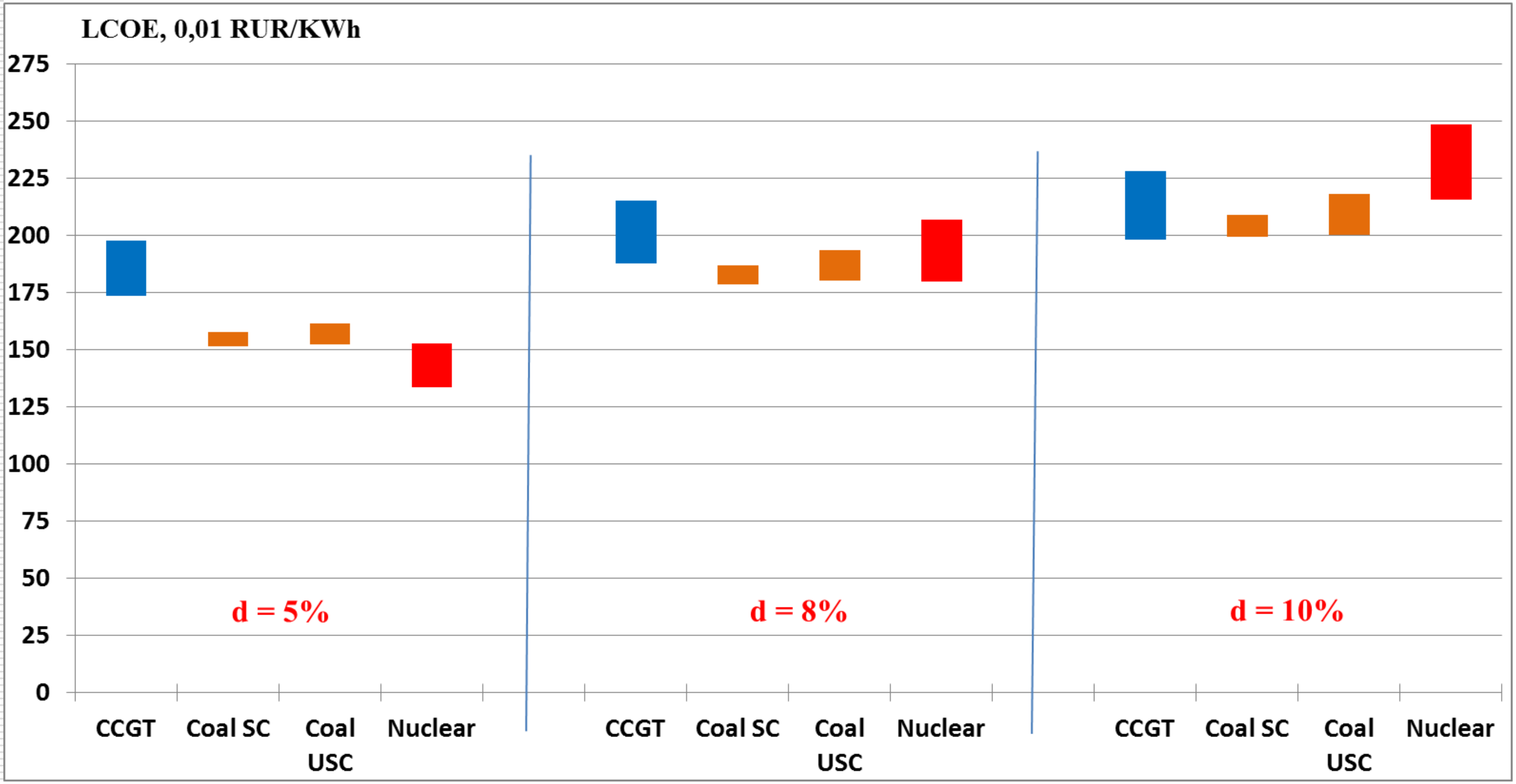
$$\sum_{t=1}^{T} P_{el} \cdot W_t \cdot (1-\alpha_{own.needs})/(1+d)^t = \sum_{t=1}^{T} (Capital_t + Fuel_t + O\&M_t)/(1+d)^t$$

$$P_{el} = LCOE = const$$

$$LCOE \cdot \sum_{t=1}^{T} W_t \cdot (1-\alpha_{own.needs})/(1+d)^t = \sum_{t=1}^{T} (Capital_t + Fuel_t + O\&M_t)/(1+d)^t$$

$$LCOE = \frac{\sum_{t=1}^{T} (Capital_t + Fuel_t + O\&M_t)/(1+d)^t}{\sum_{t=1}^{T} W_t \cdot (1-\alpha_{own.needs})/(1+d)^t}$$

Discounting can give you any requested result!



Source: ERI RAS analysis

Many factors are speculated but they only seem important!

