26th Inforum World Conference
Łódź, Poland, August 27-31, 2018

Inclusion of a New Economic Activity into a Multisectoral Model: Nuclear Power in Poland

(work in progress)

Mariusz Plich
University of Lodz

Scientific work carried out within the Coordinated Research Project of International Atomic Energy Agency co-financed from the funds for science in the years 2016-2019 by the Polish Ministry of Science and Higher Education

Outline of the presentation

- Background
- Empower and extensions:
  - model
  - software
- Empower.cc
  - new activity
- Scenarios of energy mix
- What next

Background

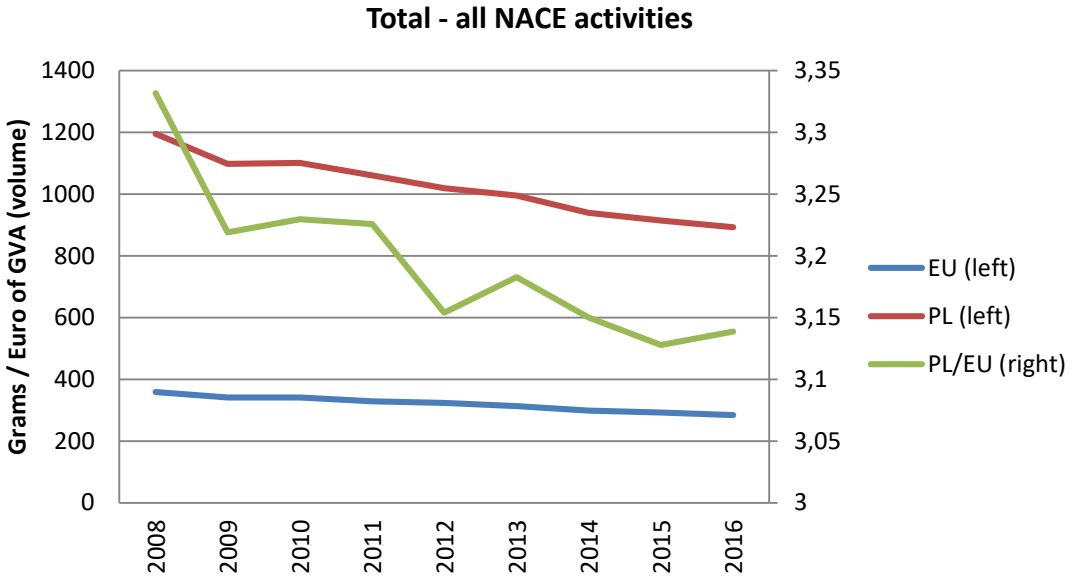
GHG emission intensities in NACE sectors

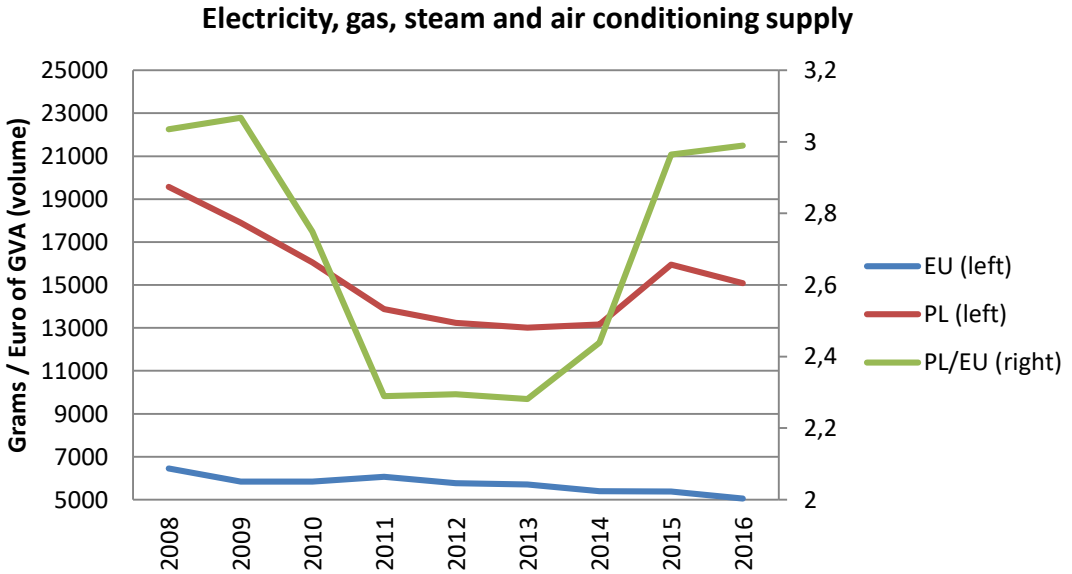
Greenhouse gases:

- CO2
- N2O
- CH4

in CO2 equivalent

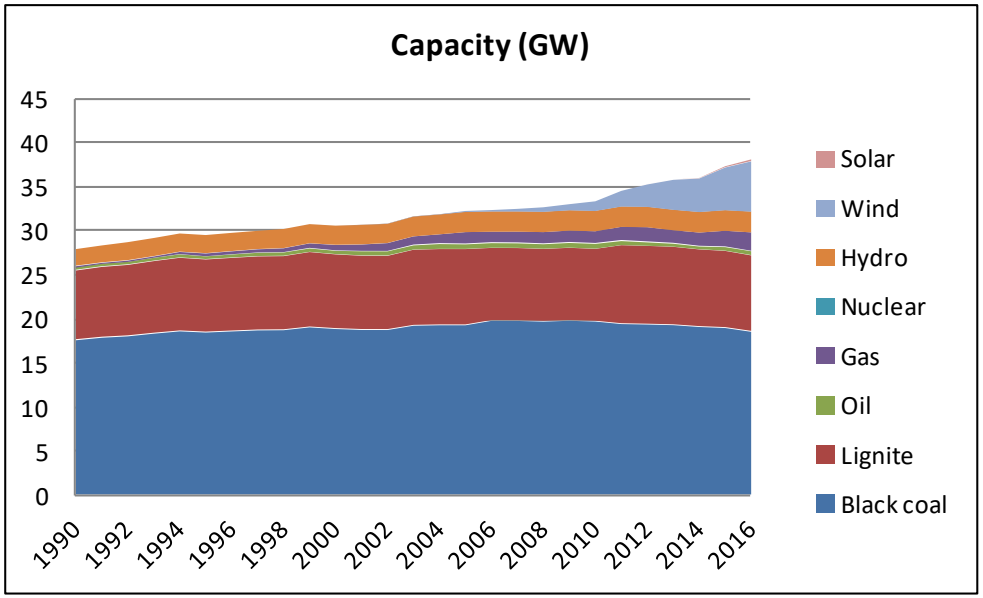
Source: Eurostat database (file env_ac_aeint_r2)