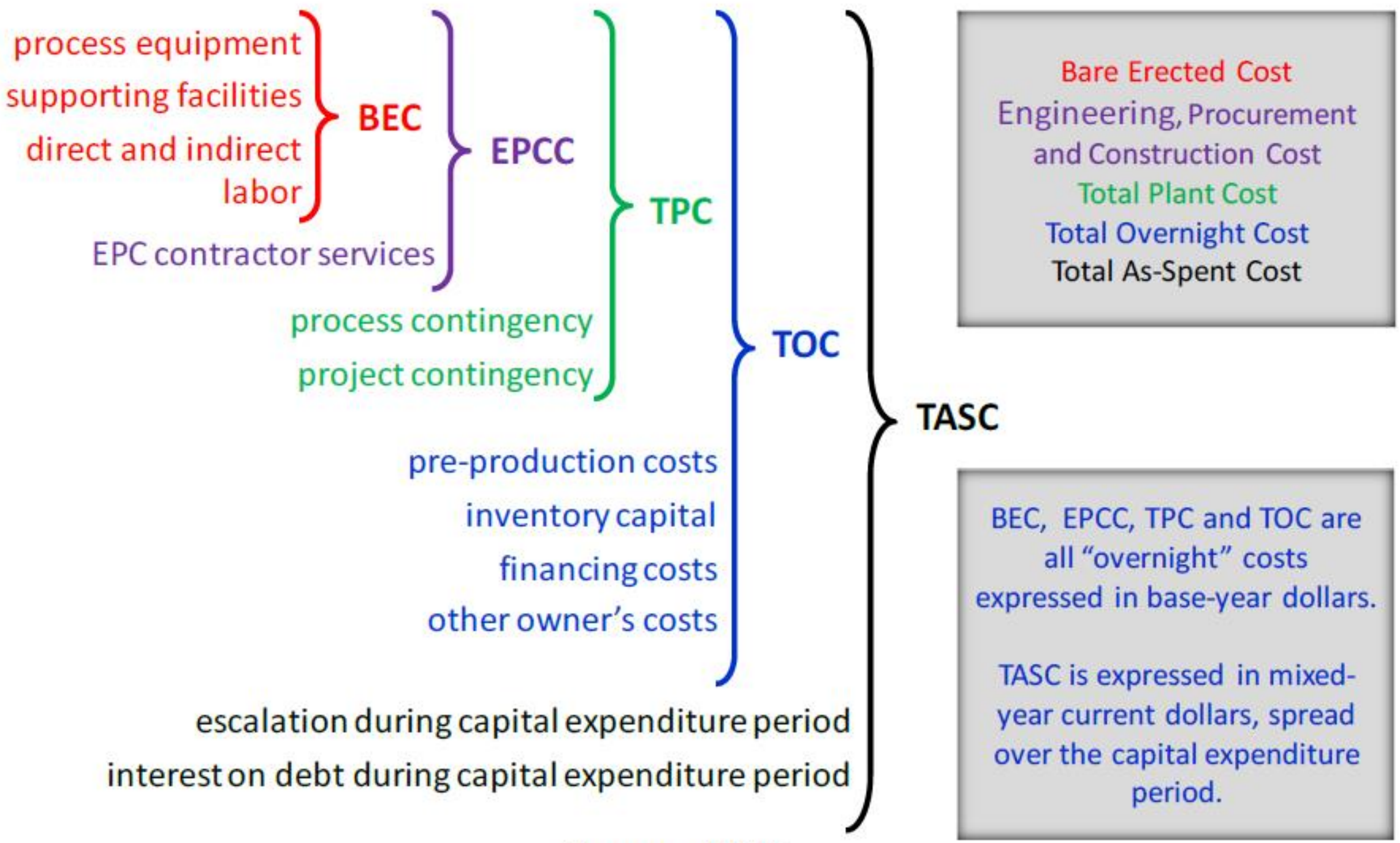
Cases of CCGT LCOE analysis	Case description	LCOE (% to the Base case)
1 (Base case)	One investment period (3 years) + 30 years of operation time	100%
2	Equalization with NPP life cycle (60 years). Another one CCGT is commissioned after 30 years	100%
3	Operation time is limited by 15 years (the lifetime of gas turbine)	109%
4	Case 1 + costs for the replacement of gas turbine after 15 years of its operation (50% of CCGT capex)	106%
5	Case 4 + decommissioning costs after 30 years (15% of CCGT capex)	107%

Cases of NPP LCOE analysis	Case description	LCOE (% to the Base case)
1 (Base case)	One investment period (5 years) + 50 years of operation time	100%
2	Case 1 + decommissioning costs (30% of capex)	100,4%
3	Case 1 + decommissioning costs (100% of capex)	100,8%

Source: ERI RAS analysis

Comparability of capital costs

Capital cost levels and their elements

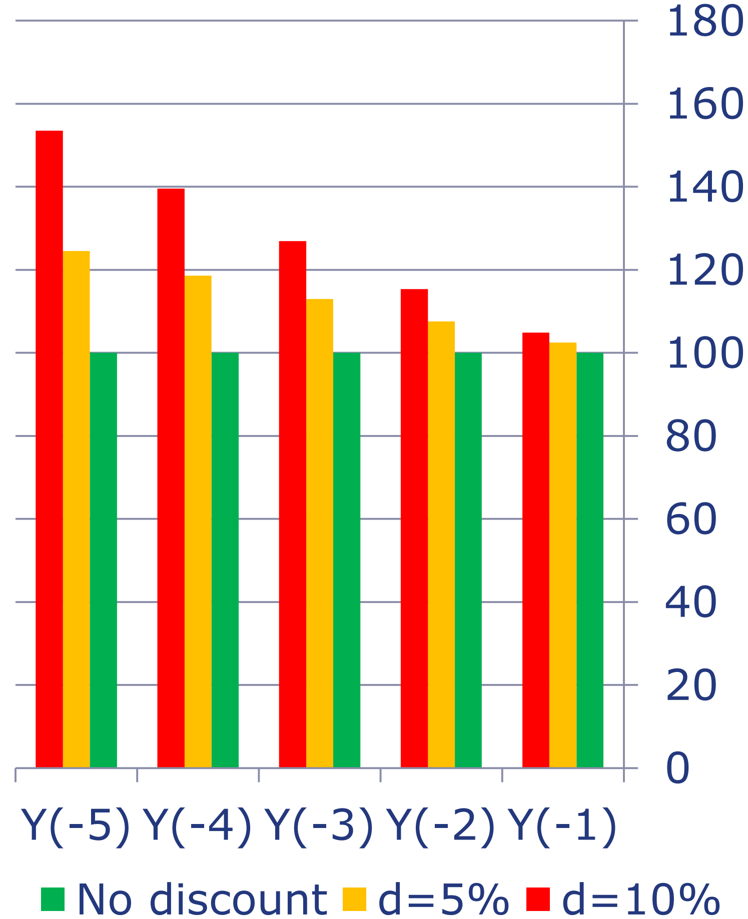


Source: NETL

Discounted capital costs are increasing

Plant type	Construction time, years	IDC impact on capital costs (d=10%), %
Nuclear	5	28%
Coal	4	22%
CCGT	3	16%
Wind onshore	1,5	8%
Wind offshore	3	16%
Solar	1,5	8%
Hydro (large)	6	35%

Impact of discounting the capital costs (interest during construction)



Source: ERI RAS analysis

Different cost escalation for the domestic and imported equipment and services

Macroeconomic data

	2013	2014	2015	2016
Annual inflation (CPI)	106,5	111,4	112,9	105,4
Cumulative CPI to 2013	1	1,11	1,26	1,33
RUR/USD ratio	32,15	36	62,55	65,05

Change in the capital costs of nuclear and gas plants

	2013	2014	2015	**2016**
RUR/kW				
Nuclear	**100000**	111400	125771	**132562**
CCGT (50% import)	**34700**	38756	55577	**58104**
NPP/CCGT costs ratio	**2,9**	**2,9**	**2,3**	**2,3**
USD/kW				
Nuclear	**3110**	3094	2011	**2038**
CCGT (50% import)	**1079**	1077	889	**893**

Source: ERI RAS analysis

What kind of efficiency we estimate in the models?

- **Social**
  - Estimation of the effects from investments for the whole economy and society. Efficiency of the investments from the macroeconomic point.
- **Commercial**
  - Estimation of the effects from investments for the individual investor (company) society. Efficiency of the investments from the corporate point.
- **Budget**
  - Estimation of the effects from investments for state budget. Efficiency of the direct or indirect budget expenses (subsidies, tax discount or exempts) related to the project inflow to the budget.

Different costs are taken into account in the efficiency analysis!

	Social efficiency	Commercial efficiency
Capital costs	Yes, directly	Yes, directly of as capital charge (CC) rates
Depreciation	No	Yes
Fuel and O&M costs	Yes	Yes
Financial costs and taxes	No	Yes
Electricity prices	Shadow prices based on marginal costs (prefect market)	Actual prices (competitive or regulated)
Discount rate	Incremental or alternative cost of capital	WACC

All financial transfers for the national economy (taxes, debt liabilities, depreciation) are excluded from the estimation of social efficiency)

What efficiency is estimated in the models?

Almost all optimization models used for energy planning (also MESSAGE and WASP) correspond to the “least-cost planning” paradigm.

At this, the cost function is formed as a sum of discounted capital, fuel and O&M costs throughout the planning time horizon, i.e. represents the cost of energy supply for the whole economy.