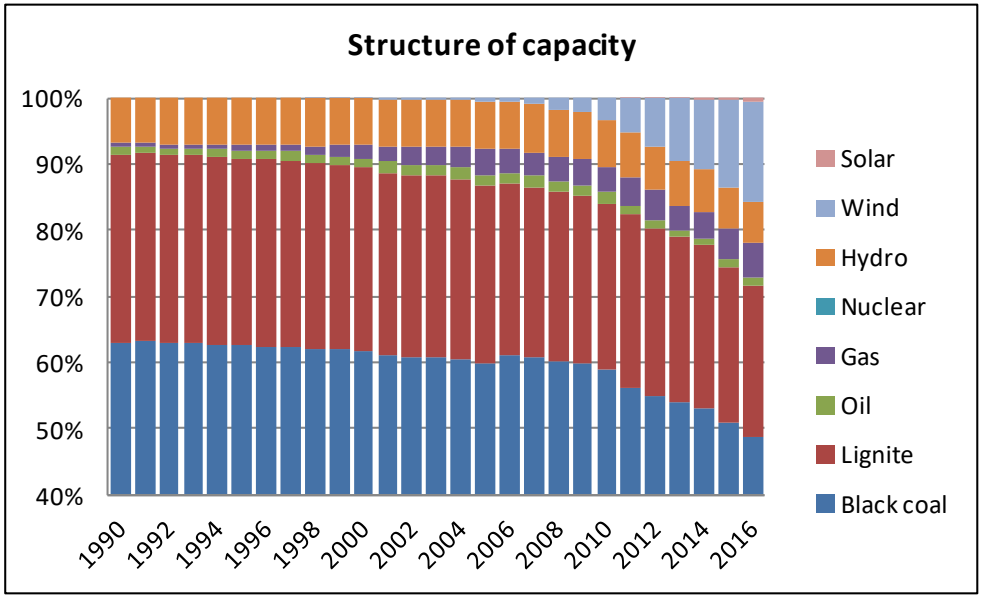




Background

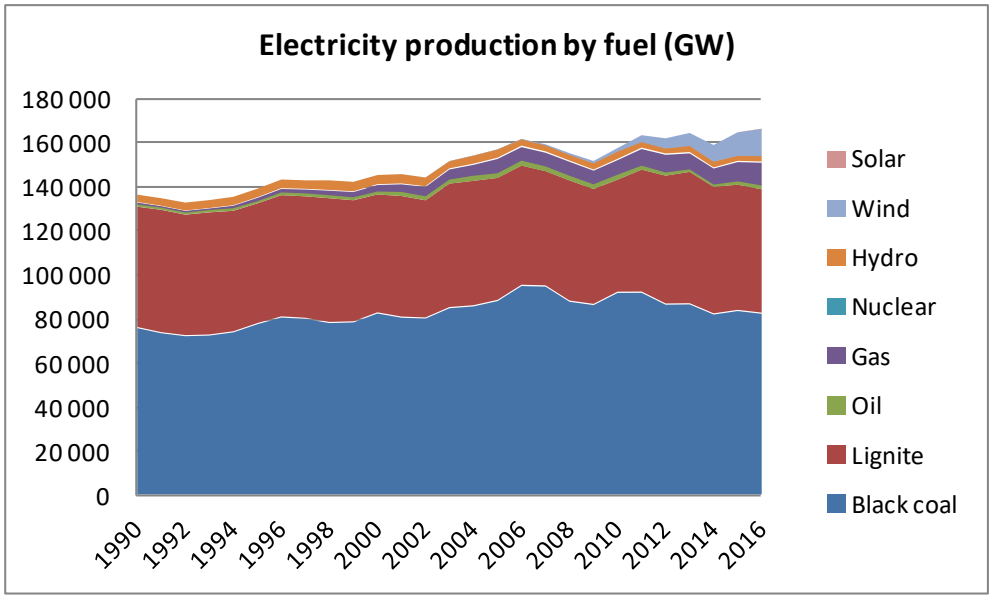
Gross installed capacity in Polish power plants

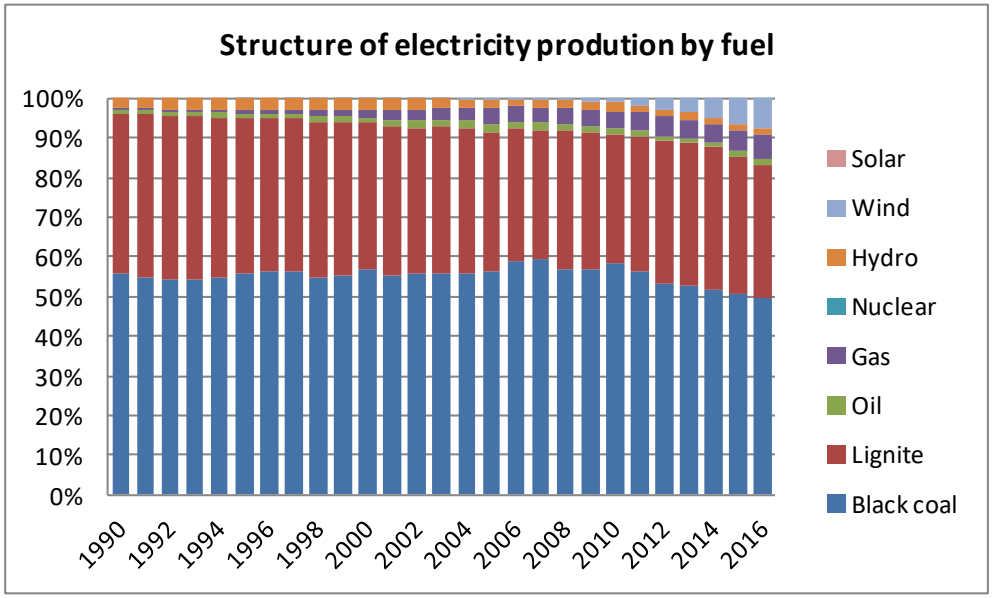




Background

Electricity prduction by fuel in Poland





Background

Polish Nuclear Power Programme (PNPP)

1982-1989: Construction of first Polish NPP (Żarnowic 1600 MW)
2009 : Start preparation for a new nuclear power program
2014: Realease of Polish Nuclear Power Programme (PNPP)

Table. Assumptions of the PNPP concerning the construction of a nuclear power plant

Issue		**Assumptions of the *Polish Nuclear Power Program* / problems of modeling**			
When		2020	2024	2030	2035
Power (in MW)		0	>= 1000	>= 3000	<= 6000
Technology		No			
Share of Polish in funds		10%	30%	...	60%
Construction costs	Power station 1 (3000 MW)	40 - 60 bln. PLN (3,3 – 5 mln USD/MW ex. rate 1 USD = 4 PLN)			
	Power station 2		???		

Source: own elaboration based on PNPP 2014

IAEA Empower

Genesis of the model

IAEA: International Atomic Energy Agency

CRP I12005: Assessing the National and Regional Economic and Social Effects of Nuclear Programmes (2014-2017)

Tool of assessment: mathematical model

Preconditions of model construction...

- empirical implementation
- one scheme for different countries
- common, easy and cost free software

...forced simplifications of model in:

- analitical form
- size
- speed and method of solving

Empower: ***E****xtended Input Output* ***M****odel for the Nuclear* ***Power*** *Plant Impact Assessment*

Consists of:

- *equation system* which use econometric input-output approach
- *software* as a set of MS Excel templates and VBA procedures

IAEA Empower

Equations

Output (in nominal terms) (1)

$$\mathbf{x} = \mathbf{A}^{d}\mathbf{x} + \mathbf{cp} + \mathbf{f}^{*} + \mathbf{f}^{new}$$

Output (in real terms) (2)

$$\mathbf{x}^{r} = \mathbf{x}/\mathbf{p}$$

Disposable income (3)

$$YD = \mathbf{l}wf_{w,hh}(1 - t_{hh})\mathbf{x} + \mathbf{s}f_{s,hh}(1 - t_{hh})\mathbf{x} + YD_{oth}$$

Consumption (4)

$$\mathbf{cp} = [\exp(const_{cp} + mpc(\log(YD))]\mathbf{b}_{hh}^{d}$$

Employment: (5)

$$L = \mathbf{l}\mathbf{x}^{r}$$

Wages (6)

$$w = \exp(const_{w} + \beta_{ur}\log(1 - L/LF))$$

Unit labour costs (7)

$$\mathbf{l} = \mathbf{l}_{base}w/(0.5 * w_{base} + 0.5 * w)$$

Prices (8)

$$\mathbf{p} = \mathbf{p}\mathbf{A}^{d} + \mathbf{p}^{m}\mathbf{A}^{m} + \mathbf{l}w + \mathbf{s} + \mathbf{t}^{q}$$

Tax rate (9)

$$t_{hh}^{new} = \frac{r_{pub}\boldsymbol{i}'\mathbf{f}^{new}}{YD}$$

Four types of multipliers

- direct and indirect effect (equations 1 i 2)
- & induced effect (equations 3 i 4)
- & labor market response (equations 5-8)
- & feedback from financing of investments (equation 9)

IAEA Empower

Variables and parameters

Symbols used:

x - output;
cp - household consumption;
f - final use (excluding household consumption);
p - output prices;
w - wage rate (wag/L);
YD - disposable income (after tax);
YD_{oth} - non-wage income;
L - employment;
LF - labour force;
t_{hh}^{new} - revenue-neutral tax rate.