As a result, the optimal solution corresponds to the best **social efficiency** of the investments

Optimal investment decisions ensure the minimal cost of energy supply in the long-term

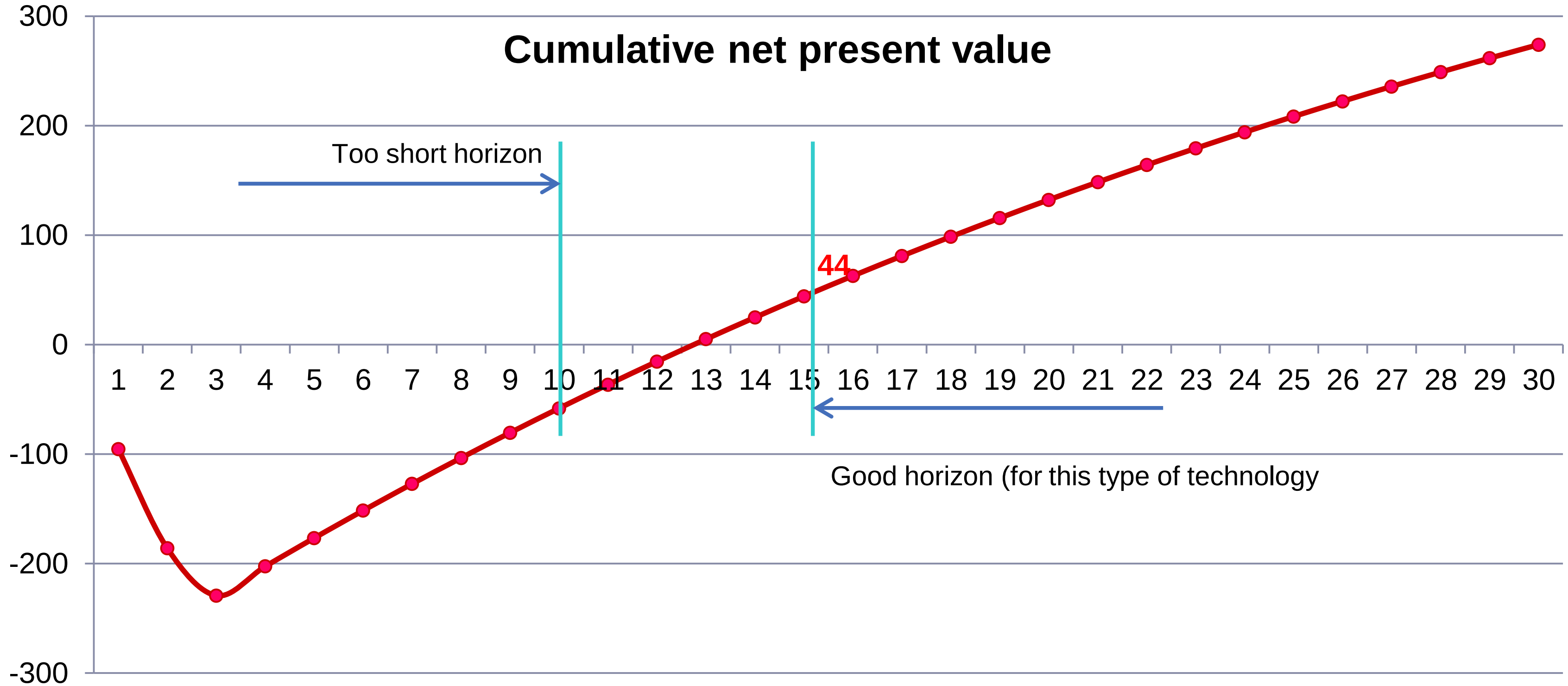
The objective function has the following general form:

$$
\begin{aligned}
&\sum_t \Bigg[\beta_m^t \, \Delta t \Bigg\{ \sum_{svd} \sum_l zsvd..lt \times \epsilon_{svd} \times \Bigg[ccur(svd,t) + \sum_i \sum_m ro_{svd}^{mlt} \times cari(ml,t) \Bigg] + \\
&\sum_{svd} \epsilon_{svd} \times \sum_{e=0}^{e_d} Usvd.e.t \times \epsilon_{svd} \times \Bigg[\kappa_e \times \Big(ccur(svd,t) + \sum_m ro_{svd}^{mt} \times car2(m,t) \Big) + \\
&cred(d,e) + \sum_m ro_{svd}^{mt} \times car1(m,t) \Bigg] + \sum_{svd} \sum_{\tau=t-\tau_{svd}}^{t} \Delta\tau \times Yzsvd..\tau \times cfix(svd,\tau) + \\
&\sum_r \Bigg[\sum_g \sum_l \sum_p Rzrgp.lt \times cres(rgpl,t) + \\
&\sum_c \sum_l \sum_p Izrcp.lt \times cimp(rcpl,t) - \sum_c \sum_l \sum_p Ezrcp.lt \times cexp(rcpl,t) \Bigg] \Bigg\} + \\
&\beta_b^t \times \Bigg\{ \sum_{svd} \sum_{\tau=t}^{t+t_d} \Delta(t-1) \times Yzsvd..\tau \times \Bigg[ccap(svd,\tau) \times fri_{svd}^{t_d-\tau} + \\
&\sum_i \sum_m rc_{svd}^{mt} \times cari(m,t) \times fra_{svd,m}^{t_d-\tau} \Bigg] \Bigg\} \Bigg] ,
\end{aligned}
$$

Source: IAEA MESSAGE manual 2010

What time horizon is good for the model?

The model "will see" the efficiency of the technology (and may be add it in the optimal solution) at the times longer than payback period

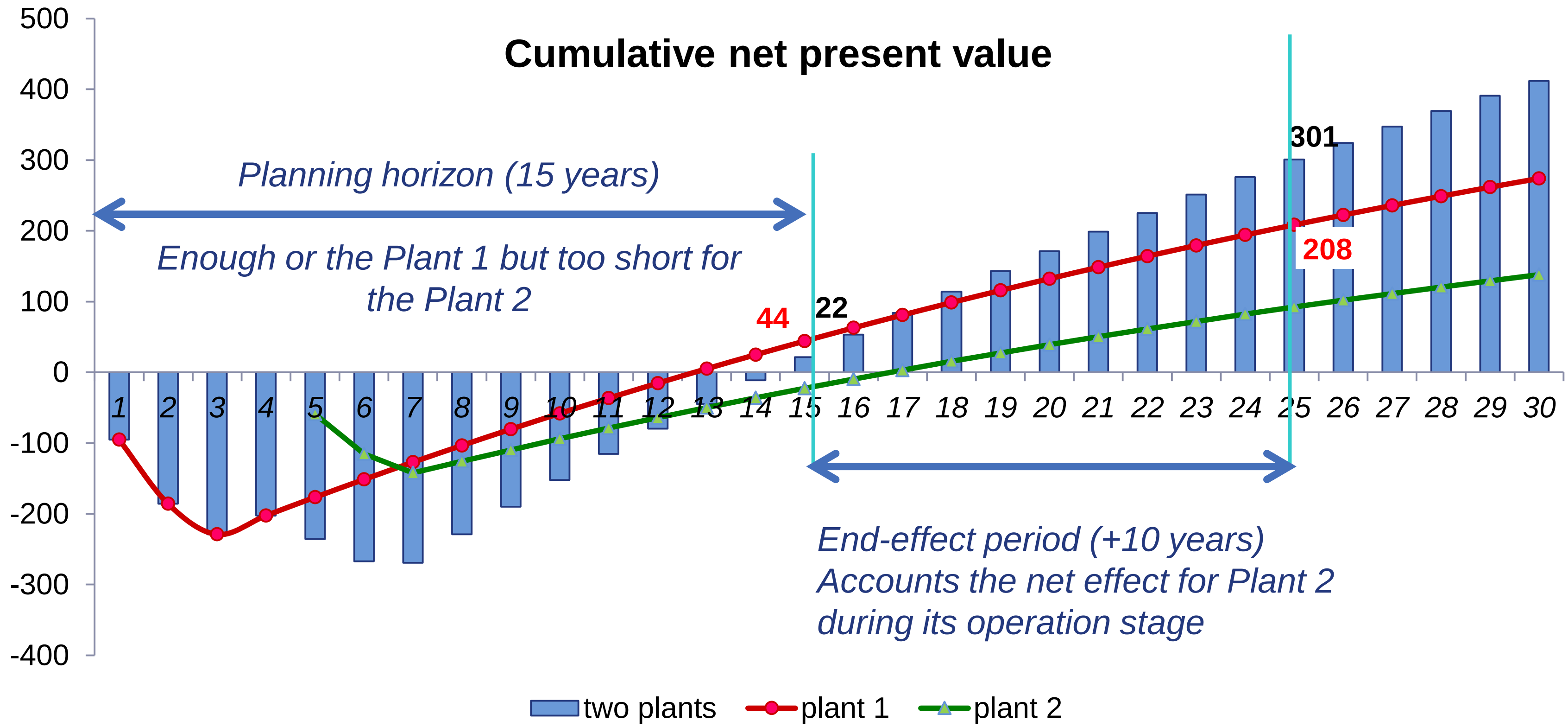


The too short time horizon may strongly affect on the decision and ignore some potentially effective technologies

Source: ERI RAS analysis

What time horizon is good for the model?