Symbols written with variables in the upper or lower index:

^{r} - in real terms;
^{d} - domestic;
^{m} - foreign;
* - original data;
^{base} - in base year.

Parameters:

l - unit employment (L/x);
s - unit operational surplus;
A - Matrix of input-output coefficients;
t_{hh} - househlod tax rate;
$f_{s,hh}$ - coefficients for harmonization wages in i-o tables and NA;
$f_{w,hh}$ - coefficients for harmonization wages in i-o tables and NA;
const- constant term;
mpc - marginal propensity of consumption;
β_{ur} - parameter of wage response to unemployment rate.

Other symbols:

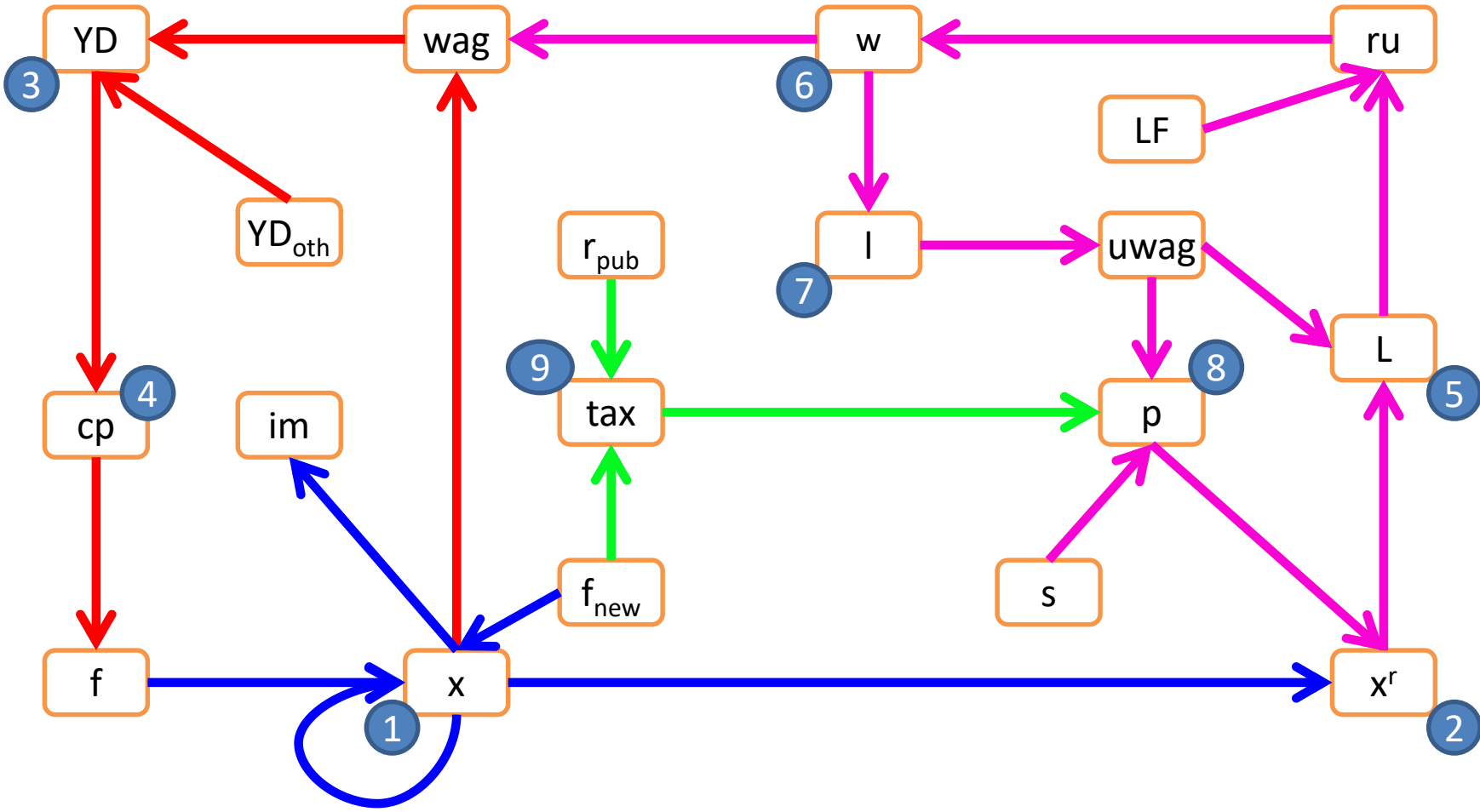
log - natural logarithm;
exp - exponential function;
i - unit vector;
' - symbol of transposition;

vectors are marked in bold

Empower.cc.pl

IAEA Empower

Block diagram of Empower model



IAEA Empower

Use

Base solution

- assumed rates of output changes + RAS
- state of equilibrium

Scenarios: disturbance of equilibrium state

- construction: additional investment outlays distributed over time
- operation: changes of unit cost of energy production as the result of structural chnges of electricity supply

Variants of simulations

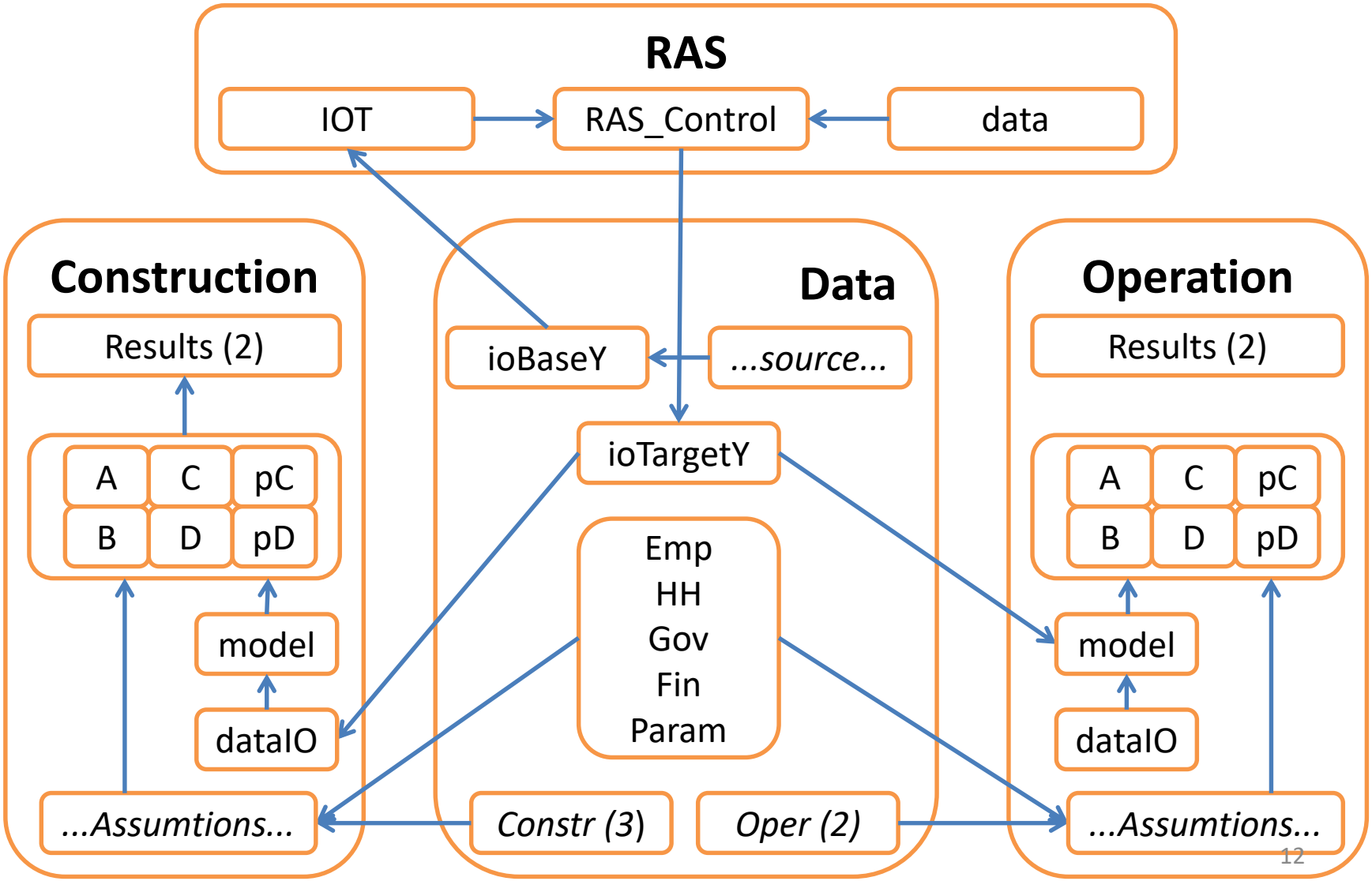
- A direct and indirect effect
- B & induced effect (A+B)
- C & labor market response (A+B+C)
- D & feedback from financing of investments (A+B+C+D)