To make proper and reasonable choice of the decisions near the end of planning horizon, the additional time interval (+10-20 years) is added to take into account net effects at the operational stage



Source: ERI RAS analysis

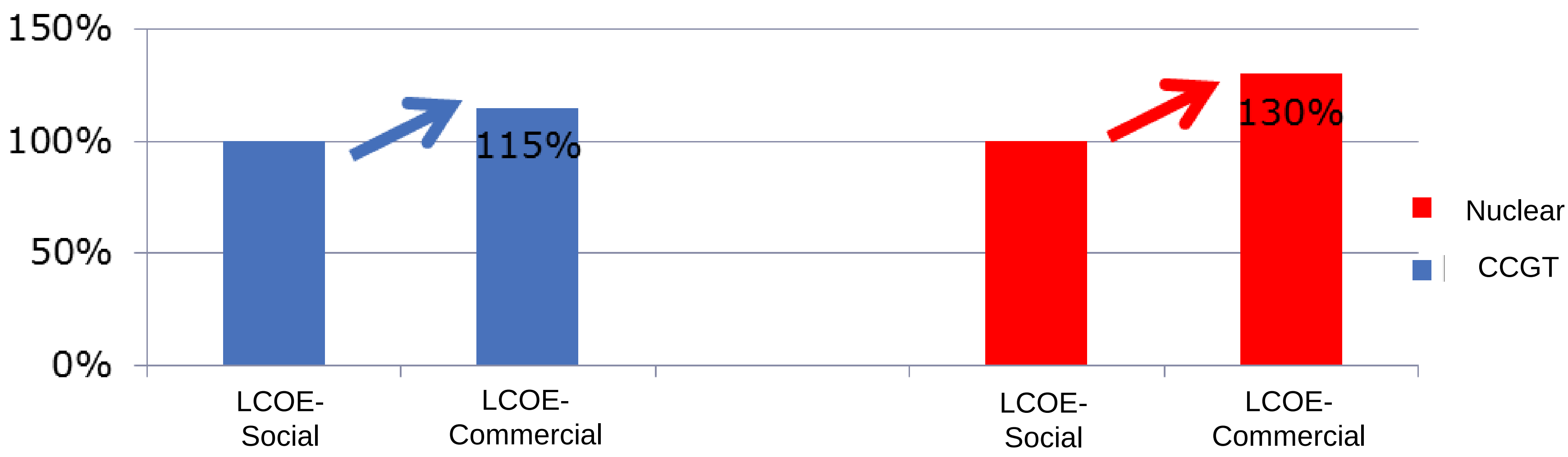
Competitiveness of energy technologies. What efficiency we can see here?

In the contrast to optimization models, LCOE calculations can reflect both social and commercial efficiency of the investments

Parameters	Social efficiency approach (IAEA, IEA, EU)	Commercial efficiency approach (EIA, EPRI, BNEF, USA)
General formula	$LCOE = \frac{\sum_t I_t + O\&Mt + Fuel_t}{\sum_t E_t}$	$LCOE = \frac{CCR * I + O\&M + Fuel + Tax}{E}$
Fuel and other variable O&M costs	Yes	Yes
Fixed O&M costs	Yes	Yes
Capital costs	Yes	Yes (generally annualized as capital charge rate, CCR)
Taxes	No	Yes (profit and property taxes)
Time horizon	Life time	Payback period
Discount rate	Based on the macroeconomic or pre-tax WACC parameters	Based on WACC parameters (pre- or after tax)
Compatibility with the social efficiency approach	*Yes*	*No (accounts tax and credit chagres)*

Competitiveness of energy technologies. From what point we estimate them?

LCOE represents a specific revenue requirement for the profitability of the technology.
Commercial-type LCOE in normally high because of tax and financial costs impact on the capital charge rate. As a result, this type of assessment is less favorable for the capital intensive technologies, like nuclear.



Source: ERI RAS analysis

Market profitability of energy technologies

LCOE represents a specific revenue requirement for the profitability of the technology.

$$lev\ cost = \frac{(fixed\ charge\ factor * capital\ costs + fixed\ O\&M)}{annual\ expected\ generation\ hours} + variable\ O\&M + fuel$$

Where:

$$AnnualExpectedGen = CapacityFactor * 8760$$

$$FixedChrgeFactor = DiscountRate + \frac{DiscountRate}{(1 + DiscountRate)^{FinancialLife} - 1}$$

LACE (levelized avoided cost of energy) represents a specific revenue from existing electricity and capacity market.

$$lace = \frac{\sum_{t=1}^{y}(marginal\ gen\ price_t * dispatched\ hours_t) + (cap\ payment * cap\ credit)}{annual\ expected\ generation\ hours}$$

Technology is commercially viable if its net economic value is positive, i.e.
LACE > LCOE

Source: EIA

Assessment of the profitability of energy technologies in the model

The level of profitability of energy technology in the model can be obtained from the dual solution – reduced cost of the technology (X)

RC = Δ (Model objective function)/ ΔX

RC is an **incremental cost** of the whole system in response to the change the capacity of certain technology (X). When the objective function is minimized:

- It is negative if the technology is profitable
- It is positive if the technology is not profitable, i.e. its costs higher than revenues

How to understand this better? Also using the dual solution

In the simplest way (without investments)

$$\mathbf{RC = (C_{O\&M} + C_{fuel}) - Electr_{ShadPrice} - h^*Cap_{ShadPrice}}$$