Leontief model in current prices?

- Dietzenbacher&Temurshoev (2012): „(...) we found that all predicted effects were very similar."
- Predictions of i-o table in current prices using RAS?

IAEA Empower

Diagram of software



IAEA Empower

Implementation dilemmas

Weaknesses of Empower software

- not user friendly
- no links between files
- construction and operation separated
- low speed of solving model
- no loops over years

An alternative software: **Interdyme**

Empower.cc

Project

CRP I12006: Assessments of the Potential Role of Nuclear Energy in National Climate Change Mitigation Strategies (2016-2019)

General project objectives for Poland:

A. Evaluation of the extent PNPP contributes to meeting national targets of GHG reduction

B. Development of generic analytical framework for the assessment of support mechanisms to address investments in low carbon technologies, including nuclear

Expected results

- **Empower.cc** model and software as spreadsheet templates and VBA procedures
- **Empower.cc.pl** – the Empower.cc implemented for Poland both in spreadsheet and Interdyme

Problems to solve:

1) Introduction of energy and emission block of equations
2) Changes of unit costs of electricity production
3) Scenarios of energy mix

Empower.cc

Extension to climate change mitigation

The proposed new features of model

New blocks of equations

- energy block (demand for energy by sector and fuel type)
- emissions block (GHG emissions as the result of energy transformation processes)

Total emission of any pollutant under consideration depends on two factors:

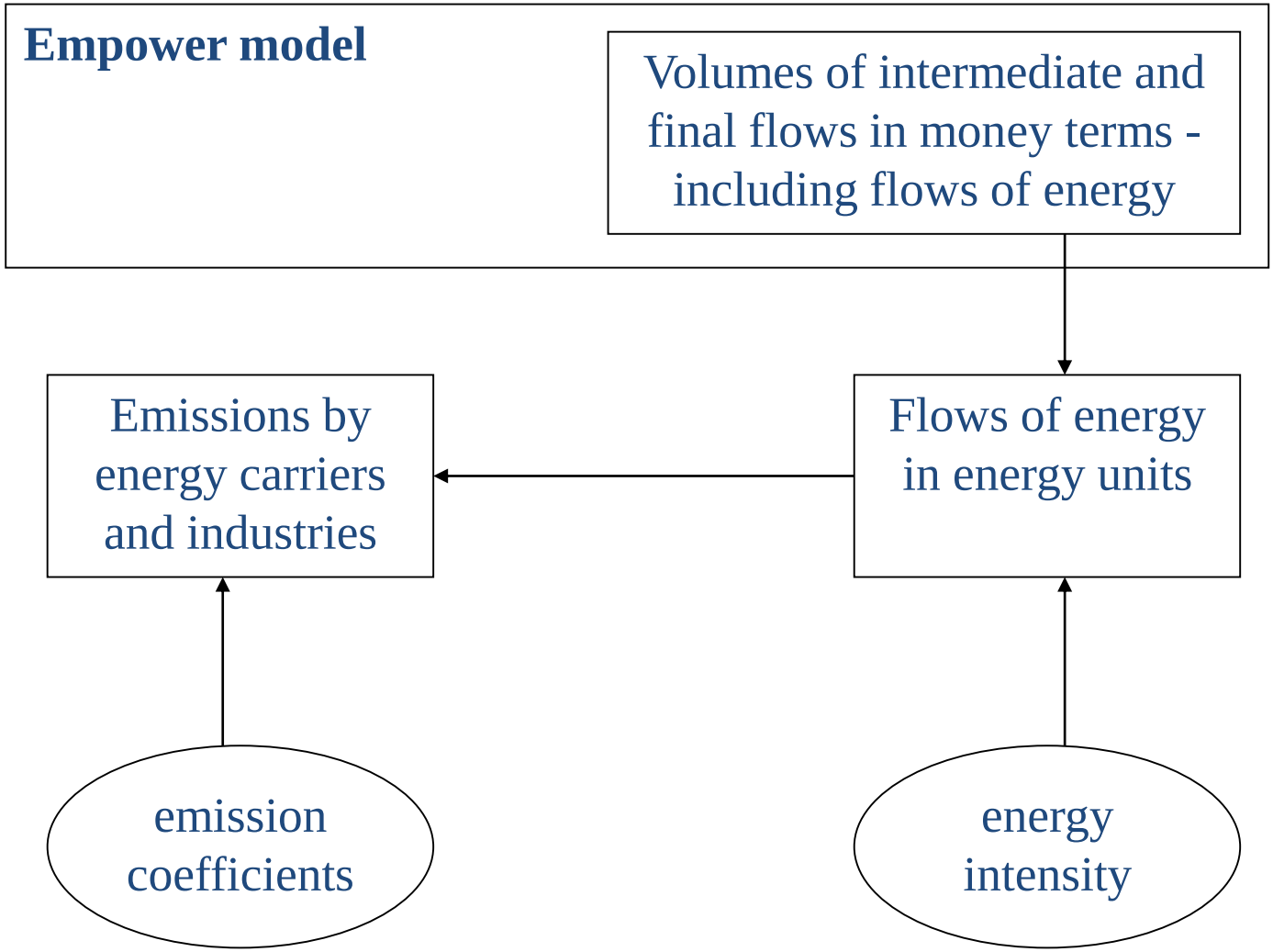
- emission coefficients (emission per unit of energy)
- amount of a fuel use (demand for a fuel)

Factors of changes of emission coefficients for a fuel

- the combustion method (differs between sectors)
- the pollution abatement method at the “end of pipe”

Empower.cc

Flow chart of Empower.cc model



Empower.cc

General form of emission equations

Emission of polutant z by industry j

$$E_{zj} = e_{zj} X_j$$

where

e – direct emission coefficients ($e_{zj} = \frac{E_{zj}}{X_j}$),

X – output

E – emission in natural units

z – type of pollutant $(z = 1,2,...Z)$

j – sector number $(j = 1,2,...J)$

Total emission of pollutant z

$$E_z = \sum_j e_{zj} X_j$$

Vector of total emissions of Z different pollutants

$$\mathbf{E} = \mathbf{eX}$$

where

$\mathbf{E}$ – vector of emissions $(Z \times 1)$

$\mathbf{e}$ – matrix of direct emission coefficients $(Z \times J)$

$\mathbf{X}$ – vector of output $(J \times 1)$

Leontief production function

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{Y},$$

$$\mathbf{E} = \mathbf{e} \cdot (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{Y}$$

Empower.cc

Equations of air pollution from fuel combustion

Emission E_{zj} - emission of type z by sector j from use of fuel f:

$$E_{zj} = \sum_f E_{zjf}$$

where f means type of fuel $(f = 1,2,...F)$

or

$$E_{zj} = \sum_f e_{zjf} \cdot X_j$$

or

$$E_{zjt} = \left(\sum_f w_{zjf\,0} \cdot v_{(f)j0} \cdot a_{(f)jt} \right) \cdot X_{jt}$$

for

$(z = 1,..., Z)\ (j = 1,..., J)\ (f = 1,..., F)$

where:

$w_{zjf} = \frac{E_{zjf}}{U_{fj}}$ emission of pollutant z per unit of fuel f in sector j,

$v_{(f)j} = \frac{U_{fj}}{x_{(f)j}}$ unit input of fuel f generated by energy sector (f) in sector j

$a_{(f)j} = \frac{x_{(f)j}}{X_j}$ direct input coeffcient of products generated by energy sector (f) in sector j

Empower.cc

Unit costs of electricity sector – IEA data

Unit costs of nuclear power technology

- Maping from IEA data to io table (used in Empower for now)
- Use io data from countries with high share of nuclear power (France)

IEA: Costs of Electricity Generation (USD/MWh)

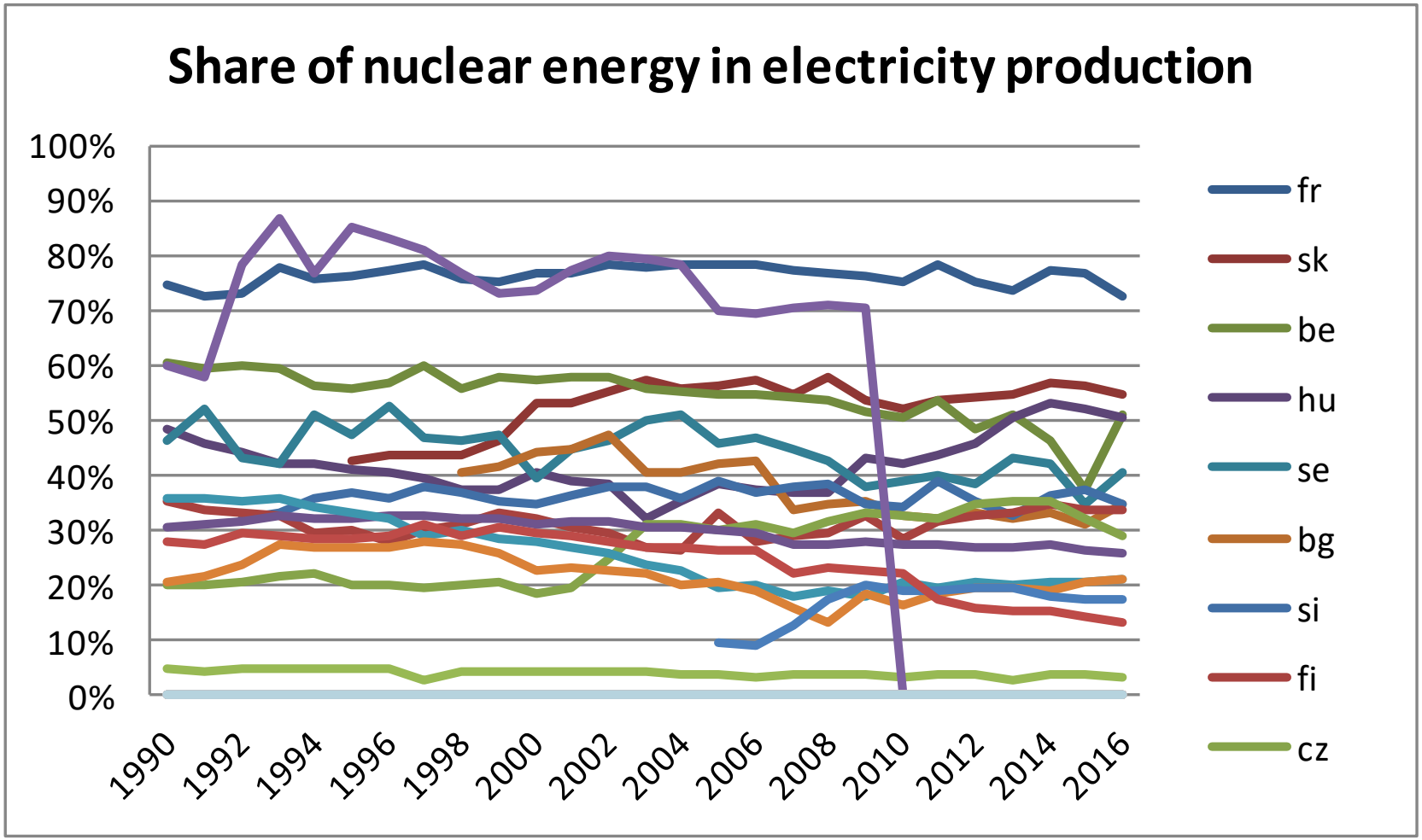
Type of cost	Wave/ tidal	Wind/ solar	Gas	Coal	Oil products	Nuclear	Hydro power
Mining and Quarrying	0	0	84	43	0	0	0
Coke, Refined Petroleum and Nuclear Fuel	0	0	0	0	84	10	0
Other operational costs	35	25	6	8	6	10	20
Labour cost	15	11	3	4	3	4	7
Subsidies/Taxes	?	?	?	?	?	?	?
Capital	?	?	?	?	?	?	?

? – country data or estimates

Shares estimated on the base of this table corespond to io coefficients (unit costs in io table): **mapping can be done**

Empower.cc

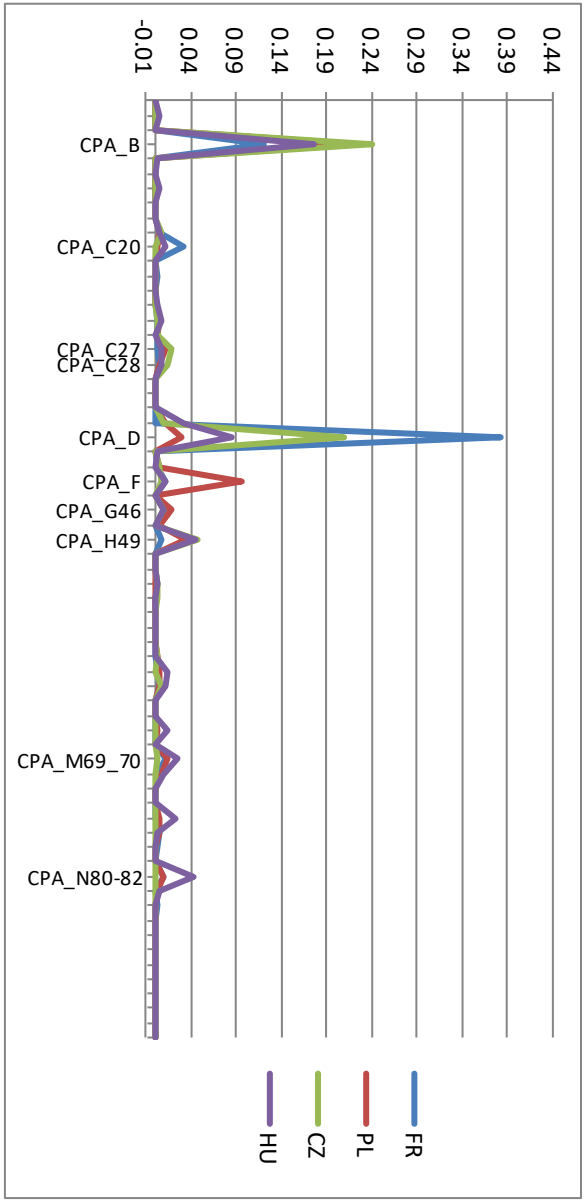
Unit costs of electricity sector - iodata