Where

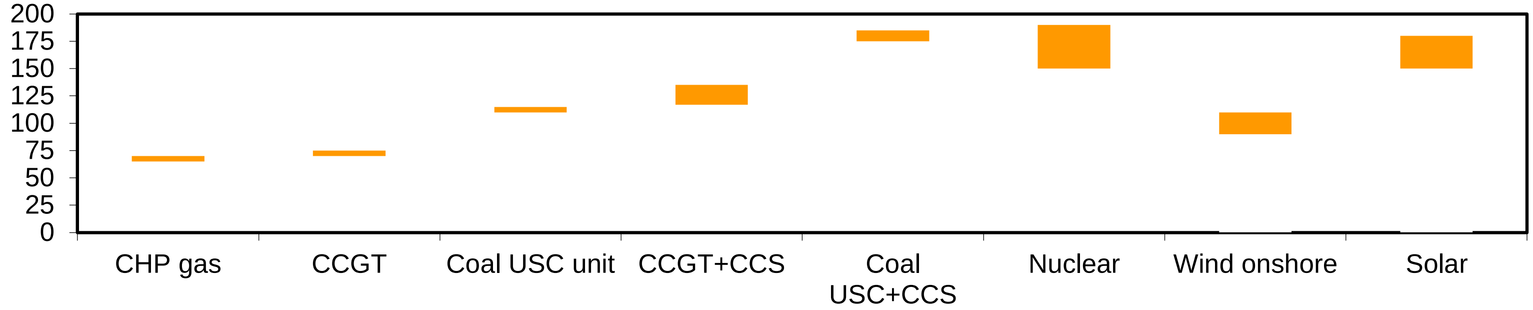
$C_{O\&M} + C_{fuel}$ – technology-related costs (normally a part of objective function)

$Electr_{ShadPrice} - h^*Cap_{ShadPrice}$ – shadow electricity and capacity prices from dual solution (reduced costs of appropriate balance equations)

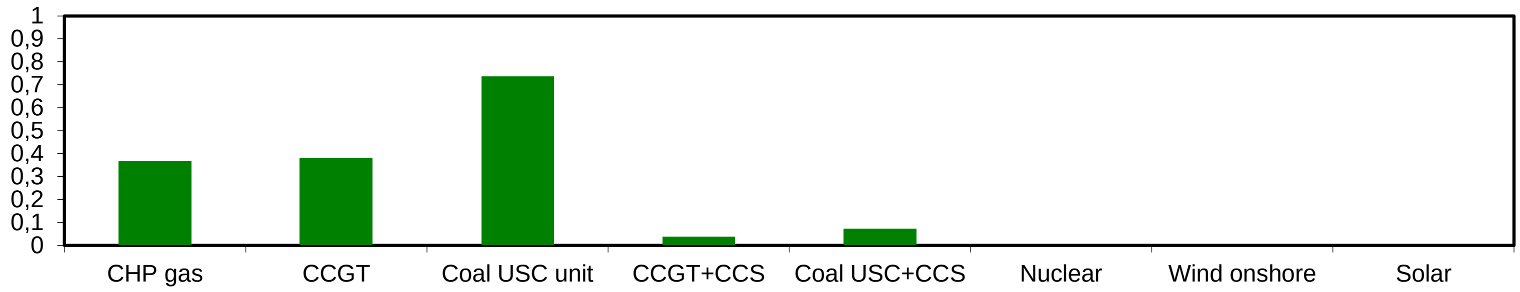
$$\mathbf{Cap_{ShadPrice} = \Delta\ (Model\ objective\ function)/\ \Delta B}$$