Empower.cc

Unit costs of electricity sector – io data

Unit costs in the sector: *Electricity, gas, steam and air conditioning*				
Product code	Product type	Unit costs (io coefficients)		
		FR	PL	CZ
CPA_B	**Mining and quarrying**	**0.120**	**0.226**	**0.240**
CPA_C20	Chemicals and chemical products	0.033	0.003	0.002
CPA_C27	Electrical equipment	0.004	0.013	0.020
CPA_C28	Machinery and equipment n.e.c.	0.006	0.006	0.014
CPA_D	**Electricity, gas, steam and air conditioning**	**0.383**	**0.030**	**0.210**
CPA_F	**Constructions and construction works**	**0.012**	**0.096**	**0.007**
CPA_G46	Wholesale trade services, except of motor vehicles and motorcycles	0.011	0.020	0.010
CPA_H49	**Land transport services and transport services via pipelines**	**0.008**	**0.034**	**0.047**
CPA_M69_7(	Legal and accounting, head offices, management consultancy services	0.013	0.015	0.002
CPA_N80-82	Security and investigation, to buildings and landscape, other business services	0.010	0.009	0.002



Scenarios of energy mix

Factors of energy mix

Energy mix: technologies used to meet demand for electric power

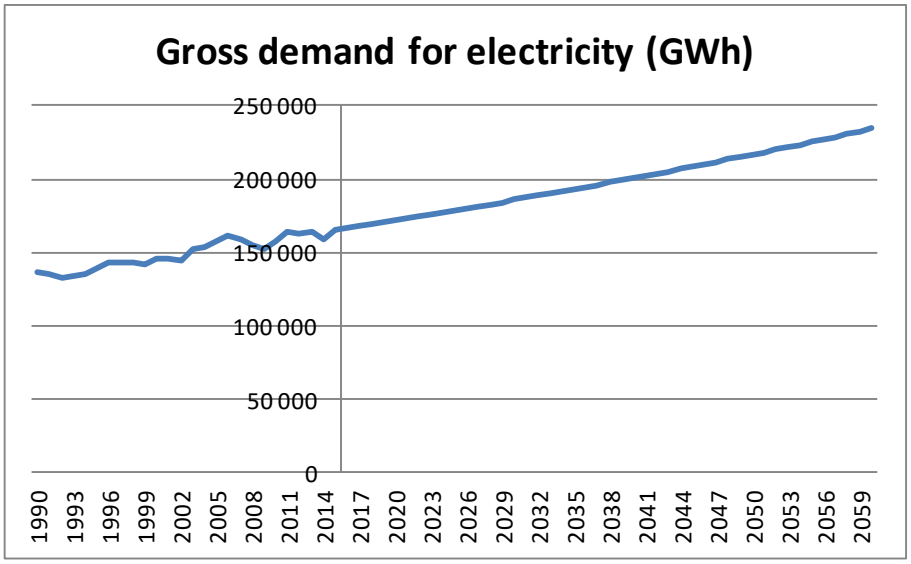
Technologies : coal (black coal and lignite), oil, gas, nuclear, hydro, wind, solar

Factors of energy mix used to build scenarios

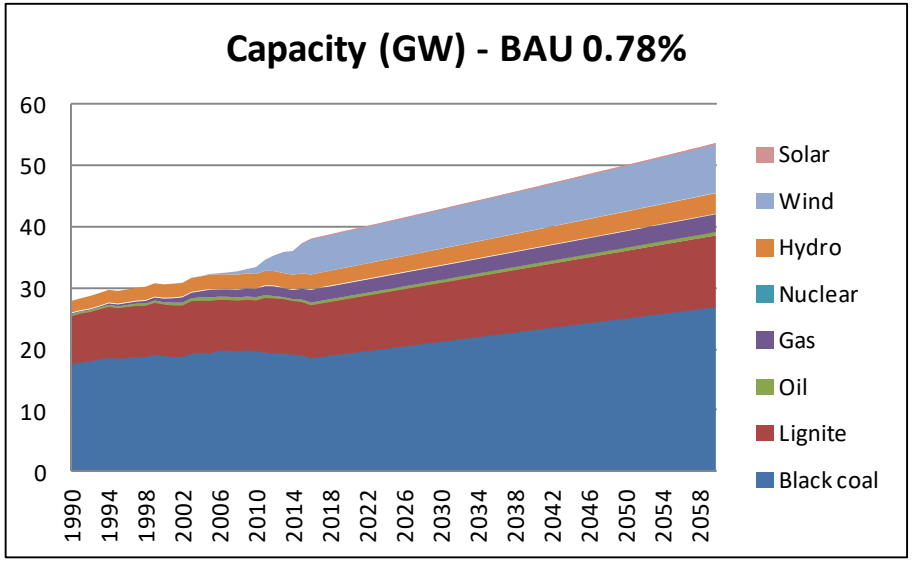
- Gross demand for electric power
- Production capacity by technologies
- Capacity Utilization Factors (CUF) by technologies

Scenarios of energy mix

BAU scenario



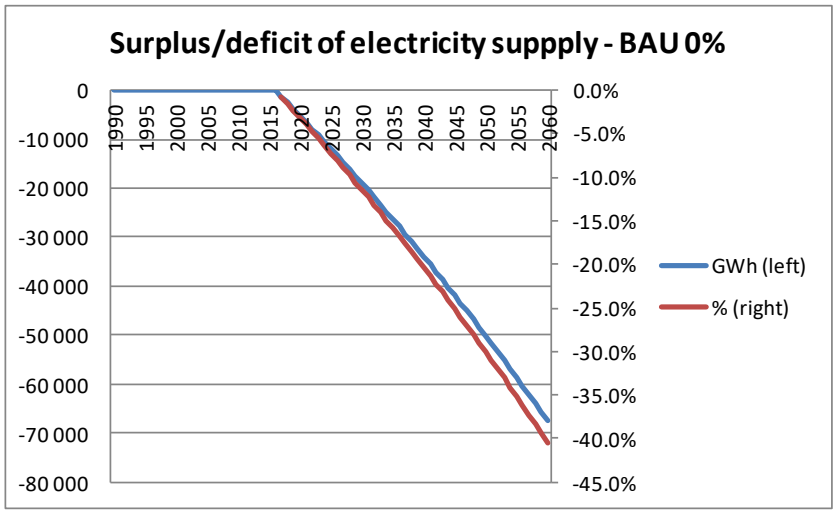
Average growth rate of demand
1990-2016: 0.78%

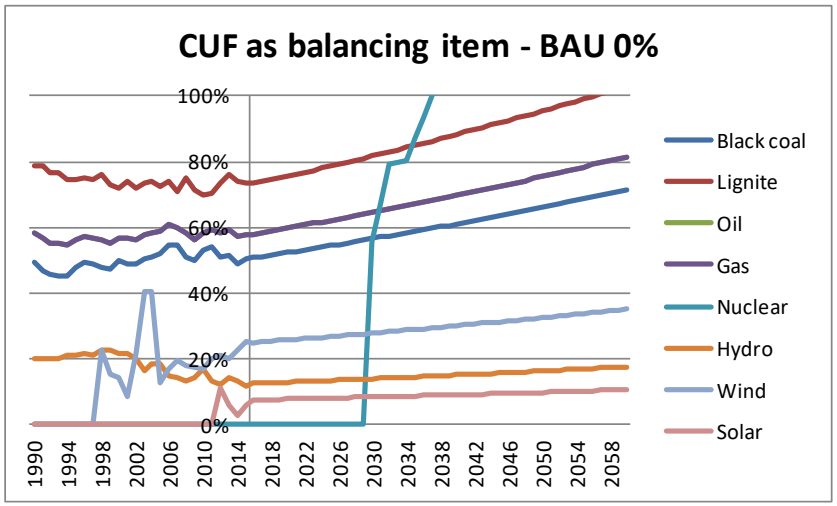


Production capacity
grow at the rate of demand

Scenarios of energy mix

BAU scenario

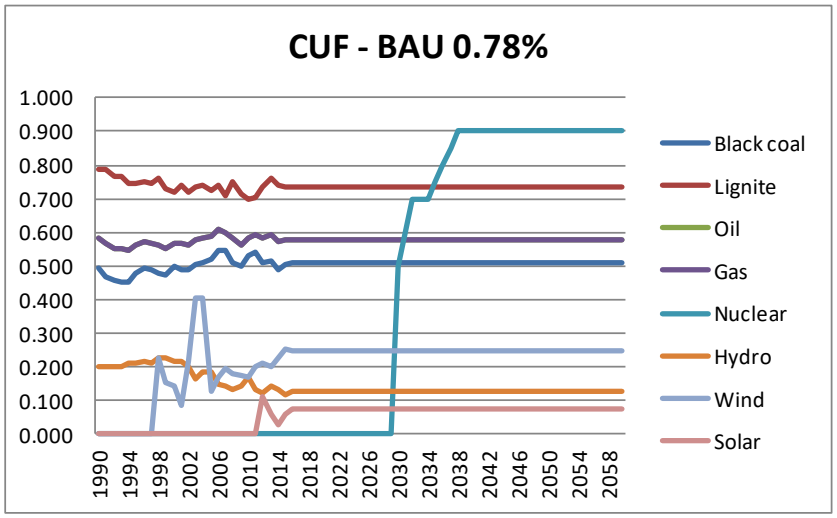




Capacity utilization factor depends on:

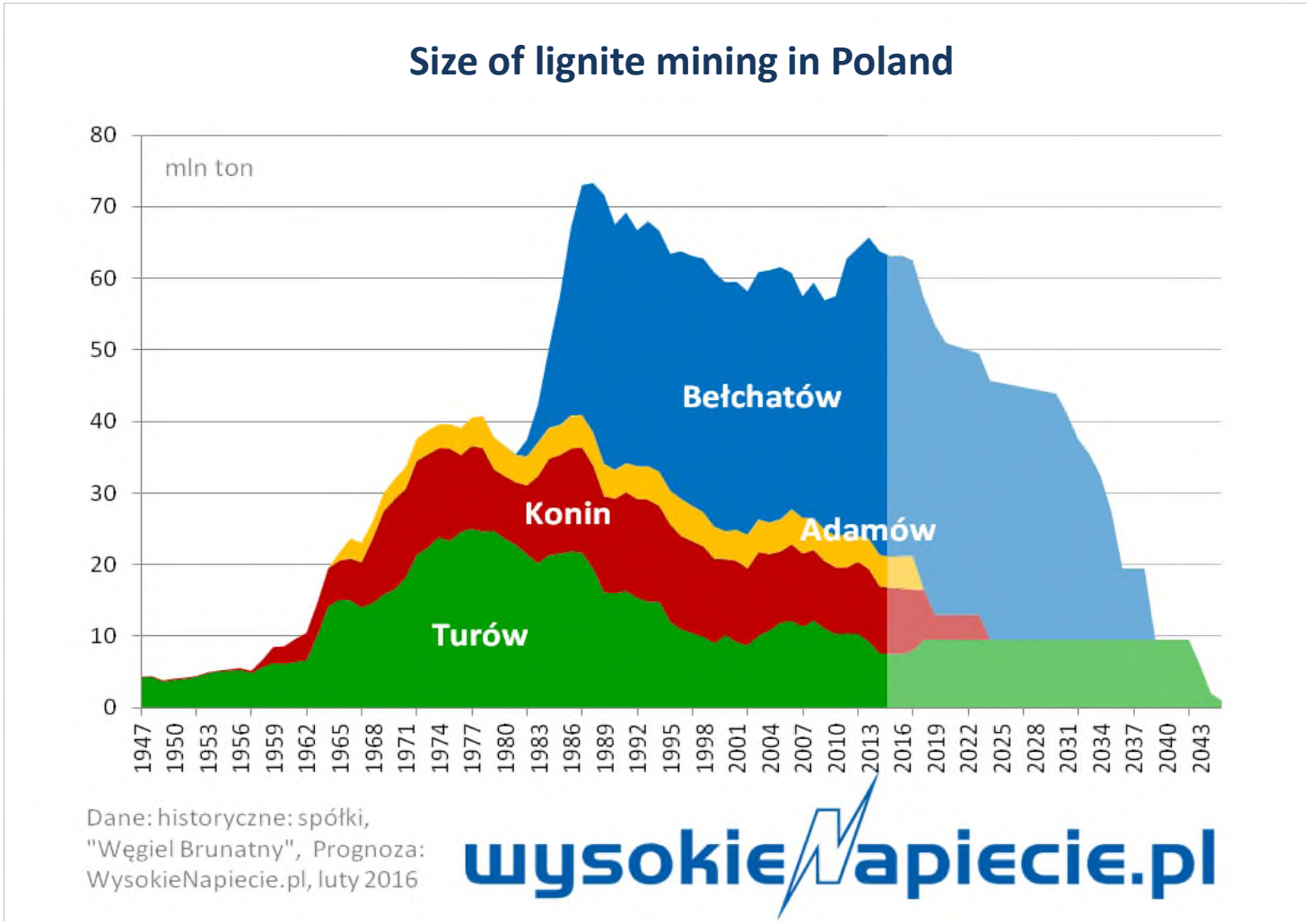
- technology
- role of power plant in energy system (base load, peak load)