Environmental competitiveness of the technologies

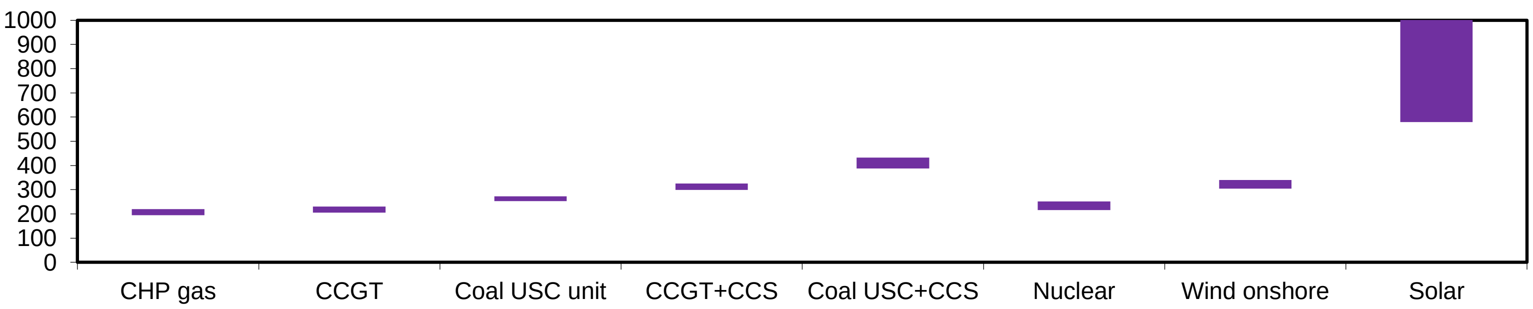
CAPEX, % to coal SC unit



CO2 emissions per MWh



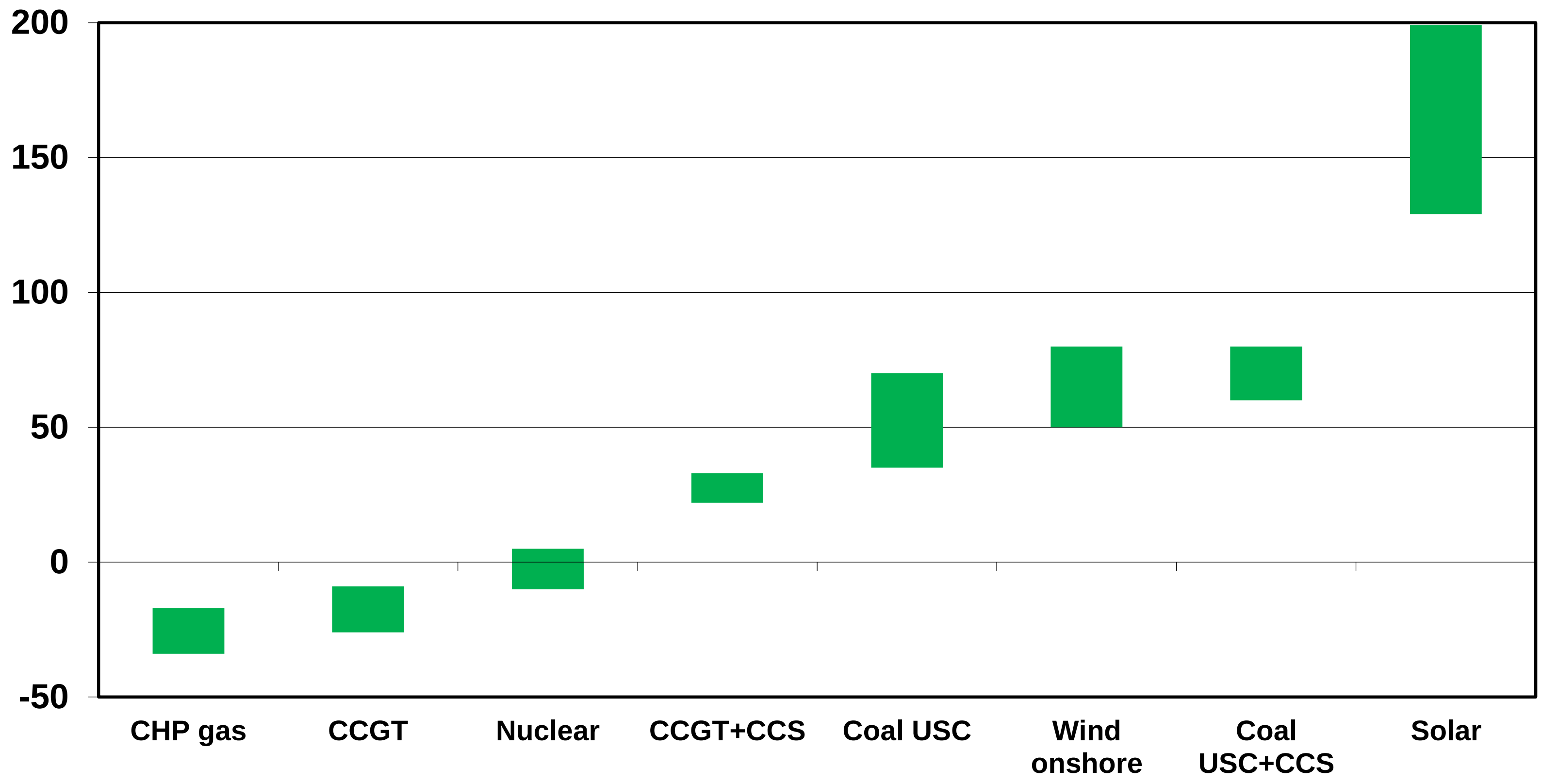
LCOE, 0,01 RUR 2013/kWh



Environmental competitiveness of the technologies

$$CarbonAvoidCosts_{alt} = (ElectrGenCosts_{alt} – ElectrGenCosts_{base}) / (Emission_{alt} – Emission_{base})$$

Carbon abatement costs, $2013/t CO2



Energy research institute of the Russian Academy of Sciences

www.eriras.ru
info@eriras.ru

Thank you for attention!