- Changes of CUF are used to balance demand and supply



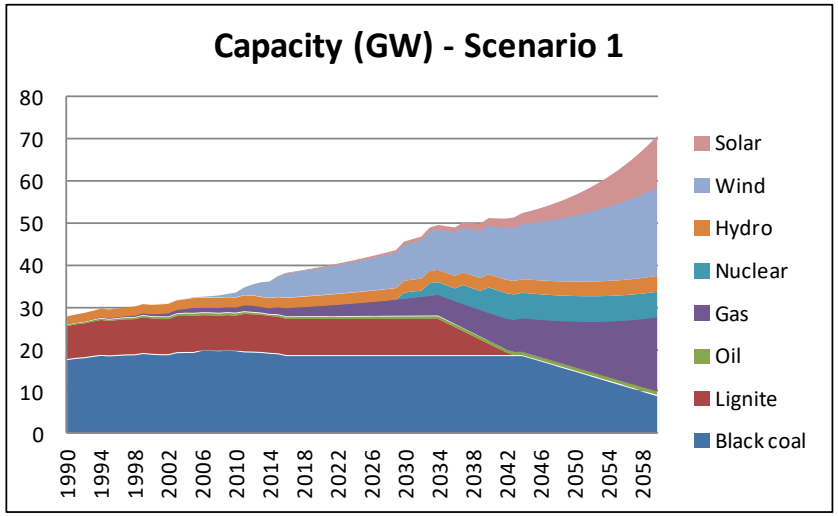
Scenarios of energy mix

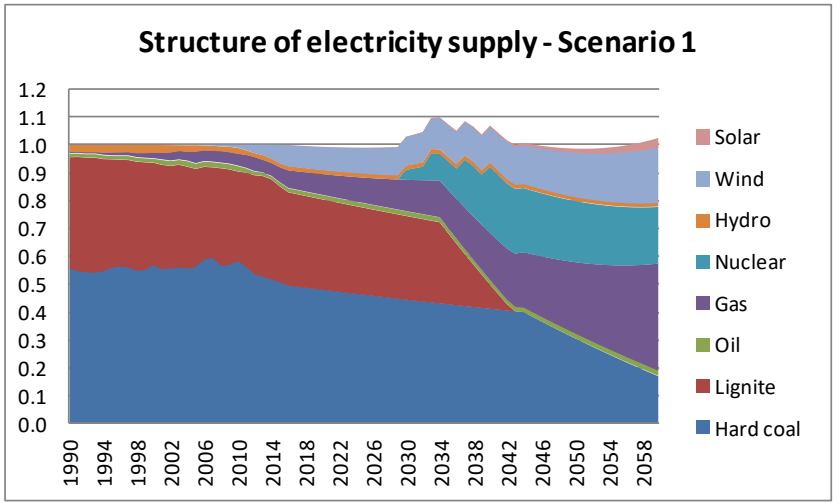
Scenario 1

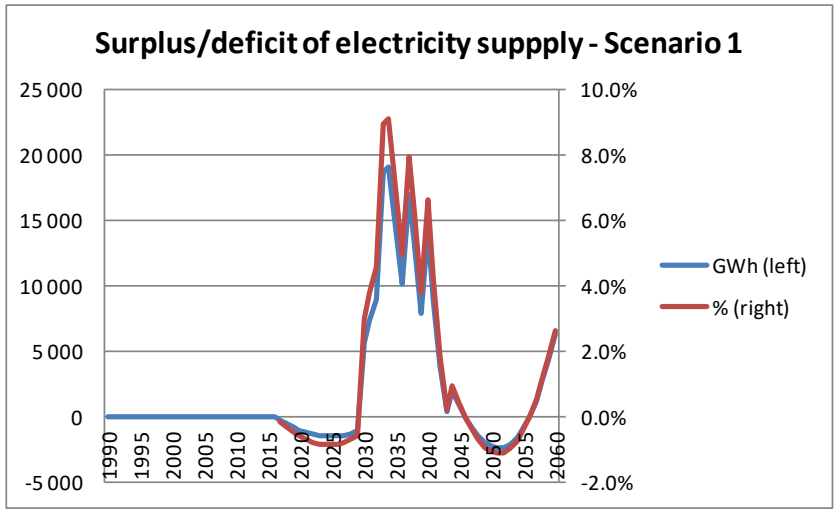


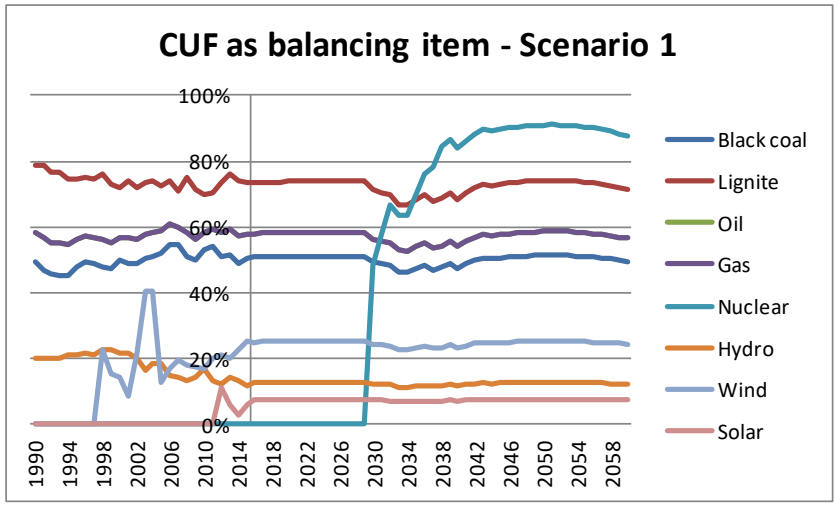
Scenarios of energy mix

Scenario 1



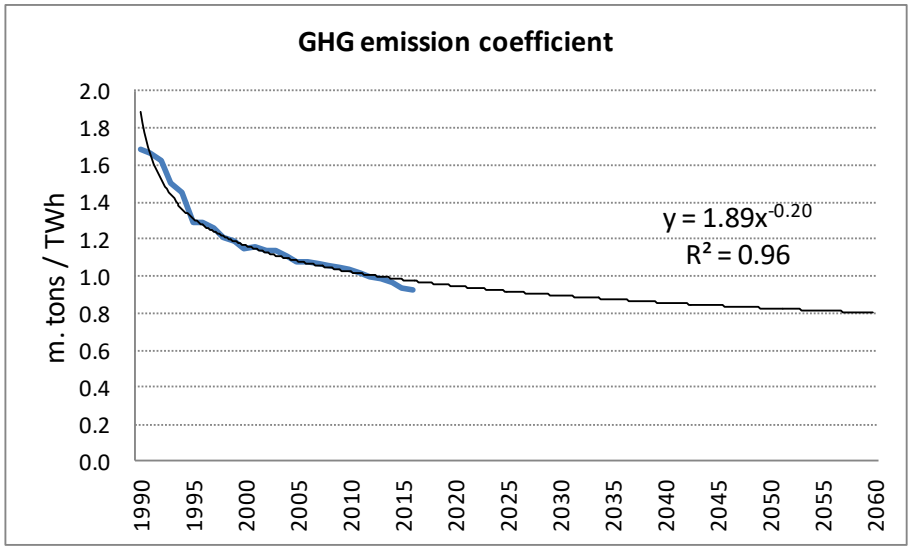


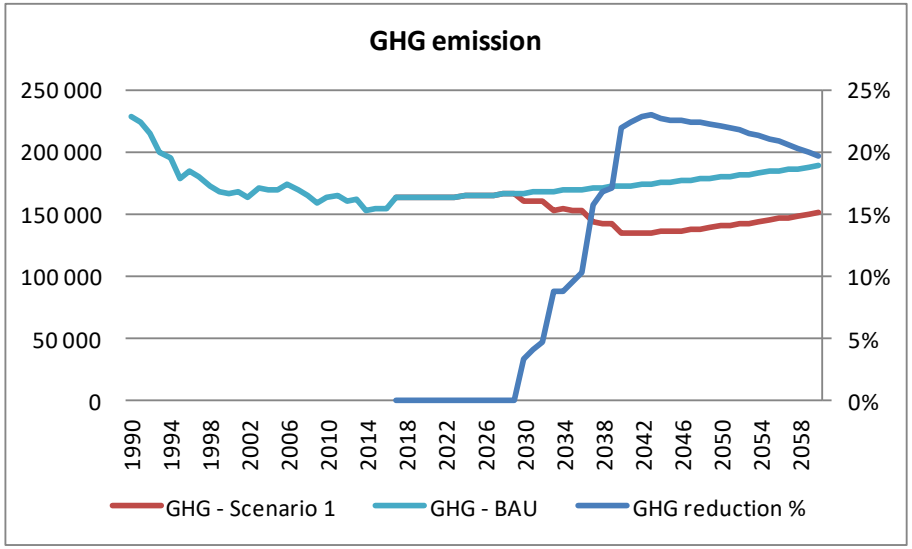




Scenarios of energy mix

Scenario 1 – GHG reduction





What's next?

Software, model, simulations

1) **Empower.cc software development** - energy and emission block
2) **Model implementation** - installing energy and emissions block in Empower.cc and Interdyme
3) **Preliminary simulations** on the role of NPP in climate change mitigation
4) **Further model development** – real and nominal side of the economy
5) **Final simulations**